Current Arable Farming Systems in the Czech Republic – Agronomic Measures Adapted to Soil Protection and Climate Change

Vladimír SMUTNÝ [1(✉)]
Lubomír NEUDERT [1]
Tamara DRYŠLOVÁ [1]
Vojtěch LUKAS [1]
Martina HANDLÍŘOVÁ [1]
Petr VRTÍLEK [1]
Milan VACH [2]

Summary

The paper is focused on evaluation various soil tillage systems for maize in terms of productivity and reduction of soil erosion in the Czech Republic. The high slope of land, combined with expanding wide-row crops (when maize had the largest area) increase the risk of water erosion. Assessed yield data are from Southern Moravia in 2011-2016. Investigation of the effects of different soil tillage and silage maize stand establishment on soil and water runoff was carried out in the experimental station Lukavec near Pacov (Bohemian region). Average of six-years results showed that there are no any differences between conventional tillage (10.08 t ha^{-1}) and minimum tillage (10.19 t ha^{-1}), but year is significant. In trial, where different tillage systems were compared with/without phacelia as cover crop, according to three-year average, the highest grain yield was in chisel loosening (8.89 t ha^{-1}) similar to ploughing (8.85 t ha^{-1}). Lower yields were in no-tillage (8.61 t ha^{-1}) and strip-tillage (8.55 t ha^{-1}). Various conservation tillage systems have to be improved and modified for different soil and climate conditions. The benefit is in reduction of soil loss, which depends on crop residues coverage on soil surface. The soil sediment loss was the lowest in no-till variant (30 resp. 38 %) and less in minimum tillage (57 resp. 88 %) in comparison with ploughing (= 100 %). Decrease of soil sediment loss due to sown cover crops (Canary grass or rye) was almost less than 10 % in comparison with variant without cover crop. The results confirm the importance of soil conservation technologies (including strip-tillage) of soil tillage to reduce the risk of land degradation by water erosion.

Key words

agronomic measures, conservation soil tillage, inter-crops, yield, soil erosion

[1] Mendel University in Brno, Faculty of AgriSciences, Department of Agrosystems and Bioclimatology, Zemědělská 1, 613 00 Brno, Czech Republic
✉ e-mail: smutny@mendelu.cz
[2] Crop Research Institute, p.r.i., Drnovská 507/73, 161 06 Praha 6 – Ruzyně, Czech Republic

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Introduction

Water erosion is a worldwide problem. Every year, water erosion causes destruction or damage to vast areas of agricultural land (Morgan, 2005).

In the Czech Republic, according to the Research Institute for Soil and Water Conservation, up to 51% of agricultural soil is threatened by water erosion (Kadlec et al., 2014). The goal of legislation is to protect soil against soil erosion especially on slope areas. According to EU and national legislation, the restrictions are concerned to cultivation of wide-row crops in seriously and slightly endangered areas by erosion. In seriously endangered areas, wide-row crops (maize, sugar beet, potatoes, sunflower, bean, soybean and sorghum) are not allowed to grow. In slightly endangered areas, growing of wide-row crops is allowed, but using conservation tillage, where limits for minimum crop residue coverage were defined. The high slope of land, combined with light soil and expanding wide-row crops (corn) increase the risk of water erosion. It is not possible to completely eliminate the risk of erosion, but it may be reduced (Novak et al., 2016).

The Czech agricultural potential represents roughly 4 mil ha of agricultural land, with the share of arable land more than 70%. The large-scale farming as a heritage from the socialistic regime has been still prevailing. The land use concentration in hundreds of large farms is accompanied by thousands of small and medium size mostly family farms. The average size of Czech farms, regardless of the sources and methods of its calculation, exceeds highly the EU average. In general, crop structure of the Czech Republic is poor, especially large farms are usually oriented prevailingly on a relatively simple production of cereals and rape seeds (Šlajs and Doucha, 2013).

Interventions usually consist of direct management of crop residues and using reduced soil tillage. Protection against water erosion of soil consists mainly of creating conditions to increase infiltration of water into the soil and reduce surface runoff rainwater. Annual tillage increases soil porosity, although immediately after the operation with the surface layer it may be in a relatively short time leading to unfavourable physical properties. Very often beneficial effects of soil conservation technologies to reduce water erosion are described. For soil conservation tillage reduced tillage by reducing the number of operations, merging them while protecting the surface of soil plant residues is essential (Novak et al., 2016). Rasmussen (1999) reported that soil conservation technology tillage reduced soil loss by erosion by half to two-thirds. Soil protection tillage can increase the capacity of the hydraulic conductivity of the soil and thus subsequently water infiltration into the soil. For this reason, it may contribute to the reduction of surface water runoff and soil erosion risks. On the other hand, conventional tillage produces a homogeneous layer of soil, which can reduce the absorption of water into the soil (Titi, 2002). The choice of a suitable system for processing soil in the given location is a complicated process, which is required to apply both deep theoretical knowledge and also a long experience.

Soil tillage in a sustainable land management harmonises the soil protection with demands of the crop to be grown on the given land and aims soil conservation, without increasing the production risks even in the long term (Birkás et al., 2002). Conservation tillage is essential prerequisite in definition of conservation agriculture. Kassam et al. (2009) defined conservation agriculture as a concept for resource-saving agricultural crop production which must meet the following conditions: (1) minimal soil disturbance, (2) soil covered residues (minimum 30 %) and (3) crop rotation should involve at least three different crops.

According to Gaudin et al. (2015) crop diversification and reduction in tillage had synergistic effects: less tillage further enhanced rotation benefits, yield stability and corn yields under unfavourable growing conditions. Rotation complexity may provide a systems approach to help adapt agroecosystems to upcoming changes in crop growing conditions while addressing the sustainability issues associated with maintaining yields under increasingly challenging production environments.

Surface mulching can be an essential and effective factor for erosion elimination from its early stages in annual row-cropping (Shelton et al., 1995). Sowing with strip tillage systems, in particular, has a higher ability to eliminate erosion processes, especially those in untreated soil (Choudhary et al., 1997). However, the absence of tillage, especially during the prolonged application of no-tillage, can lead to reduction in yield of maize compared with conventional tillage management or strip tillage (Vetsch et al., 2007). Reducing the intensity of soil tillage decreases energy consumption and the emission of carbon dioxide, while increasing carbon sequestration (Holland, 2004) and reducing labour demand (Davies and Finney, 2002).

Maize (for grain and silage) is a crop, where acreage is the largest from above mentioned wide-row crops, and is a crop which has an important place in a structure of crops grown in the Czech Republic. Maize areas have been increasing all over the world. In the Czech Republic the same trend is, in spite of the fact, that during the last twenty years, the number of livestock, which was an important consumer of silage maize, rapidly reduced. In recent years became silage maize the main source of biomass used in biogas stations.

The objective of this study was to analyse productivity level of different soil tillage systems and their ability to reduce soil erosion in current farming systems.

Material and methods

The experimental studies were focused on evaluation of different approaches in soil tillage from the view of crop productivity (yield) and reduction of soil erosion.

First study evaluates the effect of different soil tillage on yield of grain maize in two field trials. Both were done at the Field Trial Station in Žabčice (Southern Moravia, Czech Republic; 49°02’39.228”N, 16°61’78.900”E). It is located in a maize production area, at an altitude of 179 m, with fluvisol soil type. These soil is without any marked diagnostic horizons and the parent substrate consisting of alluvial material is situated below a thin humus horizon. More marked symptoms of gley proceeses can be observed in the depth of below 0.6 m. In the course of the year, the groundwater level fluctuates between 0.8 – 2.5 m. As far as the soil texture is concerned, the soil is classified as heavy to very heavy.

The local average annual air temperature is 9.2 °C and the thirty-year average annual precipitation is 480 mm (Žalud et al., 2013). Thus this location ranks among the warmest and driest areas in the Czech Republic.

The field trials, the influence of the year (2011-2016) and different soil tillage systems was evaluated. First, conventional tillage (CT) – ploughing to a depth of 0.24 m (mouldboard plough was used) was compared with minimum tillage (MT) – shallow loosening to a depth of 0.15 m (when disking was used). Grain maize was grown in a 5-year crop rotation with 80% of cereals (spring barley, pea, winter wheat, winter wheat, grain maize). This is a model concept for farming without animal husbandry, where all crop residues are cut and incorporated into the soil or leave it on soil surface, depending on tillage treatment. In second trial various soil tillage systems were used in combination with sowing of inter-crop phacelia. The crop sequence was: soybean, winter wheat, grain maize, silage maize. Phacelia was sown on half of trial. After stubble tillage and then after glyphosate application in autumn, three soil tillage variants were established: 1 – no tillage, 2 – chisel loosening, 3 – strip-tillage. Variants 4 – ploughing, 5 – chisel loosening and 6 – strip-tillage were established on plots without phacelia. The depth of all tilled variants was 0.25 m, in case of strip-tillage, the strips approx. 0.25 m width were tilled. Experimental plots were harvested with a small combine harvester SAMPO 2010.

In the second study we investigated the effects of different soil tillage and silage maize stand establishment on soil and water runoff using rain simulator. The experiment was established in the potato production area at the site of the experimental station Lukavec near Pacov (49°33'30.793"N, 14°58'44.449"E) in 2015 and 2016. At the experimental site, the soil type was cambisol with sandy-loam texture and 7° slope was identified. Three different soil tillage methods were evaluated. The conventional tillage (CT), including ploughing, seedbed preparation, and sowing, served as a control treatment. The second tillage method was based on direct sowing into no-tilled soil (NT), where, after crop emergence, at least 30 % of soil surface must be covered with mulch from post-harvest precrop residues. Minimum tillage (MT) was the third method that included shallow soil loosening to a depth 0.15 m where crop residues are incorporated into the soil at the same time. CT and MT were done in direction up and down slopes. Besides the effect of soil tillage, the protection against water erosion with cover crops sown into space between rows of maize, was assessed. Two crops were sown in growth stage 4 – 5 leaves of maize (plant height approx. 0.15 m): rye (*Secale cereale var. multicaule;* 80 kg ha^{-1}) and Canary grass (*Phalaris canariensis L.*; 15 kg ha^{-1}).

The test of soil infiltration abilities was conducted with rain simulator after the harvest of maize, once a year. Measuring with the rain simulator were done in three replications of all tillage treatments, i.e. once per plot at a designated area 0.5 m^2. The rain simulator was originally designed in Research Institute of Agricultural Engineering. 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. On the measured areas, all post-harvest residues were left on the soil surface. The simulated rain is defined by its intensity (87 mm per hour) and operating time of 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 weight of water from the surface runoff was weighted at 5-second intervals at digital scales and recorded on the PC. Collected water from the surface runoff was filtered in the laboratory. The mass of dry soil is a parameter for determining the intensity of water erosion. By the described method of measurement in the given experiment, there was assessed the influence of the observed soil and site factors on the water infiltration into the soil of the three applied different soil tillage treatment technologies.

Obtained results from above mentioned field trials were statistically processed using analysis of variance (ANOVA) with statistical software Statistica 12.0 (StatSoft); the significance of differences of mean values was tested by means of Fisher LSD test (least square difference).

Results and discussion

The yield results presented in Table 1 and Figure 1 show that there are no any differences between CT (10.08 t ha^{-1}) and MT (10.19 t ha^{-1}), but year is significant. In trial, where different tillage systems were compared with/without phacelia (Table 2), no significant differences are among variants in 2014. In opposite in 2013 the lowest yields were on variant 6 (strip-tillage without phacelia) and variant 1 – direct sowing when phacelia was used. In 2015 the lowest yields had variants 5 and 6, both without phacelia. In three-year average, highest grain yield was in chisel loosening (average of variants 2 and 5; 8.89 t ha^{-1}) similar to CT (variant 4; 8.85 t ha^{-1}). Lower yields were in no-tillage (variant 1; 8.61 t ha^{-1}) and strip-tillage (8.55 t ha^{-1}). Presented results confirmed that reduction intensity of soil tillage brought yield potential comparable with conventional tillage. Nowadays minimum tillage is common used in agricultural praxis in the Czech Republic and the farmers are well educated for modification in various soil conditions, adjustment of working depth without soil inversion, i.e. no tillage or reduced or shallow tillage with tine or discs.

Table 1. Analysis of variance (ANOVA) - yield of grain maize

Source of variability	Degrees of freedom	Mean square yield
Year	5	446.36**
Soil tillage	1	0.60
Year*soil tillage	5	0.30
Error	180	0.64

** Statistically highly significant difference (P = 0.01)

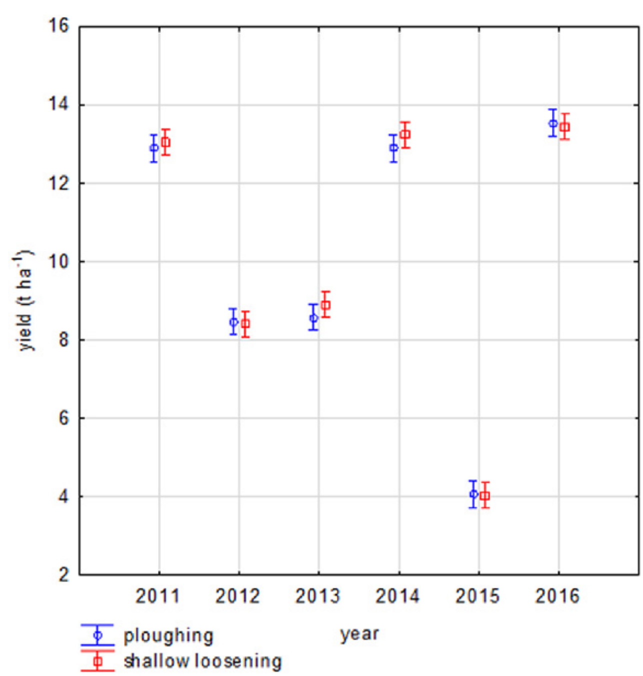

Figure 1. The impact of soil tillage on yield of grain maize in 2011-2016 (Žabčice)

Table 2. The effect of different soil tillage on grain maize yield (2013-2015; Žabčice)

Inter-crop phacelia (Yes/No)	Variants of soil tillage	Yield (t ha^{-1}) 2013		2014		2015	
Yes	1	9.82	bc	11.66	a	4.34	abc
	2	10.09	cd	11.92	a	4.86	d
	3	10.48	de	11.14	a	4.62	cd
Mean		10.13	–	11.57	–	4.61	–
No	4	10.22	cd	11.93	a	4.39	bc
	5	10.83	e	11.55	a	4.09	a
	6	9.39	a	11.65	a	4.01	a
Mean		10.15	–	11.71	–	4.16	–

The different letters (a, b, c) indicate a statistically significant difference (P = 0.95)

Figures 2 and 3 shows soil moisture changes in 2015, when the lowest values (less than 10 vol. %) were in July and in the first half of August. During whole season ploughing (variant 1) had the lowest values of soil moisture and strip-tillage variant the highest. Year 2015 was characterized with long-term drought during vegetation period which caused yield reduction to level of 4 t of grain (Table 2). In this case, higher yield of grain maize was in variants with phacelia inter-crop, especially in chisel loosening and strip-tillage in relation with soil moisture values. Probably partly incorporated organic matter from phacelia could have positive effect on water regime during season.

In trial in Lukavec, where anti-erosion strategies where assessed, the lowest soil sediment loss was recorded in the NT variant, in year 2015 and 2016 (19.90 and 28.46 g.m^{-2}.h^{-1}; Table 3). The soil sediment loss was the lowest in NT variant (30 resp. 38 %) and less in MT variant (57 resp. 88 %) in comparison with CT (= 100 %). Decrease of soil sediment loss due to sown cover crops (Canary grass or rye) was almost less than 10 % in comparison with variant without cover crop. Brant et al. (2017) stated less soil loss (14.6 – 55.9 %) in variant with ploughing combined with sowing of perennial grass in autumn, glyphosate application and strip-tillage in spring in comparison with ploughing. Higher variability in soil loss was in shallow tillage variant (7.4 – 75.5) in relation with amount of straw coverage on soil surface (as a crop residues of pre-crop). Rosner et al. (2005) mention, that reduced tillage lead to significant reduction of soil loss by conservation tillage 70 % and direct drilling 84 %.

On slope areas, the soil has to be protected against negative effect of raindrops. The solution could be conservation tillage, which leaves an organic mulch at the soil surface, reduces splash-erosion and run-off, increases the surface soil organic matter (SOM) promoting greater aggregate stability which restricts soil erosion (Franzluebbers, 2002). Other beneficial aspects of conservation tillage are preservation of soil moisture and increase of soil biodiversity (Holland, 2004).

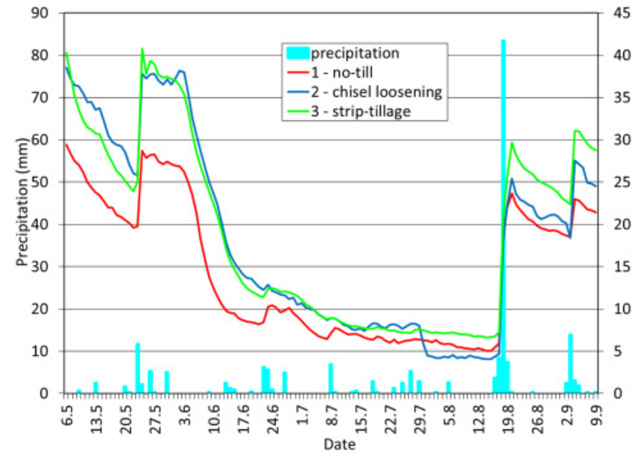

Figure 2. Soil moisture at different soil tillage systems with phacelia (Žabčice; 2015)

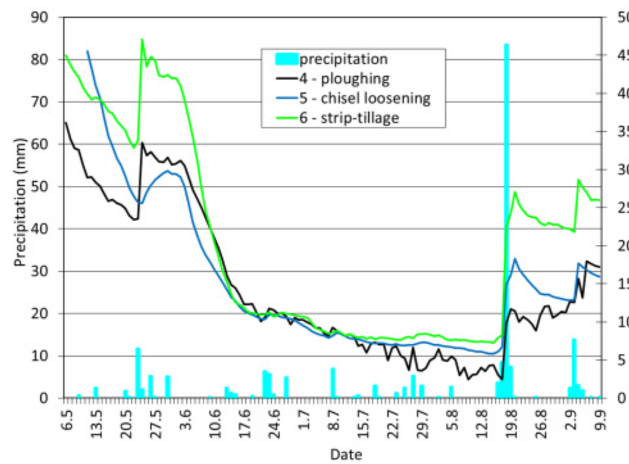

Figure 3. Soil moisture at different soil tillage systems without phacelia (Žabčice; 2015)

Table 3. Soil losses due to water runoff (2015-2016; Lukavec)

Soil tillage	Cover crop sown between rows of maize	Soil sediment losses due to water runoff [g m^{-2} h^{-1}] 2015 Value	Rel. %	Mean	Rel. %	2016 Value	Rel. %	Mean	Rel. %
No-tillage (NT)	Without	22.34	32			31.62	39		
	Canary grass	19.63	28	19.90	30	29.73	36	28.46	38
	Rye	17.72	25			24.04	30		
Minimum tillage (MT)	Without	40.46	58			73.45	90		
	Canary grass	27.78	40	37.37	57	67.20	82	65.58	88
	Rye	43.86	63			56.09	69		
Conventional tillage (CT)	Without	70.14	100			81.48	100		
	Canary grass	61.16	87	65.85	100	75.82	93	74.55	100
	Rye	66.26	94			66.35	81		

According to Czech legislation linked with protection of soil against erosion, different types of conservation tillage methods are applied by farmers. Shallow tillage that all crop residues are left on the soil surface, is usually applied. Leaving crop residues on the soil surface year around, before and after seeding provides soil surface protection at critical times to protect the soil against wind and water erosion. According to Lal (1997), soil physical properties are generally more favourable with no-till than tillage-based systems. According to Lal et al. (2007) NT technologies are very effective in reducing soil and crop residue disturbance, moderating soil evaporation and minimizing erosion losses. More stable aggregates in the upper surface of soil have been associated with no-till soils than tilled soils and this correspondingly results in high total porosity under NT plots. In Gottingen, Germany, Jacobs et al. (2009) found that MT compared with CT, did not only improve aggregate stability but also increased the concentrations of organic matter and N within the aggregates in the upper 5–8 cm soil depth after 37–40 years of tillage treatments.

The inter-crops have an important role in cropping systems. Integration of crop into crop rotation in short period between two main crops protects the soil against erosion, supplies the soil with easily decomposable organic matter (Thorup-Kristensen, 1994), enhances the physical and chemical properties of soil (Eichler-Löbermann et al., 2008) and soil biological activity (Piotrowska and Wilczewski, 2012). The effect of inter-crops on the reduction of erosion risk depends on the crop stand establishment, height of plants, leaf area index (LAI) and duration of soil coverage (Janeček, 2007). The highest values of coverage were found for variants with white mustard, phacelia and crambe, the lowest for buckwheat and common millet in field experiment in period 2007-2012 in Žabčice (Lukas et al., 2013). However, the results were strongly influenced by the year. The choice of appropriate species of inter-crops for various crop structure and soil and climate conditions is important as well (Handlířová et al., 2017)

Conclusion

Presented results from maize in Southern Moravia confirmed that reduction of soil tillage intensity brought yield level comparable with conventional tillage. Average of six-years results showed that there are no any differences between CT (10.08 t ha^{-1}) and MT (10.19 t ha^{-1}), but year is significant. In trial, where different tillage systems were compared with/without phacelia as cover crop, according to three-year average, the highest grain yield was in chisel loosening (8.89 t ha^{-1}) similar to ploughing (8.85 t ha^{-1}). Lower yields were in no-tillage (8.61 t ha^{-1}) and strip-tillage (8.55 t ha^{-1}). Various conservation tillage systems have to be improved and modified for different soil and climate conditions. The benefit is in reduction of soil loss, which depends on crop residues coverage on soil surface. The soil sediment loss was the lowest in no-till variant (30 resp. 38 %) and less in minimum tillage (57 resp. 88 %) in comparison with ploughing (= 100 %). Decrease of soil sediment loss due to sown cover crops (Canary grass or rye) was almost less than 10 % in comparison with variant without cover crop. Strip-tillage and various minimum tillage systems are suitable methods for dry areas as a water saving technologies and also effective approach to protect soil against water erosion.

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