INFLUENCE OF NO-TILL TECHNOLOGY ON REDUCING SOIL DEGRADATION DURING SORGHUM CULTIVATION*

D. Kabelka[1,2], D. Kincl[1,2], J. Vopravil[1,2]

[1]Research Institute for Soil and Water Conservation, Prague, Czech Republic
[2]Czech University of Life Sciences Prague, Department of Land Use and Improvement, Faculty of Environmental Sciences, Prague, Czech Republic

Soil degradation and water erosion are undoubtedly serious global problems. Moreover, excessive surface runoff and the lack of water in landscape are problems encountered not only in the Czech agricultural land. This condition is unsustainable in the long-term and it is necessary to find, verify and quantify suitable agricultural methods for reducing soil degradation. In this study, we tested two soil conservation technologies for sorghum (*Sorghum bicolor*) cultivation. Our results show that erosion was reduced by more than 78% (no-till) and 89% (no-till: narrow row) in rainfall simulation on naturally moist soil compared to conventional cultivation. Also, the use of conservation technologies reduced surface runoff (52% no-till, 68% no-till: narrow row). Sorghum has similar agronomic requirements as maize but it has the advantage of a good dryness tolerance and a high water use efficiency. The two-year research (2014, 2017) took place in the Central Bohemian Region. Soil degradation was verified using a rainfall simulator. The results have shown that both no-till technologies have a significant ($P < 0.05$) soil conservation effect.

soil conservation technology, soil loss, surface runoff, rainfall simulator, water erosion

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INTRODUCTION

Soil loss and insufficient water infiltration in agriculture are one of major worldwide problems (B o a r d m a n et al., 1990; N o v a r a et al., 2011). In the Czech Republic more than 51% of agricultural land is threatened by soil degradation (S a r a p a t k a , B e d n a r , 2015). Rainfall-induced soil erosion risk is especially high during summer storms or the early wet season, when plant cover is low (T a g u a s et al., 2015). As a result, there is excessive surface runoff, soil erosion and smaller fertility. Soil loss and surface runoff are increased especially due to soil management and tillage practices (B l a v e t et al., 2009; V a n w a l l e g h e m et al., 2011). Indeed, there are several reasons: conventional plowing, removal of the original vegetation, use of pesticides and herbicides that damage biological activity in soils (P e l o s i et al., 2013), low overall vegetation cover, soil compaction due to machinery traffic (T a r o l l i et al., 2014), organic matter loss (K a b e l k a et al. 2019), and absence of soil erosion control measures (A r n a e z et al., 2015). Therefore, there is a need to find soil conservation technologies that will make agriculture sustainable.

The crop which significantly contributes to water erosion and surface runoff is sorghum (*Sorghum bicolor*). Sorghum is globally the fifth most important cereal in terms of acreage and production (B e t a , C o r k e , 2004). The main reason for sorghum high erodibility is insufficient soil conservation during the entire year. The bare surface is affected by intense

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storms that induce severe water erosion and runoff processes (Borga et al., 2011). Sorghum has a great drought tolerance and requires minimum fertilization on agriculture lands (Dicko et al., 2006). In the Czech Republic, maize is the most cultivated agricultural crop, but the advantage of sorghum compared to maize is a significantly lower need for water. The weather is becoming more extreme and there is a potential for sorghum cultivation in the conditions of the Czech Republic. Currently there are several kinds of soil conservation technologies for sorghum, but their evaluation needs further research.

The beneficial effects of soil conservation technology can be summarized as follows: (1) higher water retention in landscape (Cook et al., 2006; Mulumba, Lal, 2008), (2) protection of soil against raindrop impact, reducing erosion rates (Sadeghi et al., 2015), (3) decreased sediment and nutrient concentrations in runoff (Gholami et al., 2013), (4) decreased runoff generation rates and surface flow velocity by increasing roughness (Cerda, 2001), (5) improved infiltration capacity (Wang et al., 2014), (6) increased activity of some species of earthworms and microorganisms (Wooldridge, Harris, 1991), (7) enhanced soil physical conditions such as soil structure and organic content (Jordan et al., 2011; Karami et al., 2012), (8) reduced topsoil temperature for more optimum germination and root development (Dahiya et al., 2007) and decreased evaporation (Uson, Cook, 1995).

One kind of conservation technologies is the no-till technology which we tested in our research. The basic principles of no-till agriculture include the following: growing crops without using traditional tillage, retaining surface residue that reduces erosion, sowing directly into the soil covered by residue mulch. In addition to erosion control, no-till also saves energy (Javurek et al. 2007; Vach et al. 2016). Other types of soil conservation technologies are e.g. strip-till or cover crops (Brant et al., 2017). In some cases, afforestation can be a possible way to improve degraded soil. Afforestation of agricultural lands constitutes a serious change in soil dynamics (Holubik et al., 2014; Podrazsky et al., 2016) and it has a positive influence on physical characteristics of soil (Podrazsky et al., 2015).

MATERIAL AND METHODS

The two-year research took place close to the villages Krásná Hora nad Vltavou (in 2014) and Petrovice (in 2017) located in the Central Bohemian Region. Typical climate is slightly warm and dry. The terrain of wider surroundings is rugged. Soils were classified as Haplic Cambisols (Nemecek et al., 2011).

In our research focused on water erosion, surface runoff and infiltration we tested five soil conservation technologies: (1) control – bare soil, when the experimental plot was left completely without plant cover (Wischmeier, Smith, 1978); two technologies of conventional cultivation: (2) growing crops in 0.75 m wide rows (like in maize) and (3) narrow-row cultivation in just 0.375 m wide rows; and two technologies of no-till cultivation (growing crops without using traditional tillage and sowing directly into the soil covered with a residue mulch): (4) with a seeder specifically designed to cut through the residue and sow seed in 0.75 m wide furrows and (5) narrow-row cultivation in 0.375 m wide rows. By the no-till cultivation, the pre-crops were *Phacelia tanacetifolia* in 2014 and *Secale cereal* in 2017.

The plots suitable for the technologies verification were selected particularly for their slope uniformity – around 12% (Petrovice) and 8% (Krásná Hora nad Vltavou). The verification and check of selected technologies took place at three developmental stages of the crop cover. The plots were 20 m long and 7 m wide. The experimental plots with sorghum were established in three replications because of three terms. For this reason, unique rainfall simulations for each technology type in each term could be carried out. Overall, for each technology, there were six simulations of rainfall within the two years. The terms were determined according to the guidelines Erosion control in the Czech Republic – A handbook (Janecek et al., 2012). The individual measurement terms are defined below.

Term I (the second growing period). The period from plot preparation for sowing up to one month after sowing or planting. At the end of the second growing period the plant height was the following: conventional cultivation – 30 cm; conventional cultivation: narrow-row – 30 cm; no-till cultivation – 14 cm; no-till cultivation: narrow-row – 14 cm.

Term II (the third growing period). The period for the duration of the second month from spring or summer sowing. Before rainfall simulation the plants of sorghum had the following height: conventional cultivation – 210 cm; conventional cultivation: narrow-row – 215 cm; no-till cultivation – 110 cm; no-till cultivation: narrow-row – 100 cm.

Term III (the fourth growing period). The period from the end of the third period up to harvest. The plants under the used technologies had the following height: conventional cultivation – 240 cm; conventional cultivation: narrow-row – 240 cm; no-till cultivation – 200 cm; no-till cultivation: narrow-row – 200 cm.

The soil erosion and runoff processes were measured using a rainfall simulator. The measuring principle is based on rainfall simulation on a clearly defined and designated area. The size of the rainfall simulation area was 21 m^2, from which the surface water subsequently flowed along with eroded soil particles. During the rainfall simulation the surface runoff samples were always taken at the place of outflow into a calibrated container (319 ml volume). Sampling took place every three minutes with the aim to gather the total amount of eroded particles. After the simulation, each sample was oven-dried (Memmert UFB 400; Memmert, Germany) for 12 h at 105 °C under laboratory conditions. The amount of eroded undissolved particles for the particular technology was determined from the samples adjusted in this way. The total amount of eroded sediment from the verified area can be calculated by multiplying the average amount of undissolved particles in one sample and the size of surface runoff. Soil loss was assessed based on summary statistics for the used technologies. To test for difference in soil loss, the F-test and consequently t-test ($P < 0.05$) were used. The rainfall simulator allows for monitoring the erosion effect, but also the beginning and the end of surface runoff or the soil infiltration ability. The infiltration was determined based on the total amount of water and surface runoff captured during the simulation. The measured values included an error line segment describing the deviation in the measurements during the season.

The rainfall simulation provided a comprehensive set of information on the selected technologies and their soil conservation effectiveness during the time of torrential rainfalls. During the verification process the soil and slope conditions of the individual options must be as much similar as possible. Therefore the technologies were used and verified in the same place.

The rainfall simulation was carried out in two consecutive repetitions. The first rainfall simulation took 30-minute followed by a 15-minute technological break. Then the second (repeated) 15-minute rainfall simulation took place. The two rounds of rainfall simulation were selected in order to simulate rainfall on naturally moist soil and subsequently on already water-saturated soil. As for the rain simulator, the rainfall intensity was set at 60 mm/h. The conditions stated by Janecek et al. (2012) were taken into account when setting the rainfall simulation regime. This intensity was chosen based on the recommendation of the Czech Hydrometeorological Institute and it reflects the average intensity of torrential rainfalls in the Czech Republic.

RESULTS

Soil loss and surface runoff are related to bare soil, which was regarded as the control technology. Although the same method was applied during the simulation, it is not possible to compare the results for individual terms without converting them into a percentage expression. This is caused by the fact that during the technologies verification the soil moisture and temperature parameters may differ. For this reason the presented graphs are expressed in percentage, where the bare soil is considered the basis. In this way the individual terms during one year could be compared.

Rainfall simulation outcomes

Term I. The values measured during the rainfall simulations on naturally moist soils and already saturated soil are shown in Figs. 1 and 2. The worst results of soil loss were measured by the conventional cultivation (naturally moist soil 66.1%; already saturated soil 57.2%). As early as during the first term, a positive effect on soil conservation was observed in both no-till technologies. Soil loss was lower more than one-third compared to conventional cultivation. The surface runoff was reduced as well. The best values were achieved by the technology no-till: narrow row. The surface runoff was lower on naturally moist soil by 61.2% compared to conventional cultivation. Equally, the technology conventional cultivation: narrow-row achieved positive results but the difference was not so significant.

Term II. The influence of no-till technologies on reducing soil loss was clearly apparent also in the second term of simulation. The measured values

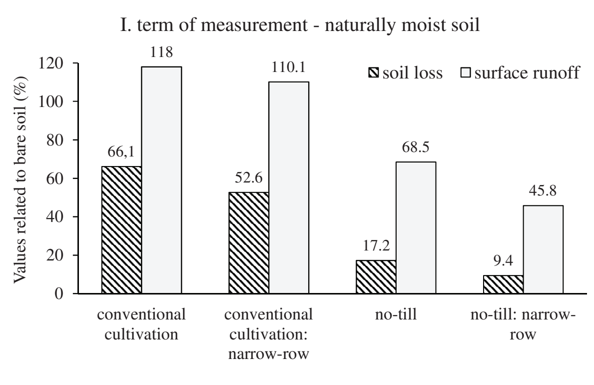

Fig. 1: The average relative values of soil loss and surface runoff from all rainfall simulations in the first term (30-minute-simulation)

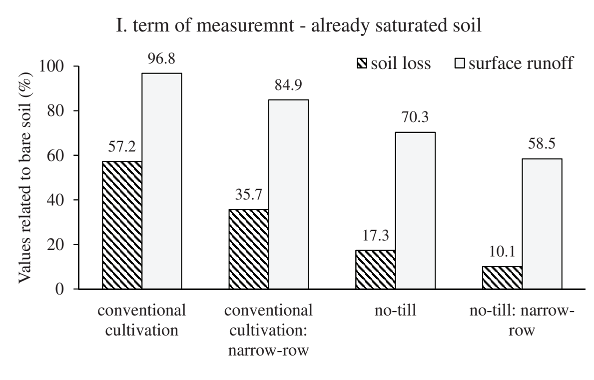

Fig. 2: The average relative values of soil loss and surface runoff from all rainfall simulations in the first term (15-minute-simulation)

were similar in character to those in term I but the differences in the total soil loss between bare soil and other technologies were higher. For example, no till: narrow row technology showed the soil loss only 0.8% related to bare soil. Excessive surface runoff showed the technology of conventional cultivation (naturally moist soil 94.3%; already saturated soil 93.3%). No-till technologies (no-till, no-till: narrow row) reduced surface runoff compared to conventional cultivation in both simulations. No-till: narrow row showed by 81.3% lower surface runoff during the simulation on naturally moist soil compared to conventional cultivation. The amount of soil loss and surface runoff during rainfall simulations is depicted in Figs. 3 and 4.

Term III. There was a still lower soil loss by both no-till technologies in the third term. The character of soil loss was again very similar to that in the previous two terms. The exception was no-till technology in the second simulation on already saturated soil where there was a low difference between conventional cultivation and no-till technology (10.4%). The values of surface runoff were positive in no-till technologies. The best value was measured in no-till technology on naturally moist soil (surface runoff by 96% lower compared to conventional cultivation). By the remaining two technologies there was an excessive surface runoff (conventional cultivation, conventional cultivation: narrow row). The results from rainfall simulations are presented in Figs. 5 and 6.

Research results evaluation

A characteristic feature of soil conservation technologies (including no-till technologies) during cultivation is retaining the residues of biomass on the soil surface (Alberts, Neibling, 1994). Bare soil, being considered the worst option, was chosen as the control plot to which the outcomes of the other used technologies were related. Surface runoff results of conventional cultivation do not differ much from those in bare soil. This fact points out to insufficient soil conservation efficiency of the traditional way of farming. Likewise, soil loss is high by the technology of conventional cultivation. Both no-till technologies (no-till and no-till: narrow row) provide much better results in all measuring characteristics compared to

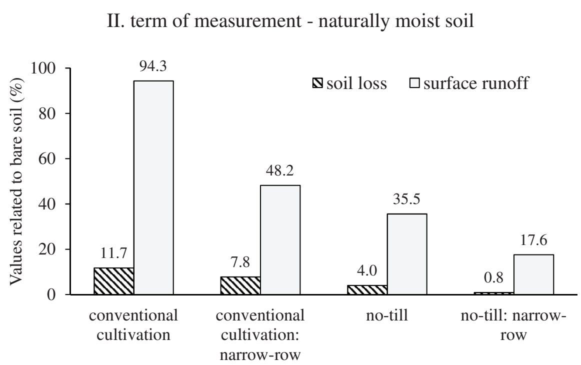

Fig. 3: The average relative values of soil loss and surface runoff from all rainfall simulations in the second term (30-minute-simulation)

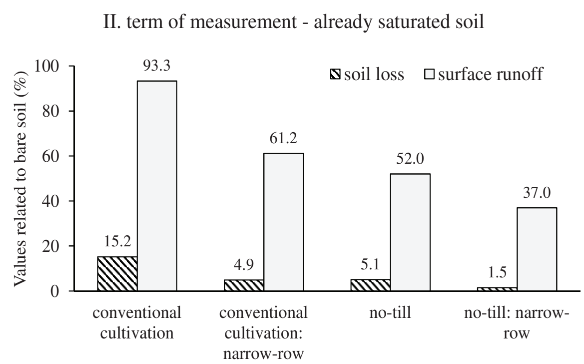

Fig. 4: The average relative values of soil loss and surface runoff from all rainfall simulations in the second term (15-minute-simulation)

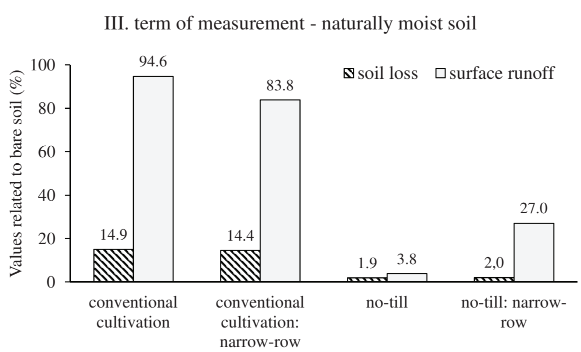

Fig. 5: The average relative values of soil loss and surface runoff from all rainfall simulations in the third term (30-minute-simulation)

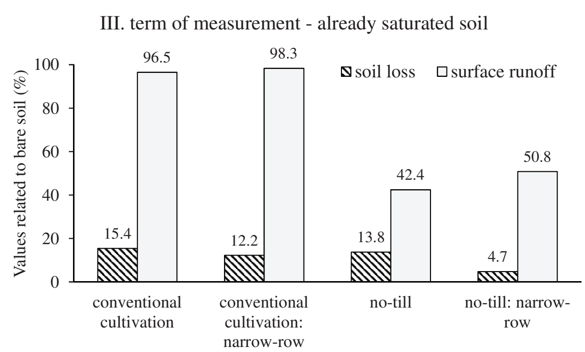

Fig. 6: The average relative values of soil loss and surface runoff from all rainfall simulations in the third term (15-minute-simulation)

Table 1. Average values from three terms of rainfall simulation measurements in the seasons 2014 and 2017

Type of technology		Surface runoff		Soil loss	
		(mm)	(%)	(t ha^{-1})	(%)
Naturally moist soil (30-min simulation)	bare soil	18.13	100	11.13	100
	conventional cultivation	16.48	90.92	3.52	31.6
	conventional cultivation: narrow-row	14.74	81.3	2.77	24.9
	no-till	7.82	43.15	0.75	6.69
	no-till: narrow-row	5.14	28.35	0.38	3.4
Already saturated soil (15-min simulation)	bare soil	10.7	100	4.54	100
	conventional cultivation	9.98	93.27	1.46	32.09
	conventional cultivation (narrow-row)	8.64	80.78	0.88	19.27
	no-till	6.37	59.5	0.57	12.44
	no-till: narrow-row	5.36	50.11	0.26	5.69

Table 2. Basic statistical parameters of soil loss

Basic parameters	Conventional cultivation	Conventional cultivation: narrow row	No-till	No-till: narrow row
Mean	2.487	1.823	0.655	0.318
Variance	7.549	4.58	0.711	0.229
Observations	12	12	12	12

Table 3. *F*-test for soil loss values

Technology	Conventional cultivation	Conventional cultivation: narrow row	Conventional cultivation	No-till	Conventional cultivation	No-till: narrow row
Degree of freedom	11		11		11	
F-test value	1.648		10.622		32.988	
P-value 0.05 (one-tail)	0.21		2.37E-04		8.13E-07	
F-test critical value (one-tail)	2.818		2.818		2.818	

conventional cultivation. Erosion was reduced by more than 78% (no-till) and 89% (no-till: narrow row) in the rainfall simulation on naturally moist soil compared to conventional cultivation. In the case of rainfall simulation on already saturated soil erosion was reduced by 61% (no-till) and 82% (no-till: narrow row). The surface runoff in conservation technologies compared to conventional cultivation was reduced as follows: naturally moist soil – 52% (no-till) and 68% (no-till: narrow row); already saturated soil – 36% (no-till) and 46% (no-till: narrow row). Conventional cultivation: narrow row also showed in most cases better results, but the soil conservation effect was not so high. The average values from all measurements are summarized in Table 1. For soil loss results we determined basic statistic parameters, *F*-test and *t*-test (Tables 2–4). The outcomes show that the values for no-till technologies are statistically different ($P < 0.05$) from those for conventional cultivation.

In this study, we further evaluated the infiltration process during rainfall simulation. A lower surface runoff from plots means a higher infiltration. The measured values are given in Figs. 7 and 8. In the rainfall simulation on naturally moist soil, the infiltration was higher by 8.68 mm in no-till technology and by 11.37 mm in no-till: narrow row technology compared to conventional cultivation. Also, infiltration was the highest in no-till technologies on already saturated soil.

DISCUSSION

The study results are among the first to provide information on the soil conservation efficiency of no-till technologies during sorghum cultivation under the conditions of the Czech Republic. The most important outcomes of this research concern the rate of water

Table 4. *t*-Test for soil loss values

Technology	Conventional cultivation	Conventional cultivation: narrow row	Conventional cultivation	No-till	Conventional cultivation	No-till: narrow row
	two-sample assuming equal variances		two-sample assuming unequal variances		two-sample assuming unequal variances	
Pooled variance	6.065		x		x	
Hypothesized mean difference	0		0		0	
Degree of freedom	22		13		12	
t-Test value	0.66		2.208		2.693	
P-value 0.05 (one-tail)	0.258		0.023		0.01	
t-Test critical value (one-tail)	1.717		1.771		1.782	
P-value 0.05 (two-tail)	0.516		0.046		0.02	
t-Test critical value (two-tail)	2.074		2.16		2.179	

erosion, surface runoff and infiltration when applying the conventional cultivation and no-till technologies. Based on our evaluation, it is apparent that no-till has a significant ($P < 0.05$) impact on soil conservation. On the contrary, the values measured in conventional cultivation show insufficient soil conservation before degradation. Blanco, Lal (2010) stated that the main cause of erosion and excessive surface runoff on the plots is a low soil cover. In this study we have arrived to the same conclusion. Erosion and surface runoff are much higher by conventional cultivation where there is no vegetation cover.

A direct correlation between erosion and soil management has been found by many authors (Shipitalo, Edwards, 1998; Javurek et al., 2008). Soil conservation technologies have been recognized as effective methods for controlling soil erosion (Lal et al., 2007). According to Wendt, Burwell (1985) erosion was reduced by more than 90% in the case of soil conservation technologies leading to a significant reduction of soil degradation processes. Strauss et al. (2003) analyzed 68 studies with 160 comparable results where soil erosion and surface runoff were determined under different soil tillage practices. On the average, soil conservation technologies have reduced soil erosion by 60% (arithmetic mean) and 76% (median). For the no-till technology Prashun (2012) stated a 90.3% reduction in erosion. Nyakatawa et al. (2001) estimated that the no-till technology reduces soil erosion by water by 75% compared to conventional tillage. Basically, our results are similar to those given by other researchers. A comparable research with sorghum was carried out by Gilley et al. (1986). From this research it is obvious that the

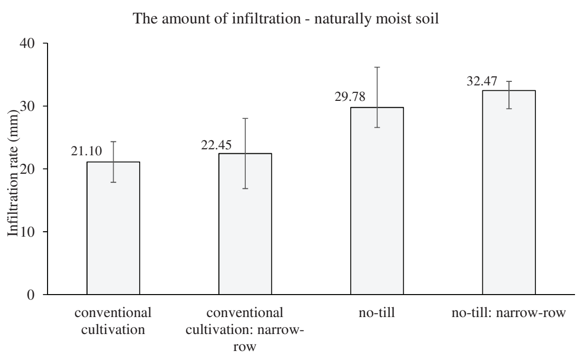

Fig. 7: Infiltration during the season from years 2014 and 2017 (30-minute-simulation)

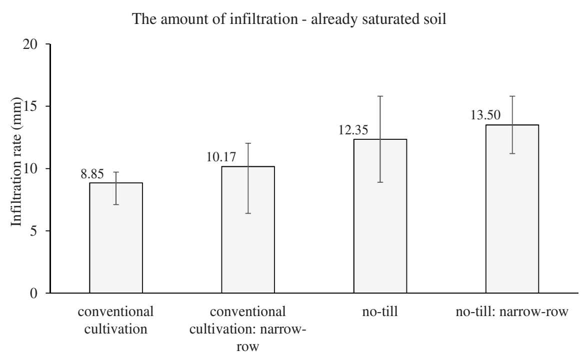

Fig. 8: Infiltration during the season from years 2014 and 2017 (15-minute-simulation)

higher the amount of residuals on the surface, the lower the soil loss and the surface runoff. In a similar way McGregor, Mutchler (1992) associated the degradation processes with the conservation tillage and no-till technology for sorghum. In no-till technology for sorghum the soil loss was reduced by 97% and the surface runoff was reduced by 44% compared to conventional cultivation. The values stemming from our rainfall simulation are from a two-year research and a certain dispersion cannot be excluded, however, there is only a little presumption of significant changes in the measured results.

CONCLUSION

The issue of soil loss and excessive surface runoff accompanying the conventional cultivation of sorghum is highly important. The results obtained in our study indicate that growing sorghum in erosion prone areas requires application of a different agricultural method. The rainfall simulation results show that the final soil loss caused by water erosion and surface runoff can be quite effectively reduced by using the no-till technology. During the season, the amount of soil loss in plots with no-till technologies was reduced to a minimum compared to conventional cultivation (by more than three-quarters in naturally moist soil). Similarly, the amount of surface runoff was reduced in plots with no-till technologies. The most prone period is the time after seeding because the plant cover is low. Nevertheless, the no-till technology shows a soil conservation effect even in the first stage. Thus, in the period of most frequent torrential rains the no-till technology prevented soil erosion. Due to the fact that soil erosion and surface runoff were lower by the soil conservation technologies compared to the conventional cultivation in all realized measurements, it can be concluded that the no-till technology significantly ($P < 0.05$) reduced soil loss and surface runoff.

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Corresponding Author:

Ing. David K a b e l k a, Research Institute for Soil and Water Conservation, Žabovřeská 250, 156 27 Prague 5-Zbraslav, Czech Republic, phone: +420 257 027 327, e-mail: kabelka.david@vumop.cz