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The effect of agronomic measures on grain yield of winter wheat in drier conditions

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Abstract: The objective of this study was to evaluate the effect of a year of cultivation and three agronomic measures (pre-crop, soil tillage, application of fungicides) on the yield of winter wheat grown in the crop rotation without the livestock production. The results from the years 2011–2017, except for the year 2012, from the Žabčice Field Experimental Station (49°01'20''N, 16°37'55''E) were evaluated. The soil texture is clay loam soil and the soil type is fluvisol. In the field trial, winter wheat was grown after two pre-crops (winter wheat, pea). Two soil tillage technologies, namely the conventional tillage – CT (ploughing – at a depth of 24 cm) and the minimum tillage – MT (shallow loosening – at a depth of 15 cm) were used. Two fungicide treatments against leaf and spikelet diseases were used, and they were compared to the non-treated variants. The obtained results showed that the grain yield of winter wheat was statistically influenced not only by a year of cultivation, but also by the pre-crop, the application of fungicides, and mostly by the interaction of these factors with the soil tillage. The importance of pea as a suitable pre-crop for winter wheat was confirmed as the grain yield was higher compared to winter wheat as a pre-crop by an average of 0.49 t/ha. It was also found that the MT is a more appropriate technology than the CT, on average by 0.12 t/ha over the six years. The importance of fungicide treatment was also confirmed, where the grain yield of winter wheat was higher by 0.26 t/ha compared to the non-treated variant. The presented results brought a new knowledge for winter wheat management practice in dry conditions.

Keywords: *Triticum aestivum* L.; cereal; weather; legume; farming system; drought

Common wheat (*Triticum aestivum* L.) is the oldest arable plant and the world's third most cultivated crop (Blecharczyk et al. 2006, Hlisnikovský et al. 2016). The main reason is that it is a major crop in the food industry where it is an important source of calories in the human diet (Mazzilli et al. 2016). In particular, its winter form is the most cultivated crop not only on a global scale but also in Europe, where it is also the main cultivated cereal (Chloupek et al. 2004).

In the Czech Republic, wheat is also the most important cereal, which confirms the stable trend of sowing areas in the long run. However, it is expected that a climate change will occur in the future with more frequent weather fluctuations in the form of rising temperatures and lack of precipitation and with more frequent extreme events, which will have a negative impact on the production (yield) of winter wheat (Knox and Wade 2012, Semenov et al. 2012). For this reason, many farmers are already trying to reconsider the crop management practice itself, i.e., the agronomic practices of growing winter wheat. A characteristic feature of some agricultural companies in the Czech Republic is the narrow structure of grown crops, given that they operate without livestock production. For the crop rotation, a lack of improving crops (clover) is characteristic, and barnyard manure is not commonly incorporated into the soil, which negatively affects soil fertility.

The yield of winter wheat is influenced by soil and climatic conditions of the given location and

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the course of weather during the different stages of winter wheat growth (Johansson et al. 2003), where the availability of precipitation can be limited, which can lead to high variability of the production itself (Bonfil et al. 2004), but also agronomic factors (Kunzová 2007) and the interaction between these factors (Erekul and Köhn 2006).

Agronomic factors that can fundamentally influence the grain yield of winter wheat include a suitable pre-crop, the technology of soil tillage in relation to the soil and climatic conditions of the given location, correct choice of the cultivar of wheat, the time of sowing, balanced fertilization, protection against harmful organisms, and last but not least, the use of intercrops and post-harvest crop residues incorporated into the soil. The joint action of two important agronomic factors, a pre-crop, and the corresponding technology of soil tillage can, in the end, result in a significant effect on the amount of yield as previously published by Houšť et al. (2012) and Ercoli et al. (2017). In addition to the influence of a pre-crop and the technology of soil tillage, it should also be remembered that even the fungicidal treatment of winter wheat can have a positive effect on the yield. Nevertheless, Hershman (2012) and McGrath (2004) found that if there is a low pressure of diseases in a year of cultivation, there is a minimal loss of yield without application of fungicides, which, on the contrary can have a positive advantage from the economic perspective of growing winter wheat.

MATERIAL AND METHODS

Experimental site. The field trial was carried out at the Žabčice Field Experimental Station (49°01'20''N, 16°37'55''E), which is a research facility in the field of plant production at the Mendel University in Brno. The Field Experimental Station is situated approximately 25 km south of the city of Brno, in the dry area of southern Moravia in the Czech Republic, in the maize production area and at the altitude of 179 m a.s.l. The average annual air temperature here is 9.2°C, and the thirty-year average of annual rainfall is 480 mm. Thus, the site belongs to the hottest and driest areas in the Czech Republic, with more frequent droughts occurring in recent years. The soil texture is clay loam soil and the soil type is fluvisol.

Field trial. The effect of three agronomic factors (pre-crop, soil tillage, application of fungicides) on the grain yield of winter wheat as well as a year of cultivation were evaluated in the field trial. The results are based on the long-term field trial, which was established in 2003. In the long-term field trial, which simulates farming system without livestock production, the crop rotation contains grain maize, spring barley, pea, winter wheat and again winter wheat following one after another. It implies that the proportion of cereals is 80%. In the crop rotation, the straw of the crops is chopped and incorporated into the soil, and the winter wheat is grown after two pre-crops (winter wheat and pea). Two soil tillage systems were used, namely the conventional tillage – CT (ploughing – at a depth of 24 cm) and the minimum tillage – MT (shallow loosening – to a depth of 15 cm). For shallow loosening (MT) chisel cultivator was used. Regarding a fungicide treatment, two fungicide treatments against leaf and spikelet diseases were used and they were compared to the non-treated variant. The results from 2011–2017, except 2012, were used in the field trial. The year 2012 was not included in the evaluation due to adverse weather conditions in the growing season of 2011/2012 when long-lasting droughts negatively affected winter wheat. During the whole period (2011–2017), the cv. Sultan of winter wheat was cultivated, the sowing rate was 4 MKS/ha (four millions of germinating seeds per hectare), the total dose of nitrogen was 180 kg N/ha.

Furthermore, P and K mineral fertilizers (39.6 kg P/ha and 99.6 kg K/ha), 1 × herbicide, 1 × insecticide and growth regulators were applied. After the harvest of pre-crop, stubble breaking (disking to the depth 10 cm) was used. Seedbed preparation was applied using a compactor after both variants of soil tillage (CT and MT). Winter wheat was sown to a depth of 3 cm, between 1st and 14th October. The harvest was carried out from 15th to 26th July, by a small-plot combine machine SAMPO Rosenlew SR 2010. The achieved yields from the harvesting areas of 22.5 m^2 (in four replicates per variation) were recalculated per hectare at grain moisture of 14%.

Meteorological data. Air temperature and precipitation data were obtained by measuring at the meteorological station at the site of the experiment. Average monthly air temperatures and precipitation totals in individual years were calculated from daily data each month. Table 1 compares average monthly air temperatures and precipitation sums in the years 2010–2017 with the long-term temperature and precipitation average (1961–1990).

Statistical analysis. The statistical program Statistica 12.0 (StatSoft software Inc., Tulsa, USA)

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Table 1. The average air temperatures (T, °C) and the sum of precipitation (P, mm) in individual months of the years 2010–2017 compared to the long-term temperature and precipitation normal (1961–1990) at the Field Trial Station in Žabčice, Czech Republic

		Month												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII
2010	T	–3.9	–0.6	4.8	10.2	14.0	18.7	21.9	19.3	13.0	7.3	6.7	–3.9	9.0
	P	46.8	22.8	9.8	53.1	102.4	79.8	87.9	75.8	57.8	10.4	32.8	11.1	590.5
2011	T	–0.4	–0.9	5.4	12.4	15.3	19.4	19.2	20.5	17.1	9.3	2.5	2.2	10.2
	P	21.4	4.6	39.3	33.2	46.2	42.9	79.8	42.4	31.1	22.6	1.6	14.6	379.7
2012	T	1.0	–3.4	7.0	10.8	16.9	19.9	21.4	21.2	16.2	9.4	6.5	–1.2	10.5
	P	27.4	7.4	2.4	19.8	21.4	101.2	64.6	43.0	40.2	49.2	19.4	35.6	431.6
2013	T	–1.0	0.7	1.8	10.6	14.7	18.3	21.9	20.4	14.0	10.1	5.4	2.1	9.9
	P	20.2	42.1	40.8	20.2	109.0	147.4	4.7	43.6	63.2	35.2	20.4	6.2	553.0
2014	T	1.1	2.7	8.5	11.8	14.5	18.8	21.5	17.9	15.6	11.5	7.5	2.4	11.2
	P	22.0	12.6	5.6	11.2	62.8	43.4	85.0	113.6	116.2	46.4	29.2	28.7	576.7
2015	T	1.9	1.5	5.4	9.9	14.4	19.0	22.9	23.3	16.5	9.7	6.2	3.1	11.2
	P	19.2	6.8	16.4	19.6	32.2	22.0	22.0	105.8	23.4	48.0	21.8	17.8	355.0
2016	T	–1.2	5.1	5.5	9.8	15.7	19.8	21.3	19.5	17.9	9.0	3.9	–0.5	10.5
	P	25.6	64.7	30.4	41.6	42.0	34.8	149.2	65.0	10.0	54.4	24.9	7.2	549.8
2017	T	–5.8	1.5	7.7	9.0	15.8	20.8	21.1	21.7	14.1	10.4	4.6	1.4	10.2
	P	32.1	10.7	18.7	42.4	24.0	25.8	68.2	22.4	83.0	35.8	23.8	20.4	407.3
1961–1990	T	–2.0	0.2	4.3	9.6	14.6	17.7	19.3	18.6	14.7	9.5	4.1	0.0	9.2
	P	24.8	24.9	23.9	33.2	62.8	68.6	57.1	54.3	35.5	31.8	36.8	26.0	479.7

was used for the statistical analysis of the obtained results. The results of the grain yield of winter wheat were statistically evaluated using the analysis of variance – ANOVA (Table 2) and subsequently compared by testing the differences of mean values by the method of confidence intervals.

RESULTS AND DISCUSSION

The three observed factors (year, pre-crop, fungicide treatment) showed the statistically significant effect on the grain yield of winter wheat (Table 2). However, soil tillage, as the fourth observed factor, did not show any effect. It was also found that some interactions between these factors were statistically significant (Table 2) and also influenced the yield of winter wheat.

Regarding the year of cultivation, the highest yield was achieved in 2014, specifically 11.23 t/ha (Figure 1a). On the contrary, the lowest yield was in 2013, only 7.71 t/ha. The yield difference between these years was 3.52 t/ha. Furthermore, it was confirmed that the most suitable pre-crop, regarding the grain yield of winter wheat, is pea. The yield after this pre-crop

Table 2. Analysis of variance (ANOVA) – grain yield of winter wheat

Source of variability	Degrees of freedom	Average square
		yield
Year (Y)	5	58.01**
Pre-crop (P)	1	11.34**
Soil tillage (S)	1	0.67
Fungicide treatment (F)	1	3.23**
Y × P	5	7.92**
Y × S	5	0.21
P × S	1	5.41**
Y × F	5	1.07**
P × F	1	0.10
S × F	1	0.57*
Y × P × S	5	0.52*
Y × P × F	5	0.60*
Y × S × F	5	0.06
P × S × F	1	0.18
Y × P × S × F	5	0.25
Error	144	0.16

*P = 0.05; **P = 0.01

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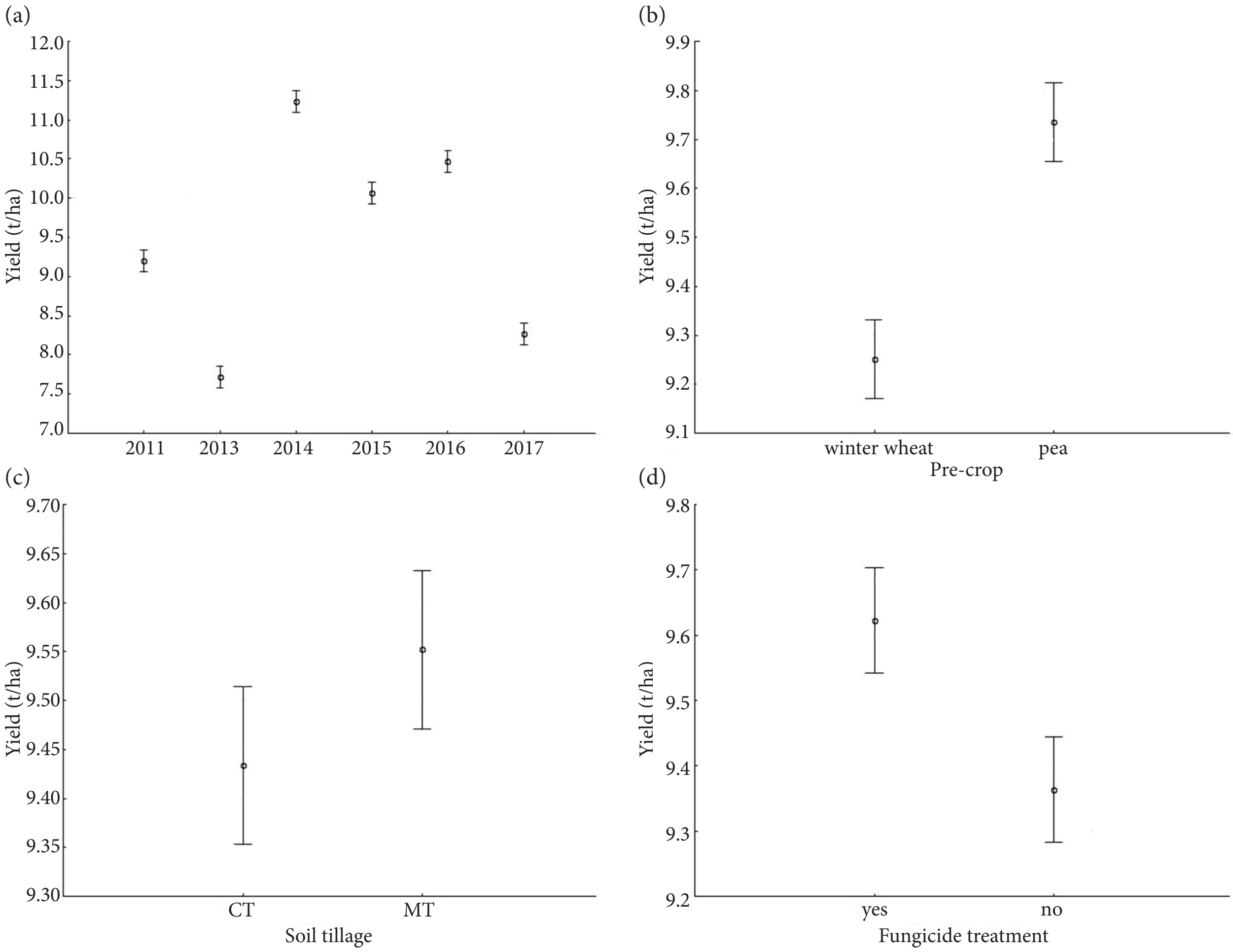

Figure 1. The effect of (a) the year; (b) a pre-crop; (c) soil tillage and (d) fungicide treatment on the grain yield of winter wheat. CT – conventional tillage; MT – minimum tillage

was 9.74 t/ha (Figure 1b), which was by 0.49 t/ha more than after winter wheat as a pre-crop. In the case of the soil tillage factor, it was found that a higher yield was achieved after the minimum tillage, where the average yield was 9.55 t/ha (Figure 1c). The yield was by 0.12 t/ha higher than after the use of the conventional tillage. From the perspective of the application of fungicides, it was found that higher grain yield was achieved in the variant treated by fungicides, specifically 9.62 t/ha, while the yield was by 0.26 t/ha lower in the non-treated variant (9.36 t/ha; Figure 1d).

Furthermore, the effect of the interaction between a year of cultivation and a pre-crop was proven (Figure 2a). The highest grain yield of winter wheat was achieved in 2014 after pea (11.31 t/ha) when the difference compared to winter wheat as a pre-crop was 0.16 t/ha. On the contrary, the lowest yield was achieved in 2013 after pea (7.22 t/ha). The difference compared to winter wheat as a pre-crop was as much as 0.98 t/ha in that year and a statistically significant difference was found between them. A higher yield after winter wheat compared to pea was also achieved in 2016, when the difference in the grain yield of winter wheat between these pre-crops was 0.21 t/ha, but it was not statistically significant. However, in 2016 no statistically significant difference was fond in the grain yield of winter wheat grown after pea and winter wheat. A statistically higher yield after pea as a pre-crop was found in 2011, 2015 and 2017).

The significant effect was also shown in the interaction between a pre-crop and soil tillage, specifically between both soil tillage treatments as well as both pre-crops in the minimum tillage variant – shallow loosening (Figure 2b). However, a statistically significant difference was not found between both pre-crops in the variant treated by the conventional tillage – ploughing. The highest yield was achieved

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after pea using the MT (9.96 t/ha). On the contrary, the lowest yield was after winter wheat with the MT (9.14 t/ha).

In case of the interaction between a year of cultivation and fungicide treatment, statistically significant differences were found in 2013 and 2016 (Figure 2c), while in 2011, 2014, 2015 and 2017 the values did not differ statistically. It was also found that the lowest yield was achieved in the variant untreated by fungicides in 2013, specifically 7.49 t/ha. The difference in that year was 0.45 t/ha compared to the variant treated with fungicides. On the contrary, the highest yield was obtained in 2014 in the variant untreated by fungicides (11.31 t/ha), where the difference to the variant treated with fungicides was 0.16 t/ha.

The statistical proof was also found in the interaction between soil tillage and fungicide treatment (Figure 2d) when a significant difference was proven between the variant treated and untreated by fungicides only in the variant with the conventional tillage. The difference in the yield of winter wheat between these variants was 0.37 t/ha. It was also found that the highest grain yield of winter wheat was achieved with the minimum tillage in the variant treated by fungicides (9.63 t/ha). On the contrary, the lowest yield was with the conventional technology of soil tillage in the variant untreated by fungicides (9.25 t/ha). The difference between these yields was 0.38 t/ha.

Statistically significant differences were found in Figure 3a, which illustrates the interaction between a year of cultivation, a pre-crop and soil tillage. A different trend in the grain yield of winter wheat was found in 2014 and 2016. In these years, the conventional technology of soil tillage (ploughing) was used after winter wheat as a pre-crop resulting in a higher yield, while with the minimum tillage,

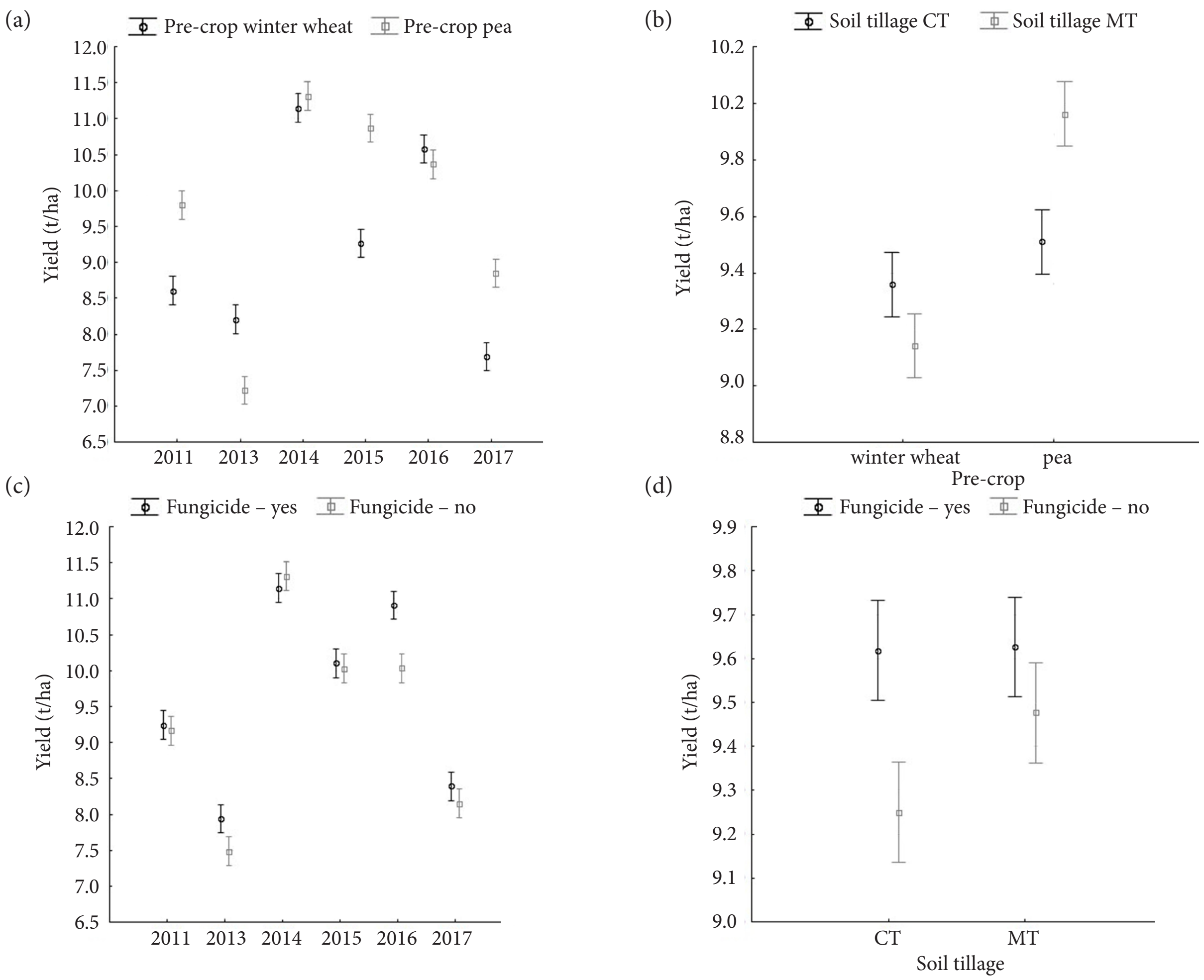

Figure 2. The effect of (a) the year and pre-crop; (b) the pre-crop and soil tillage; (c) the year and fungicide treatment and (d) soil tillage and fungicide treatment interaction on the grain yield of winter wheat. CT – conventional tillage; MT – minimum tillage

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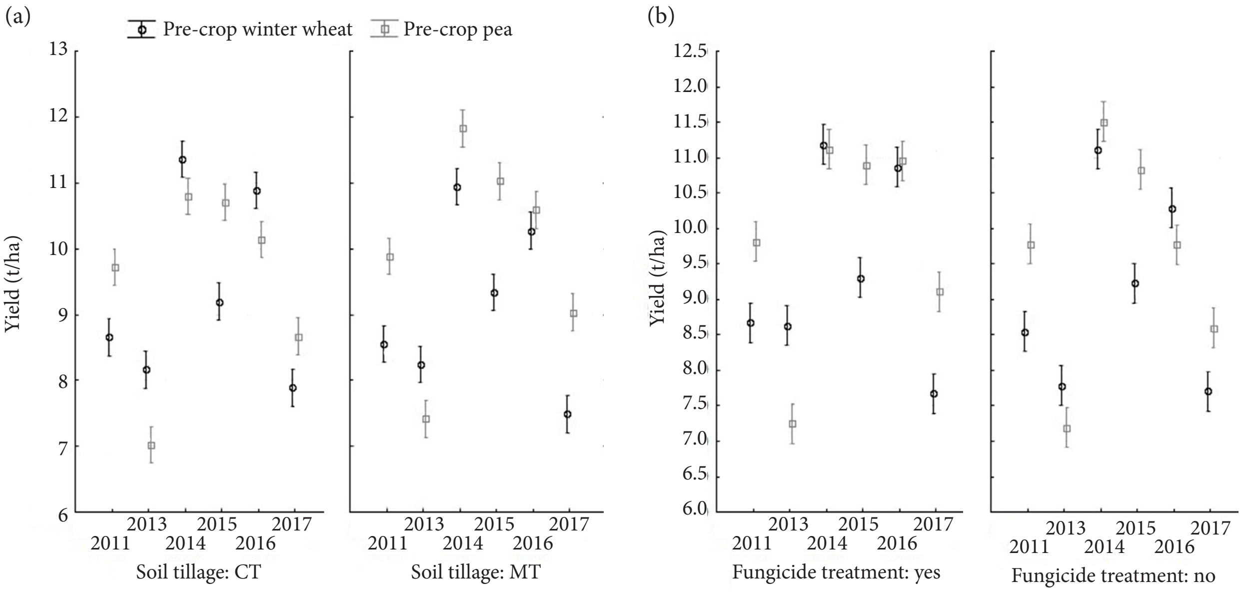

Figure 3. The effect of (a) the year, pre-crop and soil tillage and (b) the year, pre-crop and fungicide treatment interaction on the grain yield of winter wheat. CT – conventional tillage; MT – minimum tillage

there was a lower yield after pea as a pre-crop. The difference in the yield of winter wheat between the two pre-crops in 2014 was 0.56 t/ha. On the contrary, after shallow loosening, the difference was 0.89 t/ha. In 2016, the difference between both pre-crops after ploughing was 0.74 t/ha, while after shallow loosening it was 0.32 t/ha.

Statistically significant differences were also found in the interaction between a pre-crop and fungicide treatment (Figure 3b). The lowest yield in this interaction was achieved after pea in the variant untreated by fungicides in 2013 (7.19 t/ha). The highest yield was also found after the same pre-crop (pea) and the variant untreated by fungicides, but in 2014, specifically 11.51 t/ha. The difference between these years was more than 4.00 t/ha (more precisely 4.32 t/ha). At the same time, in both interactions, the statistical significance of the year of cultivation was confirmed as the most important factor for the subsequent grain yield of winter wheat which cannot be influenced by the grower in any way.

DISCUSSION

The results of the field trial of 2011–2017 confirmed the statistical significance of the year of cultivation, which was also confirmed by the results of Jug et al. (2011) and Kunzová (2007). The statistically significant differences in the grain yield of winter wheat were in particular between 2014 (11.23 t/ha) and 2011 (9.20 t/ha), 2013 (7.71 t/ha) and 2017 (8.27 t/ha). Very similar differences as in the case of the effect of a year of cultivation (Figure 1a) between individual years were also shown in the interactions of a year of cultivation and soil tillage, a year of cultivation and fungicide treatment and a year of cultivation, soil tillage and fungicide treatment. These yield differences between individual years can be associated with the effect of weather, especially during the months of March to June. In these months, there can be a lack of water available for plants during the growing season due to a lack of precipitation or its unevenness. Consequently, the number of spikelets can be negatively affected and, in the later period, also the weight of a thousand grains. Ultimately, this can lead to a decrease in the yield of winter wheat. Another limiting factor, from the perspective of weather, can be high temperatures when drying of crops and their forced maturation may occur, or wheat grains dry out in the later growing season, which may also reduce the yield of winter wheat. These weather factors were also shown in our results, with the lowest yield of winter wheat grain in 2017. This can be explained by the fact that during the months of March to June there was a lack of precipitation, which was also uneven. Another reason could be the fact that the highest average temperature was found in June, with a more frequent occurrence of hot days. This influenced the weight of a thousand grains indicator, when it was the lowest in the six years, specifically only 35.65 g. On

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the contrary, in 2013, high precipitation (256.4 mm) occurred in the months of May and June, and it was more even than in 2017. This fact resulted in a higher incidence of leaf and spikelet diseases, which could subsequently be the reason for lower grain yields of winter wheat this year. This is confirmed by the results of Chrpová et al. (2013), who found that the incidence of diseases is very closely related to weather patterns and it can thus influence the subsequent yield of winter wheat. Furthermore, Llano et al. (2012), Powell and Reinhard (2016) and Semenov and Porter (1995) also confirmed that the varied weather changes during the growing season are likely to be more widespread and will also be connected to significantly lower grain yield of winter wheat. Except for a year of cultivation, the high effect on the achieved grain yields of winter wheat can be attributed to a suitable pre-crop and a given method of soil tillage, as evidenced by Jaskulska et al. (2013) who found that the yield of winter wheat depended on a pre-crop and a soil tillage system. Similar results were also presented by Blecharczyk et al. (2006). In our six-year results of the field trial, it was found that pea, as a legume, is a more suitable pre-crop than winter wheat for the subsequent grain yield of winter wheat. Hejcman and Kunzová (2010) also confirmed the importance of a pre-crop; through the evaluation of some long-term experiments, they found that higher grain yields of winter wheat were obtained rather after legumes than after cereals. The same result was found by Blecharczyk et al. (2006) and Piekarczyk (2010). The effect of a pre-crop but also a method of soil tillage on the grain yield of winter wheat was also confirmed by Neugschwandtner et al. (2015). This was confirmed in our results from the years 2011–2017, when it was found that in the interaction between a pre-crop and soil tillage, the higher average grain yield of winter wheat was reached after pea as a pre-crop with the minimum tillage, specifically 9.96 t/ha, which was by 0.45 t/ha higher compared to the conventional tillage. Furthermore, our six-year results suggest that except for a pre-crop and soil tillage, fungicide treatment also had the effect on the grain yield of winter wheat, and not only as a separate factor, but also in the interaction with other factors (Figures 2d and 3) when statistically significant differences and also higher yields were found in the variant treated by fungicides compared to the untreated variant. Similar results were obtained by Lopez et al. (2015) and Wiik and Rosenqvist (2010). At the same time, however, they argued that the application of fungicides must not always affect higher yields. According to them, not only soil class and type in a given location affect the yield, but especially the course of weather during the growing season. Despite these findings, however, they confirmed that fungicidal treatment was more advantageous regarding the yield as well as economic appreciation. In conclusion, it can be added, that the presented results are particularly suitable for growers who farm in the farming system without livestock production, especially in the South Moravia dry conditions, which have been more frequent in recent years (2015, 2017, 2018).

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