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The impact of the conservation tillage "maize into grass cover" on reducing the soil loss due to erosion

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Abstract: Maize (*Zea mays* L.) belongs among the most important agriculture crops all over the world. The conventional way of cultivating maize with wide row spacing does not have a soil conservation effect and significantly contributes to water erosion and surface run-off. In our research, we tested the soil conservation technology (strip-till into grass cover) which took place in 2016 and 2017 in the location of Central Bohemia. The impact of a strip-till system of maize into grass cover on reducing the soil loss due to erosion was verified on the area of 21 m^2 using a rainfall simulator. During the research, 70 measurements were realised. The strip-till was compared to fallow land, conventional cultivation and no-till methods. Profound differences were found in the soil loss between the treatments. There was a decrease in the soil loss of about 98% in the strip-till compared to the conventional cultivation. Moreover, the surface run-off was reduced by 79%. The ANCOVA (analysis of covariance) models of the log-transformed soil loss on the surface run-off and treatment were highly significant ($P < 10^{-15}$). The measurement results clearly demonstrate the positive effect of the strip-till into the grass on the surface run-off and soil loss. This positive soil conservation effect was observed even in springtime, as well as the rest of the season. Using a grass cover for establishing the maize significantly contributes to the soil conservation on the land threatened by erosion and offers farmers a suitable way of farming when growing maize. Strip-tilling is a technology that has great potential in sustainable farming.

Keywords: erosion control measures; rainfall simulator; soil conservation; strip-till; surface run-off

Water erosion is a global problem (Novara et al. 2011) and causes destruction or damage to enormous areas of agricultural land every year (Morgan 2005). Agricultural land in the Czech Republic is largely exposed to the risk of water erosion due to the large land blocks, but also due to the agrotechnology used. More than half of the agricultural land is threatened by water erosion in the Czech Republic (Janeček 2005; Šarapatka & Bednář 2015). Soil degradation caused by water erosion is a complex process which

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depends on many factors (Cerdan et al. 2002), and is also very site dependent, mainly due to the differences in the soil climatic conditions (Davidová et al. 2015).

Over the past seventy years, large land degradation has taken place due to intensive farming, which is continuing presently. Agricultural subsidies have led to a significant increase in maize cultivation for the generation of energy from biomass in the Czech Republic. The expansion of maize acreage has resulted in the increased risk of water erosion due to the low vegetative soil cover after the sowing of the maize and the linear structure (Vogel et al. 2016). Brant et al. (2017) adds that the next major factor affecting arable soil erosion is large distance of the maize rows.

Within optimising cultivation systems of wide-strip crops (especially maize), new technological methods and procedures are being researched worldwide, which would ensure an increase in their energy and economic efficiency. In these technologies, under the conditions of European agriculture, a significant emphasis is put on eliminating the degradation of the soil processes, especially erosion, on increasing the infiltration abilities of the soils, on mitigating the technogenic soil compaction and on supporting the soil structure. One of the ways on how to fulfil the above-mentioned requirements is using a strip-till technology (Brant et al. 2016). Strip-tilling is a method of seedbed preparation in which confined strips of soil are tilled prior to planting. Seeds are then planted directly into the tilled strips, leaving inter-row areas protected by residue while avoiding residue contact with the seeds and seedling plants. Interest in strip-tilling has increased in recent years due to evidence that it combines many of the best aspects of the no-till and conventional cultivation systems (Randal & Hill 2000).

The main advantages of strip-tilling are obtaining a positive soil conservation effect as a result of the remaining crop residues in the inter-rows (Vyn & Raimbult 1993), improving the soil conditions for the crops' development in the rows and depositing fertilisers close to the roots (basic fertilisation and the application of nitrogen) enabling a reduction in their required amount. Another advantage is the more favourable conditions for sowing based on an earlier term for sowing compared to the no-till technology. Also, the strip-till technology has lower requirements in terms of the initial dosages of fertilisers compared to other technologies (Sundermeier et al. 2006).

Compared to conventional technologies, the application of a strip-till definitely leads to the overall decrease in the fuel consumption per area unit and, thus, to a reduction in the energy and economical inputs (Sundermeier et al. 2006; Brant et al. 2016). Various experiments with sowing maize into the cover crops (grass cover and fodder) with minimum soil treatment as protection of the slope areas against erosion and against washing-out the agrochemicals have been carried out in Switzerland (Rüttimann et al. 1995).

MATERIAL AND METHODS

The evaluation of soil conservation technologies for maize (*Zea mays* L.) in terms of soil conservation was carried out using a field rainfall simulator and also based on a soil survey and taking samples. The individual plots (established on an experimental areas) were compared with a control plot fallow. The magnitude of the surface run-off and soil loss due to the erosion were observed in the individual experiments. The verification of the technologies by the rainfall simulator took place in 2016 and 2017. The soil conservation technologies for the cultivating maize were established in cooperation with the cooperative farm Krásná Hora nad Vltavou, a joint-stock company in the Central Bohemian region. This cooperative is focused on animal production and it owns two bio-gas stations. The more frequent sowing of maize into the cropping system also follows from these activities (other crops in the crop rotation: canola, wheat, rye, sorghum, legumes).

Experimental areas. The study area is located in Central Bohemia (Czech Republic) at the experimental station of Skoupý (520 m a.s.l.). The climate is moderately warm with an average annual temperature of 7.5 °C and an annual precipitation of 550 mm (516 mm in 2016; 548 mm in 2017). The geographical coordinate system is 49°34'36.456''N, 14°20'44.084''E (Figure 1).

The soil type Cambisol was classified on all the experimental areas – the Main Soil Unit MSU 31. Based on the soil survey, it can be stated that the basic physical-chemical properties are similar in terms of the soils for the individual tested plots and, thus, the tested plots are comparable. The upper horizon of all the compared sites shows a texture type structure typical of sand-loamy soils. The basic soil properties: 1.27% total oxidizable carbon (C_{ox}); humus 2.19%; total nitrogen (N_{tot}) 0.156; C/N ratio 8.1. The topsoil layer is up to 30 cm (the soil texture: < 0.002 mm, 7.8%; < 0.01 mm, 15.5%; < 0.05 mm, 28.6%; < 0.1 mm,

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37.0%). The plots for the tested technologies were selected particularly for their uniform slope of 15%.

Field rainfall simulator. A rainfall simulator is a device which has been increasingly used to study soil erosion processes, and the use of rainfall simulators is widely accepted (Kovář et al. 2012; Ma et al. 2014; Lassu et al. 2015; Prosdocimi et al. 2017). The principle of measuring by a field rainfall simulator is based on the water spraying on a clearly defined and delimited area of 21 m^2, when the water jets, in a selected mode, spray water on the area for the whole measurement time. The rainfall simulator was situated down the slope just like the main crop with the strips of grass. The water spraying mode lasts for 30 min during the first rainfall simulation, then there is a 15-min technological break, after which the second rainfall simulation lasting 15 min follows. The intensity of the rainfall simulation was chosen based on the recommendation by the Czech Hydrometeorological Institute, based on the average intensity of torrential rainfalls in the Czech Republic. This intensity is considered to be 60 mm/h, and, during the mode construction, the condition (for the course of 15 min at least 6.25 mm) stated in the Guideline "Erosion Control in the Czech Republic – handbook" by Janeček et al. (2012) and Wischmeier and Smith (1978) was also taken into account.

The surface run-off and suspended solids in each variant were measured. The surface run-off was collected in a tipping bucket, which is a machine enabling one to measure the surface run-off. At constant time intervals of 3 minutes, the samples were taken into a calibrated container of 319 mL in size. The amount of the suspended solids for the particular variant was determined from the samples adjusted in this way.

Figure 1. The geographic location of the study area

Selection of the dates for the field experiment. The uniform and standard conditions on all the experimental plots were selected to verify the efficiency of the erosion control measures. The terms of the individual trials of the rainfall simulator are based on the terms of the growing periods given for the determining factor, the protective impact of the vegetation cover and the tillage method. The growing periods are defined in the Prediction Rainfall Erosion Losses from Cropland East of the Rocky Mountains: A Guide for Selection of Practices for Soil and Water Conservation (Wischmeier & Smith 1965).

I. the term of the rainfall simulation – in the period from the plot preparation for sowing up to one month after sowing

II. the term of the rainfall simulation – in the period for the course of the second month from the spring or summer sowing

III. the term of the rainfall simulation – in the period from the end of the second term of the rainfall simulation up to harvest.

Verified variants (no–till, strip-till, conventional cultivation, fallow land). The first selected variant in order to verify the soil conservation effect was the no-till technology. It was prepared into the cover of desiccated rye with 75 cm wide rows. The next technology was the strip-till (sowing maize into the tilled strip grass cover) with the row spacing of 75 cm. Both variants were compared with the conventional way of maize cultivation – classical tillage and also fallow land (maintained without vegetation). The sowing of maize took place on the 20th of April 2016 and the 4th of May 2017. A more detailed description of the agrotechnical operations is stated below:

The no-till sowing of the maize into the rye cover (width of row: 75 cm)

– in autumn, the crushing and shallow ploughing-in of the intercrop by a disc harrow takes place;
– followed by the vertical aeration to a depth of 20 cm;
– soil preparation before sowing by a compactor 1×;
– rye sowing by the no-till sowing machine until the end of September;
– in spring, the cover desiccation by a total herbicide;
– maize sowing by the no-till sowing machine into rows of 75 cm.

The maize sowing into treated grass strips – strip-till

– the areal desiccation of the grass cover by a total herbicide takes place in autumn;
– until the end of October, strip-tilling to a depth of 25 cm is made in the grass cover;

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– the plot is kept in this condition until spring;
– in spring, with the appropriate moisture, strip-tilling to a depth of 25 cm can be repeated if necessary;
– maize sowing by the no-till sowing machine into rows of 75 cm;
– the whole area with the grass is treated by the selective herbicide.

Conventional way of cultivating maize
– in autumn, the crushing and shallow ploughing-in of the intercrop by a disc harrow takes place;
– followed by the deep tillage of approx. 25–30 cm until the middle of November, without surface levelling;
– the tillage remains in a rough furrow until spring;
– in spring, soil treating by a compactor 2×;
– sowing maize into wide strips (75 cm) from the middle to the end of April.

Statistical analysis. Linear models were used to assess how the soil loss as well as its relationship with the infiltration differ in the different treatments. Since the preliminary analysis revealed a considerable heteroscedasticity and normality violation in all the models, the logarithmic transformation of the soil loss values was used as a response, after which both problems were eliminated. To avoid the problem with zeros, a small constant (0.001) was added to the soil loss values before the transformation. This constant was chosen by a trial-error inspection of the diagnostic plots checking for homoscedasticity and normality. ANOVA (analysis of variance) was used to test for the differences in the log soil loss means in the different treatments, followed by Tukey's multiple comparison. Then, we modelled the exponential relationship between the soil loss and the surface run-off in the different treatments by a linear ANCOVA (analysis of covariance) of the log-transformed soil loss on the run-off interacting with the treatment. The significance of the individual predictors was tested using ANOVA Type-II tests. The separate models were fitted for the first and the second rainfall in all the analyses. To test for the difference in the soil loss between the first and the second rainfall, we used the paired Wilcoxon test, using the original (i.e., untransformed) soil loss values. All the analyses and data manipulations were performed in the R statistical program (R Core Team 2017), with the use of the packages car (ANOVA Type II tests; Fox & Weisberg 2011) and agricolae (Tukey tests; de Mendiburu 2017).

RESULTS AND DISCUSSION

The results and evaluation of the terrain observation are based on the field experiments with the rainfall simulator and the laboratory measurements of the taken soil samples and the sediment. The following were evaluated for each variant: the magnitude of the surface run-off and the soil loss caused by the water erosion. Values of the surface run-off and the soil loss gradually decreased in the course of the maize growth. This was especially influenced by the crop engaging and also by the natural soil compaction. The data were evaluated separately in the first and the second rainfall simulation.

Profound differences were found in the soil loss between the treatments, both in the first and the second rainfall (see Table 1 and Figure 2).In the first rainfall, the highest and the lowest mean soil loss was recorded in the fallow land and the strip-till, respectively, and they differed by a factor of 46. In the second rainfall, the treatments with the highest and the lowest mean soil loss were the conventional cultivation and the strip-till, respectively, the former being 11 times higher than the latter. Interestingly, there were also similar differences in the soil loss variability, the standard deviations being always of the same order of magnitude as the means (Figure 2). Both in the first and the second rainfall, the treatment had a significant effect on the log-transformed soil loss ($P < 10^{-7}$), and it explained roughly 40% of its variability (multiple R^2 = 0.428 and 0.421 for the first and the second rainfall, respectively). Multiple

Table 1. The summary statistics of the soil loss under the different treatments and multiple comparisons of the results

Treatment	*n*	First rainfall				Second rainfall			
		mean	SD	mean log	hg	mean	SD	mean log	hg
Fallow land	19	6.673	6.922	1.114	a	0.484	0.650	1.114	a
Conventional cultivation	17	1.965	2.400	–0.479	a	1.727	1.948	–0.479	a
No till	16	0.836	1.390	–2.459	b	0.194	0.356	–2.459	b
Strip-till grass	18	0.144	0.235	–3.169	b	0.160	0.213	–3.169	b

n – the sample size (same for both rainfalls); SD – the standard deviation; mean log – the mean of the log-transformed soil loss; hg – the homogeneous groups based on Tukey's multiple comparison of the means of the log-transformed soil loss

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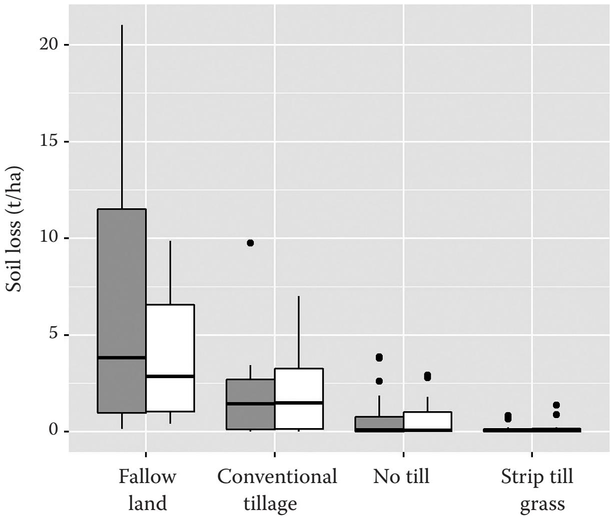

Figure 2. The quartile-based boxplots summarising the soil loss for the different treatments and the first (grey boxes) and the second (white boxes) rainfall

comparisons identified two homogeneous groups, identical in both rainfalls, with the fallow land and the conventional cultivation in one group and the strip-till grass together with the no-till in another group (Table 1). There was no significant overall difference (evaluated across all the treatments) in the soil loss between the first and the second rainfall (Wilcoxon statistic = 2 409.5, P = 0.866).

Generally, there is only little research in the strip-till technology into the grass cover. Our results are the first ones to provide information about the soil loss of the strip-till into the grass in the conditions of the Czech Republic. In the two-year measurements, a 98% decrease in the soil loss was achieved in the strip-till compared to the conventional cultivation. The soil loss was, in both research years, very similar without significant differences. Ryken et al. (2018) state a reduction of the soil loss in the strip-till technology (99%). Other results related to this technology were published by Wischmeier and Smith (1978). They determined the efficiency of the strip-till into the grass cover of between 95–97%. These results are not different from our values. Another research effort was recorded by Prasuhn (2012). In this case, a strong soil conservation effect was measured on the experimental plots in Switzerland. The soil loss achieved the value of 0.12 t/ha/year in the no-till (strip-till), while, in the plough tilled land, the soil loss was 1.24 t/ha/year. For the soil conservation technologies which include the strip-till, Wendt and Burwell (1985) recorded a reduction in the erosion higher than 90% compared to the conventional cultivation. Likewise, McGregor and Mutchler (1992) state a lower soil loss by 97% in the soil conservation technology.

The ANCOVA models of the log-transformed soil loss on the surface run-off and the treatment for the first and the second rainfall were both highly significant ($P < 10^{-15}$) and both explained 79% of the soil loss variability. The significance of the individual predictors and their interaction is summarised in Table 2, the regression lines back-transformed to the original scale are displayed in Figure 3. As expected, the surface run-off had a significant effect on the log soil loss (Table 2), all the slopes being positive (Figure 4). The surface run-off was reduced by 79% compared to the conventional tillage. In a similar way, Bosch et al. (2005) state that the surface run-off losses from the conventionally tilled plots exceeded those from the strip tilled plots by 81%. In both rainfalls, the regression slopes significantly varied between the treatments (see the significant interaction terms in Table 2), the fallow land having the lowest slope and the strip-till having the largest (Figure 4).

The presented results of the rainfall simulation show that the technology of the strip-till offers strong protection against water erosion. There is an increase in the surface water infiltration into the soil compared to the conventional cultivation. If a

Table 2. The analysis of variance tables for the ANCOVA (analysis of covariance) models of the log-transformed soil loss on the surface run-off interacting with the treatment

Source of variability	First rainfall			Second rainfall		
	sum of squares	*df*	*F* statistic[a]	sum of squares	*df*	*F* statistic[a]
Run-off	149.70	1	91.09***	130.64	1	94.36***
Treatment	21.73	3	4.41**	10.68	3	2.57
Run-off : treatment	22.93	3	4.65**	16.92	3	4.07*
Residual	101.90	62	–	85.84	62	–

df – the degrees of freedom; [a]*F* tests are of type II, following the principle of marginality; ***$P < 0.001$; **$0.001 < P < 0.01$; *$0.01 < P < 0.05$

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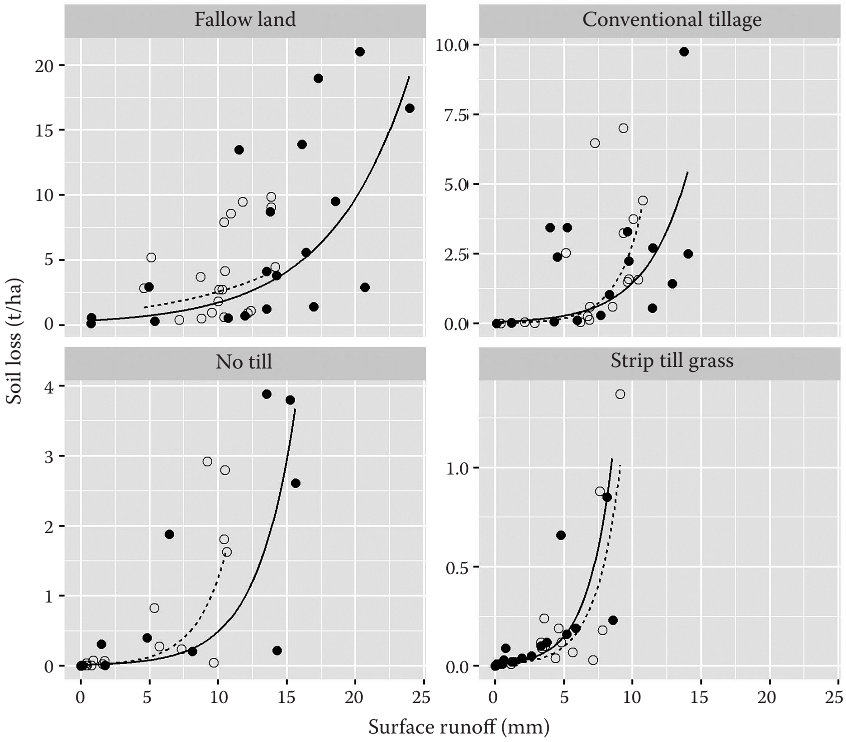

Figure 3. The relationships between the soil loss and the surface run-off for the different treatments, for the first (full circles and solid lines) and the second (open circles and dotted lines) rainfall

The lines represent the exponential regressions coming from the ANCOVA (analysis of covariance) models fitted separately for the first and the second rainfall data, with the log-transformed soil loss as a response and the surface run-off interacting with the treatment as the predictors

surface run-off occurs, the soil particles are released due to the strip-till from a significantly smaller area compared to the tillage.

The strip-till of the grass cover shows, in most cases of measuring zero soil loss values, when only clean water without sediments flowed from the soil surface. The fluctuations in the values in some measurements were influenced by the tractor tire track or by damaging the surface due to black game. All the experimental variants were prepared in the direction of the water flow line (down the slope). In practice, the leading grass strips in the direction of the contour line is expected, thus, achieving even better soil protection against erosion and surface run-off. Simultaneously, this technology supports the soil structure, reduces the evaporation from the soil, there is a better use of the nutrients from the applied fertilisers, which, in the final effect, contributes to a higher yield stability and production quality (Morrison 2002; Fernández et al. 2015).

Relatively favourable results were detected in the variant of the no-till into the rye cover. However,

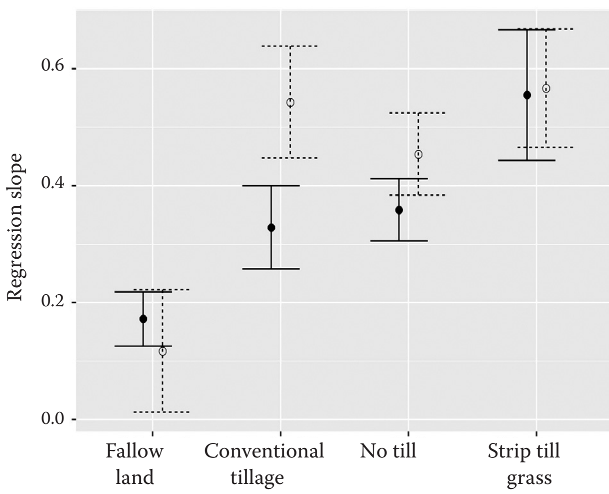

Figure 4. The estimates of the regression slopes and their standard errors from the linear regression of the log-transformed soil loss on the surface run-off for the different treatments

Data from the first (full circles and solid error bars) and the second (open circles and dotted error bars) rainfall experiments were analysed by separate ANCOVA (analysis of covariance) models

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it cannot be applied on all soil types. For example, in heavy loam soils there was a problem with the closure of the groove after sowing.

CONCLUSION

Maize is one of the most frequently grown agricultural crops in the Czech Republic. From the two years-worth of measurements it is apparent that the technologies for establishing maize into the grass strips provide a very strong soil conservation effect compared to the conventional technology. The soil loss was reduced to a minimum in the strip-till technology in all the realised measurements by the rainfall simulator. Also, the surface run-off was significantly reduced. On the other hand, the results of the conventional cultivation on the soil threatened by erosion show that the soil conservation effect is insufficient. When growing maize, the most prone period is the time after seeding. There is no soil conservation effect in the conventional technology because the plant cover is low. This is the main difference between the conventional technology and the strip-till into the grass. The strip-till technology has a positive conservation effect even in the springtime before sowing. The main aim of this paper was to introduce the results from the rainfall simulator measuring, as well as a new technological method on how to use grass covers for establishing maize and, thus, to contribute to the soil conservation on soils threatened by erosion. Due to the fact that the soil loss and surface run-off were lower throughout the season, it can be concluded that the strip-till is a suitable soil conservation technology for maize.

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