THE EFFECT OF DIFFERENT TILLAGE METHODS ON EROSION

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VACH, M. – HLISNIKOVSKÝ, L. – JAVŮREK, M.: The effect of different tillage methods on erosion. *Agriculture (Poľnohospodárstvo)*, vol. 64, 2018, no. 1, pp. 28–34.

During the years 2012–2016 at the site threatened by erosion, the effect of different intensity and depth of soil tillage on the progression of erosion were evaluated on the plots with silage maize. Three different tillage methods were compared and evaluated – conventional tillage, including ploughing (CT), no-tillage using mulch and direct drilling (NT), and minimum tillage treatment with a lower depth of soil cultivation and organic matter incorporation (MT). Water and soil runoff on all of the experimental plots were measured during erosion events. Besides an analysis of naturally occurring rainfall causing erosions, we also conducted the test of soil infiltration abilities with a rain simulator after silage maize harvest. The effect of the tillage on aboveground biomass yield and the input costs was also analyzed. The results showed that NT and MT can significantly reduce water and soil runoff comparing CT. The highest yields were recorded in MT, while the lowest were in CT. Total input costs were higher in the case of NT and MT, but the share of mechanized work was lower for these technologies. Our results showed that NT and MT technologies, as a part of silage maize with a higher plant density stand establishment, should be a useable erosion control measure in areas vulnerable to erosion.

Key words: Cambisol, conventional tillage, no tillage, minimum tillage, water erosion, soil and water runoff, grain yield

Erosion is a worldwide phenomenon that harms thousands of square kilometers of arable land. Billions of tons of topsoil are removed every year (Morgan 2005). Keller *et al.* 2013 published that in the United Kingdom about 40% of arable land is devastated each year by water erosion. It is estimated that around 3 million tonnes of high-quality soil are transported every year to drainage systems and rivers. Approximately 54% of arable land is menaced by water erosion in the Czech Republic nowadays.

According to experts, the compensations of soil losses larger than 2 t/ha a year will last approximately 50 or 100 years (Holý 1994). No universal solutions, to deal with erosion, exist. But there are several options of how to deal with erosion or to decrease erosion effects. Globally, the issue of soil erosion is solved primarily by optimizing the size and shape of the fields (by dividing fields into strips), by optimizing crop rotations, by using soil protection technologies via reduction of the inten-

sity of soil cultivation, and decreases of working operations (Martens *et al.* 2000; Sainju 2002; Hernanz *et al.* 2002), or by keeping the residues of the preceding crops at the field. Using the conservation tillage can significantly decrease negative kinetic effect of rain drops during the torrential rains (Trautman *et al.* 2005; Kovaříček *et al.* 2008) and increase the microbial community and activity, doubling the resistance against erosion (Bhatt & Khera 2006; Mikanová *et al.* 2009; Šimon *et al.* 2009). Conservation tillage not only reduces erosion (Basić *et al.* 2004; Schuller *et al.* 2007), but also positively influences the soil's ability of retention, its structure, fertility, and other parameters (Tebrügge & Düring 1999; Zhang *et al.* 2007).

The aim of our work was to analyze optimal tillage systems for silage maize, which would minimize water erosion and soil losses and compare these systems to how they influence grain yields of silage maize and input costs.

MATERIAL AND METHODS

The trials were established in the experimental station Lukavec, Czech Republic (49.56N, 14.99E, 610 m a.s.l., potato cropping area, annual mean temperature 7.3°C, and annual mean precipitation 682 mm), and were running from 2012 to 2016. The soil type at the experimental site was modal, sandy loamy Cambisol with 7° slope. The mean value of the soil pH was 6.1, mean content of the organic carbon was 1.06% and mean content of total nitrogen was 0.18%.

Three different soil cultivation methods were evaluated. The conventional tillage (CT), included ploughing (25 cm), seed-bed preparation, and sowing, which served as a control treatment. No-tillage (NT) method consisted of direct sowing into the untilled soil. The soil surface was covered by mulch from post-harvest residues of the preceding crop when maize emerged. Minimum tillage (MT) included shallow soil loosening to the depth of 15 cm, incorporating stubble residues in the same way. Three times replicated erosion plots with different tillage treatments ($3 \times 8 \text{ m} = 24 \text{ m}^2$ – longer side was in the direction of the slope) were bounded with sheet metal strips to measure exactly the amount of precipitation running off from the experimental area. For that reason, containers were installed on the bottom of each erosion plot to collect runoff water and soil particles. Collected water and soil samples were separated, analyzed, and recalculated to one hectare and statistically analyzed (Statistica 12.0, StatSoft) by one-way and multifactorial analysis of variance (ANOVA, MANOVA) and by Tukey's post hoc test. Besides the analysis of naturally induced erosion events (E1-E5), a test of soil infiltration abilities with a rain simulator was conducted. This test was carried out once a year, following the harvest of silage maize.

The rain simulator measurement was carried out on each replication of all tillage treatments at a designated area of 0.5 m² from a rain simulator designed by the Research Institute of Agricultural Engineering (Prague-Ruzyně). Surface runoff was measured at a constant operating pressure of 100 kPa from a height of 1 m (Šindelář *et al.* 2007) for 60 minutes.

All post-harvest residues were left on the soil

surface on the measured areas. Before sprinkling, the selected areas of measurement were characterized by soil moisture at a depth 10 cm (soil hygroscope Theta HH2), sloping and surface roughness with digital gradiometer (BMI Inclitronic Plus, Germany) according to method Klik *et al.* (2002)

The simulated rain is defined by its intensity and operating time of a simulator, i.e. duration of the rain. The precise amount of water, infiltrating the soil, was calculated by the difference between the simulated precipitation and the amount of cumulative surface water runoff from the experimental plot. The amount of water from the surface runoff was weighted at five-second intervals and the amount of the surface water runoff [m³/ha] and soil loss [kg/ha] during erosion was recalculated to 1 ha.

RESULTS AND DISCUSSION

Evaluation of erosion events caused by natural rainfall

During the vegetation period of 2012, five erosion events (E1-E5) with precipitation runoff and soil losses were recorded (Figure 1a, 1b). The most erosive effect was found in CT after heavy rains on July 28 (E5), when more than 30 mm of precipitation over two hours, 8.9 m³ of runoff water and 436.6 kg/ha of soil loss, was recorded. The MT significantly decreased surface water runoff (6.6 m³/ha) and soil losses (143 kg/ha). The lowest erosion was recorded in NT (water runoff and soil losses were about 60 and 21%, respectively, lower, compared to CT).

The most serious event in 2013 was recorded from 24 to 26 of June (137 mm of precipitation) (E2, Figure 1c, 1d). The highest losses of water (7.52 m³/ha) and soil (327 kg/ha) were recorded at the CT treatment. In the case of NT and MT, the water runoff was 4.61 m³/ha and 4.36 m³/ha, respectively, during E2. Even more significant differences were observed in soil runoff, where the soil losses ranged from 29.3% (NT) to 40.9% (MT) compared to the CT plots.

In 2014, we recorded five erosion events. After less intense rainfall on July 7 (E4), there was surface water and soil runoff found only on the CT plots (Figure 1e, 1f). From the graphs, it is clear that the highest amount of runoff water and soil losses were measured after a hail storm on June 11 (E3), with

53.6 mm of precipitation falling during one day.

The greatest erosion effect was visible on CT plots (10.13 m³/ha of water runoff and 435 kg/ha of soil losses). On the contrary, the plots with applied conservation tillage technologies, lower values of runoff water, and soil losses were recorded during all the erosion events.

In the dry and warm year of 2015, only one erosion event was recorded (August 18, 83.5 mm of precipitation). Surface runoff water was captured only on the CT plots. At the same time, no erosion was recorded on the NT and MT plots during the same time, confirming their ability of higher water

infiltration. There was one erosion event in 2016 (July 15th) when 63.3 mm of precipitation was recorded. The highest water erosion was recorded on CT plots (7.30 m³/ha) while the values of NT and MT were 81.4 and 85.6% lower (Table 1). In the case of soil erosion, the highest losses were found on CT plot, while NT and MT recorded 73.6% and 63.5% lower losses, comparing to the CT treatment. Similar results published by Franzluebbers (2002), who analyzed the effect of different cropping practices on water damage. He stated that organic soil matter is a key factor in limiting the water runoff surface and soil losses. The effect of different

Figure 1. The effect of different intensity and depth of soil tillage (CT – conventional tillage, NT – no tillage, MT – minimum tillage) on surface water runoff in a) 2012, c) 2013 and e) 2014 and on surface soil runoff in b) 2012, d) 2013 and f) 2014

tillage approaches on the ability of topsoil layer to catch rainwater also evaluated by Kovaříček *et al.* (2014). They also recorded the highest erosion control effect in the NT and MT cropping practices and showed that undesirable compaction of the topsoil significantly increases water and soil erosion during the intense erosion events. Also, Govers *et al.* (2017) recommend soil protective tillage approaches (with sequestration of organic carbon into the soil) as a tool of soil protection in areas endangered by erosion.

Evaluation of water erosion caused by simulated rainfall

The time intervals from the beginning of water erosion from the start of the rain simulation and the amount of soil losses from the different tillage treatments in the evaluated period between 2012–2016 are presented in Table 2. From the observed beginning of surface water runoff after simulated rainfall, the NT was evaluated as the most advantageous in terms of reduction of erosion effects. This variant was characterized by the latest onset of the beginning of the surface water runoff practically in all monitored years (in 6.92 minutes in

the average of years). Less than two minutes earlier, surface water runoff started on the MT plots. The results obtained clearly showed that the onset of soil erosion was influenced by the mulching of organic matter on the soil surface, which significantly slowed the water runoff and increased the volume of water infiltration into the soil. Only the slightly earlier onset of water runoff (4.71 minutes from the start of simulated rainfall) was found in CT. When simulating the rain in the evaluated treatments on the stubble of the silage maize, the surface layer of the soil was gradually saturated with water, and after the pores were filled, the surface runoff occurred. Water permeability decreased parallel with depth. Under constant rain simulation, the surface runoff increased for an interim period, but after 30 to 45 minutes it stabilized on the difference between the sprinkling intensity and the rate of infiltration into the subsoil (Kovaříček *et al.* 2008). In our experiment, we confirmed the general trend that, the sooner the surface runoff began, the more the soil was washed away. The lowest soil losses (25.37 g/m²/h), in the average of years, was recorded on the NT plots, while the highest losses (63.67 g/m²/h) were found on the CT plots (Table 2). Table 3 shows

T a b l e 1

Amount of surface water runoff and soil losses during erosion event in 2016

Soil tillage treatment	Surface water runoff		Soil losses	
	[m ³ /ha]	Soil tillage impact [%]	[kg/ha]	Soil tillage impact [%]
CT 1	7.98	–	197.5	–
CT 2	6.93	–	180.3	–
CT 3	6.98	–	157.2	–
Average CT	7.30±0.34 ^a	100.0	178.3±11.68 ^a	100.0
NT 1	6.66	–	120.3	–
NT 2	5.68	–	108.5	–
NT 3	5.47	–	110.7	–
Average NT	5.94±0.37 ^a	81.4	113.2±3.62 ^b	63.5
MT 1	6.92	–	138.3	–
MT 2	6.08	–	130.6	–
MT 3	5.77	–	124.8	–
Average MT	6.25±0.34 ^a	85.6	131.2±3.91 ^b	73.6

Legend: CT – conventional soil tillage; NT – sowing into no-tilled soil; covered with mulch; MT – minimum soil tillage; 1, 2, 3 – replications

Means with standard errors of the mean (SE) followed by the same letter were not significantly different at 0.05 probability level

the results of the year 2014, as the typical and characteristic example.

Results provided evidence that in the case of severe rainfall, the NT and MT significantly reduce surface water runoff, soil losses, and improve rainwater infiltration into the soil.

Evaluation of soil tillage methods on maize yield and financial costs

Soil tillage methods do not only affect erosion, but also the yield of cultivated plants and financial costs. As our experiment lasted from 2013 to 2016, weather conditions of each year significantly affect-

T a b l e 2

Beginning of surface water runoff and soil losses during erosion events in 2012–2016

Tillage treatment	Year	Beginning of surface water runoff [min]		Soil losses due to water runoff [g/m ² /h]	
		Value	Average	Value	Average
CT	2012	5.03	4.71	50.64	63.67
	2013	5.38		77.36	
	2014	4.22		52.53	
	2015	4.65		56.34	
	2016	4.27		81.48	
NT	2012	7.28	6.92	18.90	25.37
	2013	7.12		18.37	
	2014	6.58		14.14	
	2015	6.83		24.04	
	2016	6.79		51.41	
MT	2012	6.16	5.08	63.37	48.16
	2013	5.42		30.18	
	2014	4.28		55.71	
	2015	4.97		28.09	
	2016	4.57		63.45	

T a b l e 3

Cumulative surface water runoff from the test area measured in the intervals of 15 minutes under the constant intensity of simulated rain 87 mm per hour (2014)

Tillage treatment	Variant/replication	Cumulative surface water runoff [l] per given time interval							
		15 min		30 min		45 min		60 min	
		Value	Average	Value	Average	Value	Average	Value	Average
CT	CT 1	2.78	4.86	12.85	14.41	22.92	23.74	29.52	30.58
	CT 2	5.83		16.69		27.63		34.80	
	CT 3	5.98		13.69		20.66		27.41	
NT	NT 1	0.59	1.31	7.54	8.35	15.22	14.83	17.92	19.28
	NT 2	0.65		6.79		9.36		13.71	
	NT 3	2.68		10.71		19.92		26.22	
MT	MT 1	2.77	3.84	10.10	11.27	17.61	19.07	24.20	25.11
	MT 2	2.85		7.88		15.46		19.54	
	MT 3	5.89		15.82		24.13		31.58	

T a b l e 4

The effect of the year (2013, 2014, 2015 and 2016) and NT, MT and CT on the average yield of maize

Tillage treatment	2013	2014	2015	2016	$\bar{x} \pm SE$
CT	38.56±0.54a	39.30±0.97a	31.65±0.98a	30.27±0.77a	34.59±1.26A
NT	36.55±0.81a	43.77±1.07b	34.79±1.06ab	33.94±0.95a	37.26±1.24B
MT	42.37±1.16b	45.15±0.85b	37.33±1.11b	31.66±0.85a	39.13±1.61C
$\bar{x} \pm SE$	39.16±0.96C	42.77±1.01D	34.59±0.98B	31.96±0.69A	–

Means with standard errors of the mean with the same letter (small letters vertically, big letters for the means of the year and technology) are not significantly different at 0.05 probability level.

T a b l e 5

Economic evaluation of CT, NT and MT (€/ha)

Soil treatment	Material costs	Costs of mechanization + fixed costs	Total costs	Diesel consumption [l/ha]	Workload [h/ha]
CT	497	466	963	73.8	5.75
NT	609	421	1,030	54.3	5.04
MT	602	425	1,027	49.2	4.18

ed maize yield (Table 4). According to MANOVA, the “year” factor affected yields of maize by 76%, while “tillage system” influenced maize yield only by 19%. The MT (39.13 t/ha) was the most productive system with significantly higher yields than NT (37.26 t/ha) and CT (34.59 t/ha, Table 4). The difference in yields between NT and CT was also significant. The reason for higher grain yields in MT and NT systems is that these approaches positively affect water regime and help to resist weather fluctuation during the season. The same results were published by Mikanová *et al.* (2012), who studied different tillage and its impact on yield of cereals. Håkansson (2005) outlined that soil-protected tillage can also positively affect soil properties, such as bulk density or porosity, accumulation of soil organic matter, and less mobile nutrients in topsoil layer. The economic evaluation of CT, NT, and MT for silage maize was based on our previous experiences from evaluation of winter wheat, spring barley and white mustard (Vach *et al.* 2016), on “Normatives of agricultural production technologies” (Kavka *et al.* 2006) and the normatives of the cropping technologies (www.agronormativy.cz).

In the case of MT and NT, compared to the CT, higher costs for inputs (mainly pesticides) were found. On the other hand, the cost of mechanization was lower, as the number of input measures was reduced (Table 5). This is due to the need of more exacting operations in CT, especially cost of medium deep ploughing (22 cm). It can be stated that with decreasing intensity of soil cultivation, the cost of mechanization can be reduced parallelly.

However, material inputs can significantly increase with reduced processing due to higher pesticides consumption.

CONCLUSIONS

According to the results obtained, we can confirm that NT and MT provided the best erosion control results. On the other hand, CT was evaluated as the method increasing the risk of erosion. In this way, higher erosion control effects of NT and MT were verified by statistically significant higher water infiltration into the soil and significantly lower surface water and soil runoff. The results of this study

confirmed the legitimacy for the inclusion of conservation soil tillage in the system of erosion control measures and soil protection against damage by surface runoff of rainwater in eroded areas. At the same time, they reduce the losses of the most fertile soil layers and applied agrochemicals and thus reduce subsequent pollution of the surface and groundwater. NT and MT can better processes soil water regime, positively affecting soil properties, keep soil organic matter and less mobile nutrients in the topsoil layer, positively influencing the yield of crops. These tillage approaches are also cheaper in the case of mechanization, but more expensive for pesticides. When choosing a method of tillage, approaches with less soil cultivation should be preferred not to only reduce costs, but to simplify workload and decrease erosion.

Acknowledgements. Supported by the Ministry of Agriculture of the Czech Republic, Project No. RO0418

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Received: November 11, 2017