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Splash Erosion in Maize Crops under Conservation Management in Combination with Shallow Strip-tillage before Sowing

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Abstract

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Soil under maize cropping is among the most endangered by erosion. The effect of conservation tillage management on values of splash erosion when using shallow strip tillage before sowing maize was evaluated in the Central Bohemian region (Czech Republic) during the period 2010–2012. The following types of tillage management using conventional technology and shallow tillage were evaluated: ploughed plots with mulch formed by weed biomass (PL_W), ploughed plots with mulch from perennial ryegrass plants (PL_{PR}), ploughed plots without mulch (PL) and shallow tillage (ST) where the mulch was formed by cereals straw. Furthermore, values of the splash erosion, plants and plant residues coverage ratio of soil by image analysis and the stability of soil aggregates were monitored during the whole experiment. The average value of splash erosion (MSR) was higher by 18.7% in the variant of PL_W, lower by 35.9% in PL_{PR}, and lower by 39.5% in ST, than in the control treatment PL (MSR value for PL = 100%) for the whole evaluated period (2010–2012). The average values of the soil surface plant coverage ratio in the plots with mulch ranged from 1.5 to 43.0% at the beginning of the vegetation period, and from 4.9 to 85.5% in the second half of the vegetation period. A positive correlation was observed between the average values of the stability of soil aggregates and the plant coverage ratio of the soil surface in 2010 and 2011.

Keywords: aggregate stability; conservation tillage; mulch; plants cover; plants residues; silage maize; soil protection

Soil erosion is one of the most serious environmental and public health problems facing human society (Pimentel 2006). Soil erosion reduces long-term productivity of agricultural land, and transports chemical fertilizers and nutrients into ground water causing a serious problem concerning public health (Choudhary *et al.* 1997). Soil erosion is generally dependent on soil type, rainfall characteristics, topography, soil and crop management, and soil conservation practices (Hudson 1995). There are several stages or types of water erosion, including splash, sheet, interrill, rill, gully, and streambank erosion. Splash erosion is a function of raindrop energy and the stability of aggregates to withstand the raindrop impact energy (Kukal & Sarkar 2011). The impact of raindrops on the soil surface is the primary detachment agent and a precursor to water erosion (Morgan 2005). The most effective measures to reduce soil splash are thus the use of amendments for the improvement and reinforcement of soil aggregates and physical barriers against these raindrop impacts (Sadeghi & Homaee 2012).

Splash is an essential process in so called interrill erosion. Raindrops strike exposed soil, detach the soil particles, and splash them into the air and into shallow overland flows. Raindrops striking these

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shallow flows enhance turbulence of the flow and help transport more of the detached sediment to a nearby rill or flow concentration. Interrill detachment is affected by the soil coverage provided by residues and plant canopy. Delivery of interrill sediment to the rill channels is a function of the field slope, coverage, and surface roughness (van Dijk *et al.* 2002; Leguedois *et al.* 2005). Sharma *et al.* (1991) and van Dijk *et al.* (1996) describe also that splash erosion largely depends on the plant cover, kinetic energy of rainfall, soil shear strength, and aggregate stability. Also the water layer thickness at the soil surface can be decisive for the splash erosion intensity (Kinnell 1991) and is a function of the surface covered either by stones or vegetation (Wainwright 1996). Quansah (1981) describes a positive relationship between rainfall intensity and the soil splash. Crop cover or crop residues on the soil surface play an important role in terms of the splash erosion elimination (van Dijk *et al.* 1996; Morgan 2005).

Bui and Box (1992) and Paltineanu and Starr (2000) refer to the differentiation of the throughfall of water into the maize crop and the subsequent impact of rainfall distribution on erosion. Surface mulching can be an essential and effective factor for erosion elimination from its early stages in annual row-cropping (Dickey *et al.* 1985; Shelton *et al.* 1995).

Edwards *et al.* (2000) stated that straw coverage had a significant effect on splash erosion, which was by 36% lower with 20% than with 5% straw coverage. Similarly, in a mouldboard ploughing system, the tillage treatments leaving 20% or more soil surface covered with plant residue reduced the soil erosion at least by 50% (Dickey *et al*. 1984). In fact, according to Shelton *et al.* (1995), the values of the residue cover for maize can range from 18.6 to 46.5% in dependence on different conservation management applied in complete tillage and planting systems. Also Guy and Cox (2002) refer that tillage intensity had more influence on carryover residue levels than previous crop type.

In general, the soil processing systems play an important role in splash erosion and can be divided according to the rate of processing of the soil surface (Estler & Knittel 1996; Morgan 2005). Choudhary *et al.* (1997) stated that soil splash was significantly higher in the mouldboard ploughing tillage methods than in either the chisel ploughing or no-tillage system. Prasuhn (2012) refer that 88% of soil erosion took place on plough tilled land, 9% on non-ploughed land with less than 30% surface residue cover, 1% on mulch-tilled land with more than 30% surface residue cover, and 2% on non-tilled or striptilled land with >30% soil cover. Sowing with strip tillage systems, in particular, has a higher ability to eliminate erosion processes, especially those in untreated soil (Dickey *et al.* 1985; 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 (Randall *et al.* 1996; Vetsch *et al.* 2007). Area-wide tillage systems, in comparison with the previously described management, generally show a lower level of the ground coverage by plant residues (Shelton *et al.* 1995). Referring to Guy and Cox (2002), together with plants residues decomposition over the time and particular tillage systems which incorporate some part of plant remains into soil profile, it is difficult to ensure a certain level of biomass to be left on the field surface as an erosion protective layer – concretely over the 30% groundcover by plant residues recommended for erosion control. The soil coverage can be increased by sowing overwintering or winter non-surviving intercrops into maize and other wide-sowing crops (Bohren 2000; Feil & Liedgens 2001), but always just to a certain extent.

The aim of the study was to assess the effects of area-wide conservation tillage management for maize crops on splash erosion while applying shallow tillage of soil before sowing. Namely the following objectives were pursued: to assess the effect of different management on splash erosion during the vegetation period, the effect of soil surface plant coverage on the stability of soil aggregates, and the relationship between natural rainfall and splash erosion intensity.

The study is really of great importance because maize (*Zea mays* L.) in developed countries is still more used for energy purposes. Maize stover is one of the potential renewable energy feedstocks (Blanco-Canqui & Lal 2007). Yet growing interest in the use of crop biomass and crop residues for biofuel production may counter the benefits gained in the adoption of conservation practices (Lal & Pimentel 2007). Because of the above mentioned facts, maize can be sown in fields which are endangered with soil erosion and some kind of erosion control has to be established at these sites.

To be more specific, in the Czech Republic, more than 50% of agricultural land is endangered by water

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erosion. The main reason is the intensification of production in agriculture and the change in preferred plants for growing. The need for soil erosion elimination is mentioned in European Union (EU) legislation and these regulations are implemented into EU state member's national policy as Good Agriculture and Environmental Condition (GAEC) standards.

Therefore, further aim of the presented experiments is to evaluate and put into practice a suitable technology for maize growing which is based on long term presence of live or dead mulch on the field surface acting against soil erosion. Namely the mulch realized by sowing of ryegrass into strips in autumn and with exploitation of the plants regeneration ability after glyphosate spraying in spring. It means that the field surface is covered by ryegrass plants since autumn till spring, then by the dead biomass after glyphosate spray, and after regeneration the soil is regrown by new ryegrass plants. The evident effect of this technology should be a significant elimination of splash erosion.

This system is really advantageous for common agricultural practice because it is supposed to ensure soil protection since autumn till harvest time of maize in the following year and represents the combination of stubble and under-sown intercrop.

MATERIAL AND METHODS

Field experiments were carried out in 2010–2012 in Central Bohemia (Czech Republic) at the experimental station of Červený Újezd (398 m a.s.l.) with an average annual temperature of 7.9°C and annual precipitation of 525.8 mm (geographical coordinates: 50°04'34.45"N, 14°09'22.351"E). The soil was classified as Haplic Luvisol (IUSS Working Group WRB 2014). The texture of the soil was silty clay loam consisting of 31.5% clay, 58.3% silt, and 10.2% sand (Soil Survey Staff 2014). The organic carbon content (C_{ox}) ranged between 0.75% and 1.51% (1.08% on average) and the average pH was 5.3 in the sampled layer 0–0.1 m.

Crops of silage maize (row distance 0.75 m) were grown using four different tillage systems (Table 1). The size of experimental plots was 3 × 7 m. Each experimental arrangement had four replicates. Crops were sown by a precision seeding machine on May 13, 2010 (Celio 250 hybrid), April 28, 2011 (P8488 hybrid), and April 27, 2012 (P8488 hybrid). The basic tillage (ploughing or shallow tillage) was carried out on September 14, 2009 (with winter wheat as a preceding crop), October 12, 2010 (with spring barley as a preceding crop) and September 6, 2012 (with spring barley as a preceding crop). The influence of preceding crop on the measured values was not monitored during the experiments, but at least the same group of plant species was ensured to be on plots – cereals were always on the fields as preceding crop. The day after completing the basic tillage, the levelling of the land surface (by presowing combinators) was performed on ploughed plots with mulch formed by weed biomass (PL_W), ploughed plots with mulch from perennial ryegrass plants (PL_{PR}), and shallow tillage (ST) experimental plots. Perennial ryegrass (*Lolium perenne* L.) was sown into 0.35 m wide strips (seed rate 30 kg/ha, set for area sowing, Lonar variety) in the PL_{PR} plots. Unsown strips (0.4 m wide) were left between the sown strips. Maize was sown in the centre of each unsown strip in spring.

Table 1. Technology systems of maize cropping

Experimental arrangement	Autumn treatment	Spring treatment	Inter-row surface mulching
PL_W	mouldboard ploughing (working depth 0.2 m) + surface levelling	glyphosate application + strip loosening + maize sowing	weeds
PL_{PR}	mouldboard ploughing (working depth 0.2 m) + surface levelling perennial ryegrass sowing	glyphosate application + strip loosening + maize sowing	perennial ryegrass, weeds
PL	mouldboard ploughing (working depth 0.2 m) – conventional tillage	seedbed preparation + maize sowing	without mulch
ST	shallow non-inversion tillage (working depth 0.12 m) + surface levelling	glyphosate application + strip loosening + maize sowing	straw, weeds, volunteer of cereals

PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw

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The ploughed plots without mulch (PL) variant was left intact in the rough furrow and for further evaluation it was taken as the control which other tillage and management treatments were compared to. Spring surface application of Roundup Classic (active ingredient Glyphosate-IPA 480 g/l) was carried out on April 25, 2010, April 11, 2011, and March 28, 2012 respectively (at the herbicide rate of 4 l/ha). In spring, shallow loosening was carried out in the PL_W, PL_{PR}, and ST experimental arrangements using arrow tines in combination with a one-sided tine at the edges of the strip (width of the tilled strip was 0.3 m, the depth of loosening in the strip centre was 60 mm). The soil between the loosened strips was not processed. The aim of the loosening was to provide suitable conditions for planting and germination as well as sprouting of plants. The loosening was immediately followed by sowing in the centre of the strip. Seedbed preparation and sowing of maize was carried out in the PL plots on the same date. PL plots were prepared uniformly over the whole area.

Fertilizing of crops was identical in all experimental years. Pre-emergence herbicide application was the same in all experimental plots depending on the occurrence of weed species.

Values of splash erosion were monitored using the method according to Bollinne (1975). Plastic funnels with collecting bottles (volume 0.5 l) were installed in the centre of inter-rows of maize. The funnels (wide body diameter 125 mm, diameter of inlets 25 mm) were placed at a height of 4 mm (the edge of the inlet) above the soil surface (flooding prevention). Splashed sediment samples were collected after every rain event with total rainfall exceeding 0.4 mm. Captured suspension (water and soil particles from splash erosion) was filtered and oven-dried until a constant weight was achieved. The soil in the funnel was then expressed as a real mass of splashed soil material per unit area (MSR, g/m^2), using the algorithm according to Poesen and Torri (1988). The coverage of the soil surface by plants (weeds, perennial ryegrass plants) and plant residues (cereals straw, dead weeds, and perennial ryegrass) on the experimental plots was also evaluated on two separate dates, prior to planting maize and in the second half of the vegetation period. The coverage was determined by image analysis of photographs which were taken in infrared spectrum. For this purpose, the camera Panasonic Lumix DMC-G5 (Panasonic Corporation, Osaka, Japan) was modified by removal of the internal NIR-blocking filter and additional placement of the visible-light-blocking filter (Hoya R-72; Hoya Corporation, Tokio, Japan) in front of the lens. Adobe Photoshop CS5 Extended (Version 12.0.4, 2011) was used for the image processing. This computer processing transformed the colour pictures into black-and-white ones, where the white colour represented the plants and the crop residues and the black colour represented the soil surface (Figure 1). The next step of the analysis expressed the presence of

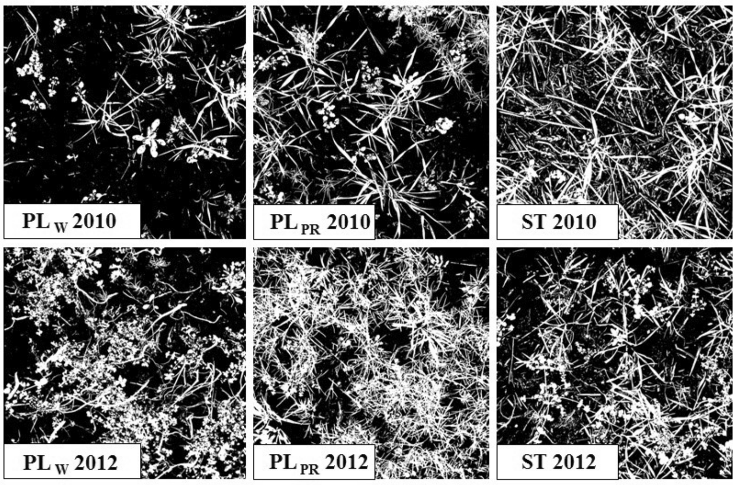

Figure 1. Soil surface conditions (degree of coverage by plants and plants residues) on the plots with different management strategies (PL_W, PL_{PR}, and ST) before sowing of maize (April 19, 2010 and March 28, 2012) in the inter-row; white colour represents the plants and the crop residues and the black colour represents the soil surface

PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw

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white and black pixels in both categories (B, W) and their percentage values were determined accordingly.

The next step of the analysis expressed the presence of white and black points in the image and determined their percentage values. Coverage was expressed as an integral value of weeds, volunteers, or straw and perennial ryegrass – Plant Coverage Ratio (PCRsoil, %). One image analysis was made in each replication (centre inter-row). The size of shooting area (square) was 0.25 m2.

At the beginning, and during the second half of the vegetation period, the Water Stability of soil Aggregates (WAS) in trial plots was also assessed using the Wet Sieving Apparatus (Ejkelkamp, Giesbeek, the Netherlands) according to the manufacturer's methodology. The average soil sample was made from each replication of the variants (soil layer 0–0.1 m) in four samples of soil from the centre of the inter-rows. Precipitation totals (P_{T}, mm) and intensity of precipitation (P_{I10}, mm per 10 min) were measured using a rain gauge SR 03 (Meteoservis, Vodňany, Czech Republic). Production of the dry aboveground biomass of perennial ryegrass at the end of the vegetation period was determined by the collection of plant biomass from the inter-row place (sampling area size 0.33 × 0.33 m) in two samples per each replication. Statistical analyses were carried out in the Statgraphics® Plus 4.0 (Statgraphics, Warrenton, USA). The analysis of variance (ANOVA, Tukey's test, α = 0.05) and simple regression were used. Within each method and period of vegetation (beginning, middle, end), the correlations between MSR and P_{T}, or P_{I10} variables were analyzed by linear correlation or partial linear correlation in the software STATISTICA 9.1 (Statsoft, Tulsa, USA). Across the years, the relationships between MSR (dependent variable) and $P_{T\text{-period}}$, $P_{I10\text{-period}}$, and the applied methods (explanatory variables) were displayed in an ordination diagram, performed in the CANOCO for MS Windows 4.5 (Microcomputer Power Attention, Ithaca, USA) by Ter Braak and Šmilauer (2002). $P_{T\text{-period}}$ is the sum of precipitation (mm) during the observation period with the average intensity of rainfall ≥ 0.2 mm per a 10-minute interval.

RESULTS AND DISCUSSION

Splash erosion and soil management. The PL plots were taken as a control treatment because this technology represents the typical establishment of maize crop in agricultural practice. In most cases the highest values of MSR were recorded on plots with PL conventional tillage (Table 2) in 2010. For the whole measuring period in 2010 the average value of MSR was lower by 24.5% in the PL_{W} experimental arrangement, by 55.9% in PL_{PR}, and by 75.5% in ST than in the variant PL (MSR value for PL = 100%). In 2011, the average value of MSR through the observation period was higher by 38.3% in the PL_{W} plots compared with the PL ones. For other experimental arrangements, the mean MSR values were lower (by 37.2% in PL_{PR} and by 7.4% in ST) for the whole vegetation period of 2011 again compared with the PL. Similar results were calculated in 2012. High reduction of MSR compared with PL plots was observed for ST (average MSR for the measurement period was by 35.6% lower). The experimental plots PL_{PR} showed by 14.6% lower MSR values and the PL_{W} plots, by contrast, by 42.2% higher values compared with PL. The reduction of MSR values occurred in areas with higher plant residues coverage (ST) or presence of perennial ryegrass plants (PL_{PR}) – Table 3. Due to the quite warm spring, the biomass of weeds decomposed faster in PL_{W} treatments in 2011, 2012 and this fact could affect the higher values of MSR. On the other hand, the lower MSR values in PL treatment could be caused by the presence of clods on the field surface which were formed during spring pre-sowing tillage, whereas PL_{W} arrangements were established already in autumn and thus without any clods later on. According to Elliot *et al.* (1999), field surface roughness and plant residues reduce soil erosion but autumn tillage just reduces plant residues and field surface roughness in fields. Ma *et al.* (2014) refers that total masses of erosion sediment decreased as a power function with an increasing size fraction. Khan *et al.* (1988) refer that the soil loss was significantly reduced by increased mulch cover, however, the percentage of small aggregates and primary clay in the sediment increased while that of large aggregates decreased. The positive effect of crop residues on splash erosion elimination is also mentioned by Dickey *et al.* (1984).

Relationships between residue cover and soil loss showed that 20% of either soybean or corn residues generally reduced soil loss by at least 50% of that which occurred from cleanly-tilled soils. Edwards *et al.* (2000) reported that straw coverage had a significant effect on sediment dry mass due to splash, which was by 36% lower with 20% straw coverage than with 5% straw coverage. In our experiment, on the date of maize sowing, the perennial ryegrass

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Table 2. Average values of the real mass of splashed soil material per unit area (MSR g/m2) with different treatments; cumulative precipitation ($P_{\text{T-period}}$, mm) and the average intensity of rainfall ≥ 0.2 mm for 10 min ($P_{\text{I10-period}}$, mm) for the evaluated period of the years 2010–2012

Exp.	MSR (g/m^{2})																	
2010	2.6.–3.6.	3.6.–9.6.	9.6.–11.6.	11.6.–15.6.	15.6.–18.6.	18.6.–28.6.	28.6.–8.7.	19.7.–23.7.	23.7.–5.8.	5.8.–10.8.	10.8.–16.8.	16.8.–26.8.	26.8.–13.9.					
PL_W	321.8^{b}	7.1^{a}	1008.5^{b}	192.5^{c}	86.5^{c}	9.3^{a}	2087.2^{b}	161.9^{b}	596.3^{ab}	208.9^{bc}	164.8^{a}	55.1^{a}	132.2^{b}					
PL_{PR}	–	–	905.4^{b}	121.5^{b}	51.5^{b}	21.0^{a}	746.3^{a}	27.2^{a}	46.4^{a}	79.1^{ab}	69.1^{a}	54.8^{a}	60.1^{a}					
PL	406.9^{c}	9.9a	1371.4^{c}	262.5^{d}	123.1^{d}	35.8^{a}	2222.1^{b}	192.4^{b}	1298.5^{b}	225.9^{a}	255.8^{a}	46.1^{a}	150.5^{b}					
ST	65.5^{a}	6.6a	369.0^{a}	15.0^{a}	32.9^{a}	2.4^{a}	580.8^{a}	43.3^{a}	100.0^{a}	47.9^{c}	74.4^{a}	42.3^{a}	62.3^{a}					
$P_{\text{T-period}}$	26.4	1.6	3.8	15.8	4.9	1.1	17.5	27.6	79.8	48.6	34	3.7	41.5					
$P_{\text{I10-per.}}$	0.43	0.20	1.13	0.35	0.46	0.20	1.28	0.66	0.67	0.57	0.96	0.33	0.80					
2011	18.5.–24.5.	24.5.–7.6.	7.6.–9.6.	9.6.–13.6.	13.6.–17.6.	17.6.–20.6.	20.6.–22.6.	22.6.–23.6.	23.6.–4.7.	4.7.–7.7.	7.7.–11.7.	11.7.–14.7.	14.7.–18.7	18.7.–20.7.	20.7.–25.7.	25.7.–1.8.	1.8.–10.8.	10.8.–16.8.
PL_W	1119.1^{b}	3560.8^{b}	77.6^{b}	108.3^{b}	327.0^{b}	232.1^{a}	29.8^{a}	441.4^{b}	41.6^{a}	27.7^{a}	75.5^{b}	83.2^{a}	16.9^{a}	167.2^{b}	206.9^{b}	50.6^{a}	22.1	39.8^{a}
PL_{PR}	888.6^{ab}	2093.5^{a}	26.2^{a}	58.8^{a}	154.0^{a}	111.0^{a}	20.3^{a}	152.4^{a}	21.8^{a}	10.4^{a}	14.8^{a}	25.5^{a}	9.4^{a}	41.3^{a}	41.3^{a}	27.9^{a}	21.4	14.8^{a}
PL	959.7^{b}	2507.4^{a}	25.8^{a}	66.6^{a}	185.4^{a}	279.6^{a}	15.2^{a}	234.7^{a}	36.6^{a}	17.5^{a}	64.5^{b}	57.1^{a}	20.4^{a}	156.3^{b}	181.3^{b}	37.7^{a}	42.6	40.3^{a}
ST	639.1^{a}	1757.4^{a}	43.2^{a}	64.7^{a}	224.3^{a}	167.8^{a}	30.5^{a}	306.4^{ab}	63.2^{a}	12.8^{a}	54.1^{ab}	73.7^{a}	8.3^{a}	105.0^{ab}	92.7^{ab}	32.6^{a}	21.8	17.2^{a}
$P_{\text{T-period}}$	8.3	36.0	5.3	10.5	11.6	10.3	4.6	10.4	16.0	4.0	18.9	11.0	7.4	27.9	46.9	33.6	12.0	15.4
$P_{\text{I10-per.}}$	0.9	1.2	0.5	0.3	1.2	0.6	0.3	1.0	0.4	0.4	0.6	1.1	0.3	2.5	0.7	0.3	0.4	0.5
2012	4.5.– 7.5.	11.5.–15.5.	23.5.–12.6.	12.6.–13.6.	13.6.–19.6.	19.6.–21.6.	21.6.–3.7.	3.7.–5.7.	5.7.–10.7.	10.7.–18.7.	18.7.–23.7.	23.7.–13.8.						
PL_W	62.9^{b}	26.1^{a}	94.5^{a}	122.2^{b}	25.2^{a}	917.0^{b}	2941.4^{a}	248.3^{a}	547.1^{bc}	198.8^{bc}	39.6^{a}	11.4^{a}						
PL_{PR}	37.8^{ab}	16.1^{a}	118.3^{a}	59.6^{a}	15.0^{a}	330.3^{a}	690.0^{a}	114.4^{a}	139.3^{a}	54.8^{a}	29.3^{a}	8.6^{a}						
PL	22.5^{a}	30.1^{a}	41.4^{a}	107.0^{b}	15.1^{a}	777.0^{b}	1970.2^{a}	309.8^{a}	598.0^{c}	313.7^{c}	74.9^{b}	52.8^{b}						
ST	42.6^{ab}	17.7^{a}	34.7^{a}	84.4^{ab}	15.1^{a}	557.9^{ab}	968.9^{a}	140.1^{a}	234.5^{ab}	97.8^{ab}	29.2^{a}	5.0^{a}						
$P_{\text{T-period}}$	12	6.3	24.6	5.4	8.6	19	59	17.4	31.6	25.8	13.2	18						
$P_{\text{I10-per.}}$	1.1	0.4	0.4	0.7	0.4	0.9	1.6	0.6	2.3	0.7	0.4	0.5						

Exp. – experimental arrangement; PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw; ANOVA; $P < 0.05$; different letters document statistically different means column wise

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plants were dead as a result of the application of glyphosate. But in May, the regeneration of plants and their subsequent growth started. Ryegrass plants regeneration can be explained by the lower absorption of glyphosate into plants due to lower temperatures on the date of the application and after it. It can be assumed that the lower absorption has also led to slower translocation into the root system. Low temperature influence on the glyphosate translocation is mentioned e.g. by McWhorter *et al.* (1980) and Devine *et al*. (1983). The development of perennial ryegrass plants in PL_{PR} plots decreased the MSR values significantly compared with PL in the second half of the vegetation period (Table 2). The average value of MSR from July to the last date of splash erosion evaluation in PL_{PR} was lower than in PL by 61.1% in 2010, by 54.0% in 2011, and by 72.0% in 2012. The production of dry aboveground biomass in the perennial ryegrass inter-rows of maize was 0.16 kg/m^2 (September 15, 2010), 0.07 kg/m^2 (September 20, 2011), and 0.22 kg/m^2 (September 21, 2012). In 2011 and 2012 (Table 2), the values of MSR were higher in PL_W compared with PL. The vegetation cover before maize sowing consisted of weed plants and volunteer cereals in PL_W plots. The application of glyphosate led to the death of plants. Subsequently, plant residues rapidly decomposed and the soil was then without a biomass coverage. By contrast, in PL the formation of larger aggregates and clods occurred during the seedbed preparation (they were located on the surface of the soil). The presence of large aggregates could then contribute to erosion elimination. This ability of large aggregates to eliminate the erosion processes has been pointed out by Morgan (2005) and others.

Soil cover and stability of soil aggregates. The highest values of the soil vegetation coverage were observed at the beginning of 2010 and 2011 in ST, and then in 2012 in the PL_{PR} plot (Table 3). When evaluating PCRsoil in the second half of the vegetation period, the highest values were observed in PL_{PR} plots with perennial ryegrass. PCRsoil values in PL_{PR} were statistically significantly higher compared with other experimental arrangements. Average values of PCRsoil on plots where mulch on the soil surface was placed in inter-rows ranged from 1.5 to 43.0% at the beginning of the vegetation period, and from 4.9 to 85.5% in the second half of the vegetation period in all evaluated years.

Soil organic matter, namely organic carbon content, was measured by means of C_{ox} analysis and there were no statistically significant differences found. Taking into account the character of the field experiments, where the maize crop was sown always on different field, it is not possible to assume a significant effect of tillage system on soil organic matter content.

Soil surface conditions (degree of coverage by plants and plants residues) on the plots before sowing maize (April 19, 2010 and March 28, 2012) are documented in Figure 1. In the PL_W plots, the plant coverage consisted of different weed species. Dominant species before maize sowing were as follows: common chickweed (*Stellaria media* L. Vill.), hembit dead-nettle (*Lamium amplexicaule* L.), knotgrass (*Polygonum aviculare* L.) and Shepherd's-purse (*Capsella bursa pastoris* L.). During the observed period 2010–2012, 11 weed species were documented within the range of 60–186 plants per m^2 on average. According to van Dijk *et al.* (1996) research, the average surface coverage by plant residue (either winter rye (*Secale cereale* L.) or cut straw) on maize plots during the growing season ranged from 22.2 to 44.2%. Shelton *et al.* (1995) reported values of the residue coverage for complete tillage and planting systems ranging from

Table 3. Plant (weeds and intercrop) and crop residues (straw, dead weeds, and intercrop) on the surface of the soil (PCR_{soil}, %) at the beginning and during the vegetation period in 2010–2012

Experimental arrangement	PCR_{soil}					
	April 19, 2010	July 2, 2010	March 29, 2011	August 22, 2011	March 28, 2012	August 21, 2012
PL_W	13.2^a	6.0^a	4.1^a	1.5^a	32.5^a	4.9^a
PL_{PR}	23.3^b	30.7^b	8.1^b	34.3^b	35.8^a	85.5^b
PL	x	9.0^a	x	2.3^a	x	3.2^a
ST	43.0^c	25.7^b	12.6^c	9.8^a	28.5^a	7.7^a

PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw; x – bare soil; ANOVA; P < 0.05; different letters document statistically different means column wise

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Table 4. Stability of soil aggregates (WAS, stable fraction) at the beginning and later in the vegetation period of the years 2010–2012

Experimental arrangement	WAS					
	June 9, 2010	September 21, 2010	March 29, 2011	August 18, 2012	March 28, 2012	August 21, 2012
PL_W	0.35^{ab}	0.35^{a}	0.52^{a}	0.45^{a}	0.44^{a}	0.54^{b}
PL_{PR}	0.40^{bc}	0.47^{b}	0.44^{a}	0.54^{b}	0.48^{a}	0.51^{b}
PL	0.31^{a}	0.33^{a}	0.45^{a}	0.44^{a}	0.48^{a}	0.46^{a}
ST	0.47^{c}	0.41^{ab}	0.46^{a}	0.49^{ab}	0.40^{a}	0.48^{ab}

ANOVA; $P < 0.05$; different letters document statistically different means column wise; PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw

18.6 to 46.5%. The degradability of the plant residues during the vegetation period has a significant impact on soil plant coverage, which is expressed by the ratio C:N (e.g. Probert *et al.* 2005; Morvan & Nicolardot 2009). It can be assumed that the narrow ratio of C:N in weeds, which were destroyed by glyphosate applications in the PL_W variant, contributed to its rapid degradation. Table 3 also shows a noticeable difference in the soil coverage on ST plots following the previous crop (winter wheat in 2010) and subsequent years (where preceding crop was spring barley). Different quantities of straw produced by two preceding crops respectively can be considered as the cause of the soil coverage ratio difference on the compared plots. The higher value of wheat straw, compared with barley, has been described by, for example, Di Blasi *et al.* (1997). At the beginning of the vegetation period the statistically significant differences between the values of WAS between the monitored experimental arrangements were not estimated, except for the year 2010. The average values of WAS in PL_{PR} areas positively affected the development of perennial plants regeneration in the second half of the vegetation period.

In all evaluated years the mean WAS values in PL_{PR} were statistically significantly higher compared with the WAS in PL (Table 4). In 2010 and 2011, in the second half of the vegetation period, a positive correlation between the average values of WAS (dependent variable) and PCR_{soil} was observed, WAS = 0.302 + 0.00492 × PCR_{soil}, r = 0.947 (90% confidence level, year 2010) and WAS = 0.446 + 0.00286 × PCR_{soil}, r = 0.965 (95% confidence level, 2011). Van Dijk *et al.* (1996) reported that mulch protects aggregates and clods against the impact of raindrops. The same authors demonstrated a negative correlation between the values of splash erosion and plant residue cover on the soil surface.

Relationship between natural rainfall and splash erosion. The combined effect of implemented planting system with the specified tillage technology and the precipitation parameters on MSR values is shown in Figure 2. This effect was highly significant (P = 0.002) and 22% of MSR variability was explained by the first canonical axis. According to the first axis,

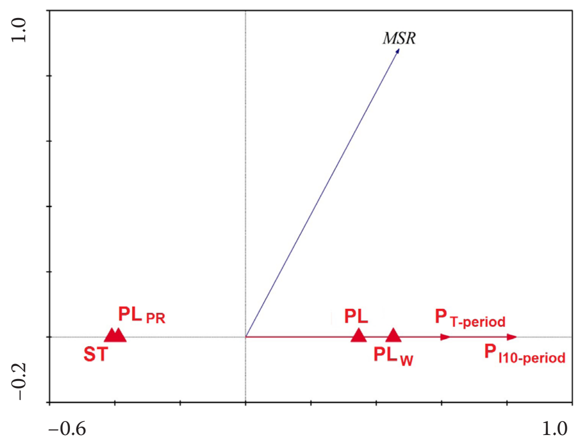

Figure 2. The ordination diagram of the effect of the implemented technology, sums of precipitation ($P_{T\text{-period}}$, mm) and the average intensity of rainfall ($P_{I10\text{-period}}$, mm per 10 min) over a three-year period on the real mass of splashed soil material per unit area (MSR, g/m^2) – redundancy analysis (RDA), 22% of MSR variability is explained by the axis 1, P = 0.002, and 499 permutations by the Monte Carlo permutation test were used

PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw

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the most important factor was the $P_{\text{I10-period}}$, followed by $P_{\text{T-period}}$ variable. The implemented management was obviously separated into two groups. A closer relationship between splash erosion (MSR) and soil tillage management has been demonstrated in areas with low soil residues coverage (variants PL and PL_W). Choudhary *et al.* (1997) concluded that soil splash was significantly higher in the mouldboard ploughing system than on both the chisel ploughing and no-tillage plots. These differences were in the order of 3:1 in dry soil and over 2:1 in previously wet soil, probably reflecting high aggregate stability and carbon contents in the surface soil layer on no-tillage and chisel ploughed plots compared with mouldboard ploughing treatment. But some differences in these general relations were obtained in separate stages of vegetation (Table 5). At the beginning of the vegetation period, the significant effect of $P_{\text{I10-period}}$ was recorded and this relation was independent on $P_{\text{T-period}}$. With one exception, there were no significant correlations in the middle of the vegetation period. The effect of $P_{\text{T-period}}$ became most significant at the end of the vegetation period with some connection with $P_{\text{I10-period}}$. Quansah (1981) stated a positive relationship between rainfall intensity and soil splash. The effect of precipitation and mainly its intensity on MSR may also be caused by the influence of vegetation. At the beginning of the vegetation period the crop canopy is not closed and the precipitations fall directly on the soil surface. When the soil surface is fully covered by the crop leaf canopy and stems, the throughfall of precipitation is modified by vegetation, which is given by the ratio between the throughfall and the stem flow. At the end of the vegetation period, the structure of crops changes again in the way that leaves are mostly bent down, the oldest leaves are dry. For example, Bui and Box (1992) and Paltineanu and Starr (2000) point out the influence of vegetation on the distribution of precipitation in the undergrowth.

The implications and advantages of ryegrass utilization as intercrop for agricultural practice can be finally summarized as follows: advantageous utilization of ryegrass intercrop for soil surface protection starting already from autumn, ryegrass ensures soil protection since autumn till harvest time of maize in the following year and represents the combination of stubble and under-sown intercrop, strips without intercrop are not an obstacle for soil warming up and drying up and also are not a complication for sowing a crop, dead intercrop biomass after glyphosate treatment is not a competitive plant for maize from the beginning of maize germination and growth but prevents from soil erosion, following regeneration of ryegrass plants after glyphosate spray improves the ability of soil erosion protection and the ryegrass plants do not affect the maize concerning mutual growth competition, it is not necessary to do under-sowing of ground cover plants after maize germination.

Table 5. Correlation and partial correlation coefficients (in brackets) between the real mass of splashed soil material per unit area (MSR g/m^2) and sums of precipitation ($P_{\text{T-period}}$, mm) or the average intensity of rainfall ($P_{\text{I10-period}}$, mm per 10 min) over the years 2010–2012

Vegetation period	Technology system	$P_{\text{T-period}}$	$P_{\text{I10-period}}$
Beginning (n = 36)	PL_W	0.26 (0.15)	**0.67 (0.65)**
	PL_{PR}	0.27 (0.17)	**0.70 (0.68)**
	PL	0.16 (–0.01)	**0.71 (0.70)**
	ST	**0.42 (0.37)**	**0.66 (0.64)**
Middle (n = 100)	PL_W	0.18 (0.15)	0.11 (0.06)
	PL_{PR}	–0.04 (–0.05)	0.01 (0.03)
	PL	**0.31 (0.26)**	0.20 (0.11)
	ST	0.06 (0.03)	0.11 (0.09)
End (n = 28)	PL_W	**0.71 (0.59)**	**0.49** (–0.01)
	PL_{PR}	**0.61 (0.48)**	**0.43** (0.01)
	PL	**0.62** (0.38)	**0.58** (0.26)
	ST	**0.50** (0.12)	**0.62 (0.44)**

$P_{\text{T-period}}$ or $P_{\text{I10-period}}$ was used as a covariate in the partial correlation; PL_W – ploughed plots with mulch formed by weed biomass; PL_{PR} – ploughed plots with mulch from perennial ryegrass plants; PL – ploughed plots without mulch; ST – shallow tillage where the mulch was formed by cereals straw; beginning of the vegetation period was counted until June 11, 2010, June 7, 2011, and June 21, 2012; the end of the vegetation period was counted from August 5, 2010, August 1, 2011, and July 23, 2012; the middle part of the vegetation period was between these intervals (see Table 2); significant correlations at P = 0.05 are in bold

CONCLUSIONS

To summarize the results of the experiment for the whole period 2010–2012, it is possible to say that the splash erosion can be significantly reduced by shallow tillage system even in combination with strip tillage before sowing, in comparison with conventional technology. The average value of MSR was

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lower by 39.5% in ST than in PL (MSR value for PL = 100%). On the other hand, the MSR values showed the worst results concerning splash erosion in the PL_W variant where the MSR was higher by 18.7% than in the PL variant. The performed experiments showed that live mulch can be used to eliminate splash erosion even in the systems using ploughing tillage. The PL_{PR} plots showed MSR values by 35.9% lower in comparison with the PL variant.

Weeds germinating since autumn until the time of maize sowing, which are eliminated by non-selective herbicides before the sowing, do not provide adequate soil protection from erosion.

The average values of the soil surface plant coverage ratio in the plots with mulch ranged from 1.5 to 43.0% at the beginning of the vegetation period, and from 4.9 to 85.5% in the second half of the vegetation period. A positive correlation was observed between the average values of stability of soil aggregates and the plant coverage ratio of the soil surface in 2010 and 2011.

To sum up the outcomes from the presented experiments, it is possible to state the following recommendations for agricultural practice for farmers. Any kind of intercrop or mulch, when planting maize, is really beneficial for soil protection which is a great problem in row crops in general. The measured arrangement utilizing ryegrass intercrop with glyphosate spray is really an advantageous system concerning the soil surface protection against erosion, mainly splash erosion. Soil is protected during the maize vegetation but also before maize sowing (autumn and spring period). The sprayed and dead intercrop biomass between the sown maize rows is not a competitive plant for the maize seeds from the germination phase, but prevents from soil erosion. The following regeneration of ryegrass plants after the maize germination phase improves the ability of soil erosion protection and thus under-sowing of any other ground cover plants is not necessary.

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