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Surface water runoff of different tillage technologies for maize

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Abstract. The present paper is focused on the evaluation of efficiency of soil-conservation technologies to reduce surface water runoff in Central Bohemia Region. In the last years, there has been an increase in maize planting on hillslope plots due to the construction of many biogas plants in conditions of Czech Republic. It enhances the risk of water erosion because the occurrence of sloping lands in the Czech Republic is high. To evaluate the technologies of stand establishment a field trial was laid out with four treatments of maize planting. The trial was laid out on a plot with light soil and slope of around 12%. It was a multi-year trial. To measure erosion parameters a rainfall simulator was used (measurement of surface runoff). The values obtained in two seasons show a positive effect of the soil surface cover by organic matter when reduced soil tillage was used. Soil loss also decreased at the same time compared to treatments with conventional soil tillage. It was found up to six-fold reduction in surface runoff by appropriate soil tillage technology during two seasons of measurement.

Key words: water erosion, soil tillage, organic matter on surface.

INTRODUCTION

In the Czech Republic approximately 50% of the arable land area is vulnerable to water erosion of soil. A crucial problem is excess surface runoff during intensive rainfalls connected with topsoil washing away (Janeček et al., 2005). At the same time, there is a negative effect of the reduced soil ability to transfer the highest water amount possible from precipitation to the soil profile. An increase in soil water retention is a desirable contribution to the soil moisture budget with respect to grown crops. Reduced water infiltration into soil is usually a consequence of undesirable soil compaction. Baumhard & Jones (2002) described inappropriate soil cultivation that can contribute to the formation of compacted layers in the soil profile (in location North American Great Plains). Titi et al. (2002) confirmed a reduction in soil permeability for water as a result of the formation of homogeneous soil layer when conventional soil tillage is used in the long term. In agricultural operations, the impacts of axle load traffic on soil are the most frequent cause of soil compaction (Chyba et al., 2014).

To express the exposure of agricultural land to erosion and to assess the effectiveness of soil-conservation measures a universal equation for the computation of long-term soil loss due to erosion (universal soil loss equation) is used (Wischmeier &

Smith, 1978). An assessment of particular factors applied in this equation reveals the importance of sufficient water infiltration into soil. The model was adapted for conditions in the Czech Republic by Janeček et al. (2005). For rainfall erosivity factor (Czech conditions) the annual value of this factor is computed from long-term precipitation data while total rainfall amounts lower than 12.5 mm and rainfalls when at least 6.25 mm did not fall within 15 minutes are not included (Janeček et al., 2012).

To measure the infiltration rate of water into soil and water surface runoff rainfall simulators are used. Advantages of artificial rain generated with a rainfall simulator are the regulation of water amount falling on soil in the form of drops and the setting of rain duration. The infiltration rate is determined from defined intensity of artificial rain and surface runoff of water from the measuring surface. The weight of intercepted water from surface runoff is recorded at a regular time interval during the entire measurement time. The beginning of water runoff from the measuring surface shows the time of the origin of overland flow (Hůla & Kovaříček, 2010). The measurement time is terminated after the infiltration rate has stabilized. The origin of overland flow and stabilized infiltration rate are typical and mutually comparable parameters for defined soil properties at the measuring site (Kovaříček et al., 2008).

Sufficient water infiltration into soil and limitation of surface runoff during intensive rainfalls are very important in fields with maize and other wide-row crops. Truman, Shaw & Reeves (2005) studied the importance of soil-conservation technologies for these crops. The authors reported twice lower surface runoff and five times lower soil loss after zero tillage compared to conventional soil cultivation during rainfall simulation for 60 minutes. Leij et al. (2002) described a frequent situation: the soil can be in an unstable condition after ploughing, soil porosity and other physical properties can quickly change in time. Schillinger (2001) highlighted a risk of water erosion as a consequence of insufficient infiltration of water into soil during snow melting when the surface layer of soil has thawed but there is frozen water in soil pores at deeper layers. Particularly vulnerable are lands on long hillslopes, without vegetation cover or plant residues on the soil surface. Most studies have focused on comparing individual crops. Effect of tillage method is then assessed much less frequently. The aim was to evaluate the impact of technology tillage (maize stand establishment) to the values of surface runoff.

MATERIALS AND METHODS

For the purposes of measurements a field trial with different treatments of maize planting was laid out in location Nesperská Lhota in Central Bohemia Region. Measurements were done in two seasons, always in June. The evaluated indicators were the speed of surface runoff and infiltration rate of water into soil under intensive rainfall simulation.

The plot was on a hillslope with an average slope of 12.2%. The trial was laid out on a light soil at the altitude of 420 m. A rainfall simulator (own construction CULS in Prague) was used to measure water infiltration into soil, surface runoff of water and soil washing away (4 repeats).

The simulation of rainfalls is generated with a full cone nozzle installed above the centre of the measuring surface. Sites suitable for measurements were chosen on the plot. The square measuring surface of 0.5 m^2 in size was bounded by metal strips along the entire circumference. On the bottom side of the measuring surface there is a collector that directs running water and washed away soil into a pipe and then into a graduated vessel. The surface runoff collected in the vessel is weighed on an automated balance and the values are recorded in a portable computer. The nozzle is fed with water conducted by a hose from the pump with a pressure adjusting valve. Rainfall intensity (90 mm for these measurements, calibration was performed in laboratories CULS in Prague) and kinetic energy of rain drops are controlled through a change in spraying pressure (Kovaříček, 2008). To measure the soil surface roughness downslope a chain method was used (Klick, 2002). Soil moisture before sprinkling was measured in disturbed soil samples taken in the proximity of the measuring surface with a gouge moisture sensor and determined by a gravimetric method (Valla et al., 2008). Kopecky cylinders with the volume of 100 cm^3 were taken to determine the basic physical properties of soil (each variation: 12 pieces). Soil sampling was performed prior to measurement (15.6.2017, 20.6.2018).

Measurements were performed in four treatments of the field trial that differed in the method of soil tillage for maize.

Experimental treatments

Treatment 1 – In autumn skimming was performed by a disk harrow. Plant residues and emerged shattered seeds of triticale were left to cover the soil surface over the winter season. The emerged shattered seeds were killed with a nonselective herbicide in spring. Before maize planting the soil tillage was done by a tine cultivator to a depth of 0.08 m and after this operation maize was planted.

Treatment 2 – In autumn skimming was performed by a tine cultivator to a depth of 0.15 m. Winterkilled catch crop (white mustard) was sown at the same time. Over the winter season the catch crop cover was left on the soil surface. The emerged shattered seeds were killed with a nonselective herbicide in spring. The soil was left untreated in spring, only maize was planted.

Treatment 3 – In autumn 2009 a part of the plot was ploughed to a medium depth (0.20 – 0.22 m) when contour ploughing was used. The soil surface was left in rough condition over winter. In spring the seedbed preparation was done (by field drag and spike-tooth harrow) and maize was planted. The soil surface cover by organic matter was almost zero at the time of planting.

Treatment 4 – The soil was also ploughed to a medium depth in autumn 2009. The soil surface was left in rough condition over winter. A week before maize planting the seedbed preparation was done (like in Treatment 2) and subsequently a cover under planted crop was sown in the space between rows (grain crop sown in spring before maize planting). Maize planting followed.

RESULTS AND DISCUSSION

Table 1 shows the results of the measurement of physical properties of soil. In general, the values are very similar. Differences between treatments are smaller than expected. From the values, it is obvious that the effect of ploughing (significant soil loosening) at the time of measurement has already faded. Slightly more favourable values of physical properties of soil have treatments with reduced soil tillage. However, the difference is below the threshold of statistical significance. Measurement in 2018 was strongly influenced by the dry course of spring.

Table 1. Soil bulk density and total porosity

Treatment	Depth, m	Porosity, %		Bulk density, g cm^{-3}	
		2017	2018	2017	2018
1	0.05–0.1	44.87	37.04	1.57	1.46
	0.1–0.15	41.10	38.51	1.47	1.48
	0.15–0.2	39.40	42.41	1.61	1.56
2	0.05–0.1	43.45	39.58	1.53	1.44
	0.1–0.15	42.05	43.45	1.44	1.48
	0.15–0.2	42.25	42.05	1.48	1.44
3	0.05–0.1	40.99	39.90	1.53	1.59
	0.1–0.15	37.90	41.99	1.48	1.58
	0.15–0.2	40.86	43.44	1.44	1.51
4	0.05–0.1	38.63	38.63	1.54	1.54
	0.1–0.15	41.23	41.23	1.48	1.48
	0.15–0.2	40.97	40.97	1.52	1.52

The results (see Fig. 2) of the 2017 season measurement demonstrate the need to use appropriate maize growing technologies. The results clearly demonstrate the beneficial effect of reduced technologies on surface runoff (Treatment 2 especially). The results are shown in the graph in Fig. 1. Here are the cumulative runoff values of the individual treatments during simulating rainfall. Curves can be successfully supplemented with linear dependencies. It can be seen from the graph that conventionaltreatments exhibit greater cumulative runoff values. There is a difference between conventional treatments. The grain crop between rows significantly protects the soil. Interrow crop reduced surface runoff by half. Conversely, the conventional treatment has shown minimal ability to infiltrate water. More than 80 percent of the water from the applied dose flowed in the form of a surface effluent. This was undoubtedly affected by the soil crust. The crust prevented infiltration and the water flowed freely throughout the simulation. The crust was not disturbed in the interrow space by any growth as in Treatment 3.

Figure 1. Field experiment (a), rainfall simulator developed on CULS in Prague (b).

Minor differences were noted for reduced treatments. The first half hour was better infiltrated treatment 1. After saturation, however, the surface runoff rate increased Treatment 2 then utilized the beneficial effect caused by the root system of white mustard. The root system has the effect of longer simulation when it significantly improves the infiltration of water to greater depths. Generally, each soil cover with organic matter has a beneficial effect on infiltration conditions. At the same time, the risk of damaging surface by water erosion is reduced. Treatment 2 during this season has shown the most beneficial effect on surface runoff reduction. The differences between the treatments this season were far more intense than in the next year.

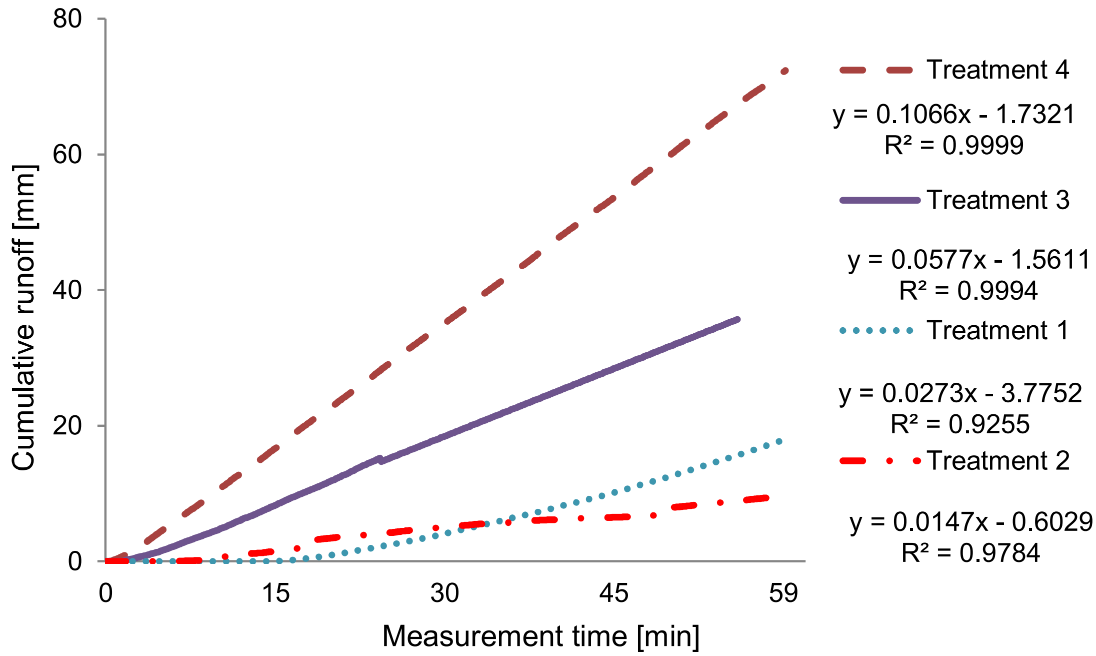

Figure 2. Cumulative runoff in June 2017.

The measurement results throughout the 2018 season reaffirm the beneficial effect of reduction technology (Treatment 2 especially) on surface runoff (see Fig. 3). It is also necessary to mention the influence of extreme temperatures and droughts throughout the spring and summer that affected the whole measurement season. Differences between treatments were far less than in the previous year due to drought. Still, the trend has remained unchanged. Very similar results of treatments 2 and 3 are very interesting. The worst results are again achieved by treatment 4. Nevertheless, in the 2018 season, it has shown a much higher infiltration capacity. All treatments after saturation, the ability to infiltrate decreased rapidly. Treatment 2 could be even worse affected by mustard vegetation where plant roots did not reach such proportions.

The input hypotheses consisted in the assumed reduction in surface water runoff using reduced soil tillage technology. These hypotheses have largely been met in evaluating the field experiment. Long-term attempts of this type have been dealt with by many other authors.

A decrease in surface runoff in non-redeveloping treatments has been found, which utilizes the covering of the soil surface with organic matter. This is confirmed by a number of authors. Moreno et al. (1997) on six plots (14 x 22 m in size) with light sandy alluvial soil comparing ploughing soil with protective soil treatment, represented only by shallow loosening and tillage of soil with a disc harrows. After 3 years of systematic soil tillage, the infiltration of the soil layer was higher at the soil protection tillage (124 mm h^{-1}) than in conventional soil treatment (66 mm h^{-1}).

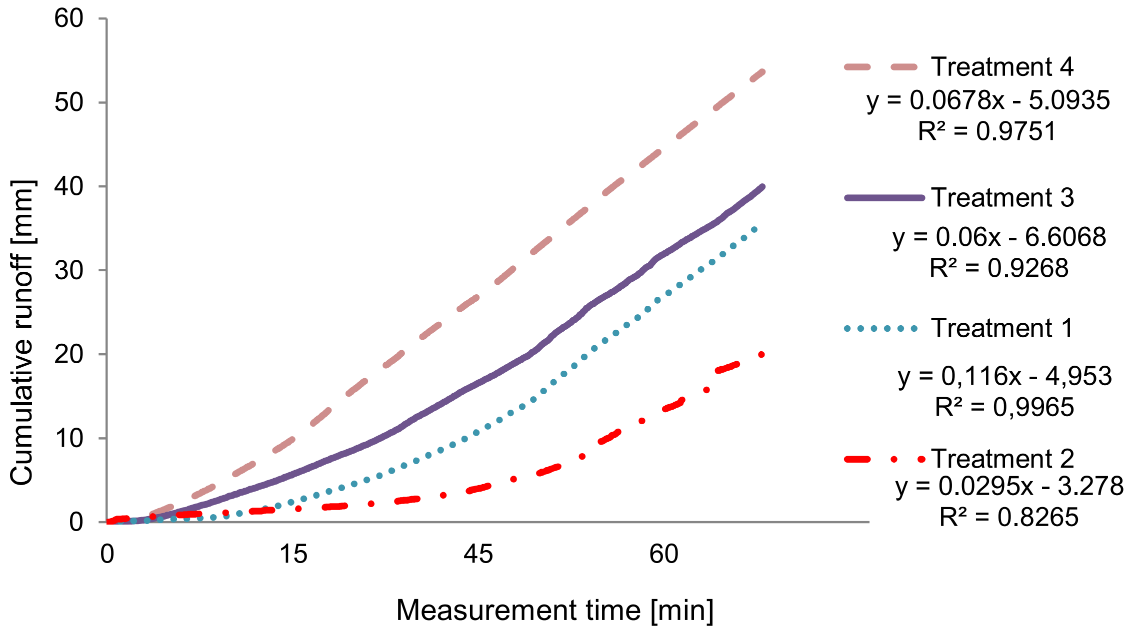

Figure 3. Cumulative runoff in June 2018.

Tebrügge & Düring (1999) carried out experiments on soils that have long been managed in a different way - ploughing and reduction tillage. After several years of repetition, they found 1.2–2.6 times higher infiltration rates of reduction tillage methods than conventional soil tillage. In analogy with infiltration, the surface runoff in conventional treatments was 1.2–2.6 times higher than in the reduced ones. Measurements were mostly performed during simulated intensity of 40 mm h^{-1}.

The rain simulator to measure surface runoff was also used by Zhang et al. (2014), who selected an area of 1 m^2 on the surface of each treatment. The irrigation intensity (90 mm h^{-1}) was the same as for measurements in this work. The authors also confirm the reduction of surface effluent in the no-flood-based technologies of planting versus plowing and emphasize the influence of organic matter on the surface.

The observed trend is confirmed by the measurements made by Baumhard & Jones (2002) or by Anken et al. (2004). They emphasize that plant residues in the surface layer of soil reduce the surface drainage of rainwater. The results of these experiments correspond very well to the results measured during the field experiment in this work. Novák et al. (2011), in their previous study, found different behaviour of soil types and less influence of soil tillage technology under the same simulation conditions. On the other hand, Hůla & Kovaříček (2010) found even greater dependence on tillage technology in Southern Bohemia (sandy soils). In their study they used an older model of rainfall simulator.

CONCLUSIONS

Our measurements showed different values of surface runoff and water infiltration into soil in the period of an increased risk of the occurrence of torrential rains and subsequent potential origin of erosion event. Treatment 2 (conventional tillage of soil with ploughing) was the most vulnerable to excess surface runoff when erosion risks of growing maize on a hillslope and light soil without soil-conservation technologies were confirmed.

The measurements proved a positive effect of the soil cover by organic matter. The infiltration rate of water into soil also influences water supply to plants. Fast infiltration also facilitates water retention in landscape, which is important with respect to the risk of local floods.

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