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Effect of Row Width on Splash Erosion and Throughfall in Silage Maize Crops

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Abstract

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Line width is one of the major factors affecting arable soil erosion. The aim of the study was to assess the effects of different row spacing on splash erosion and throughfall in maize crops. Field measurements of the throughfall (P_{th}, mm) and splash erosion (MSR, g/m^2) were carried out in silage maize crops (row spacing 0.45 and 0.75 m) in 2012–2014. The BBCH growth stages for the crops, plant length (L, m), and leaf area index (LAI) were evaluated. Positive correlation was observed between the aerial precipitation (P, mm) and the P_{th} values. With increasing P-values, higher levels of P_{th} were identified in the 0.75 m compared to the 0.45 m row spacing. The value of this proportion was decreasing from the centre of the inter-row (0.75 m) to the row of the plants direction. Statistically significant lower values of splash erosion were observed in the 0.45 m compared with the 0.75 m wide rows, especially within the years 2012 and 2014. The experiments proved the positive influence of the length of plants and LAI on P/P_{th} values. A decrease of P_{th} in relation to precipitation values with height of plants and LAI values was observed. This dependency was then confirmed from the beginning of the stem elongation (BBCH 30) to the end of flowering (BBCH 70). Tighter dependency between the plant length (L) and the values of P/P_{th} ratio in the 0.75 m wide crop rows was determined. Conversely, a more important influence of LAI on the values of P/P_{th} ratio was estimated in the 0.45 m wide crop rows. The experiments proved the positive influence of the 0.45 m wide rows on the decrease of splash erosion as well as throughfall compared with the 0.75 m row spacing.

Keywords: erosion; growth stage; leaf area index; plant length; precipitation

Line width is one of the major factors affecting the production of corn grain (Johnson *et al.* 1998; Barbieri *et al.* 2000; Farnham 2001) and corn silage biomass (Uppenkamp 2007; Nübel 2008). Narrow rows are primarily associated with higher radiation interception by corn crops (Ottman & Welch 1989; Andrade *et al.* 2002). Narrow rows (0.35 m) can cause higher values of evapotranspiration compared with wider crop rows (0.75 m), depending on the moisture conditions (Barbieri *et al.* 2008).

Maize is generally considered the most vulnerable crop to soil erosion. Soil erosion is one of the most serious environmental and public health problems facing human society (Pimentel 2006). Soil erosion is generally dependent on the soil type and texture, rainfall characteristics, topography, soil and crop management, and soil conservation practices (Hudson 1995).

Due to the fact that splash is the most important detaching agent (Morgan 2005), splash erosion can be considered as the primary factor of water erosion. It is crucial for interrill erosion, because it separates the soil particles from the soil surface, thus facilitating their transport (van Dijk *et al.* 2002; Leguédois *et al.* 2005). Splash erosion depends on the kinetic energy of rainfall, rainfall intensity, aggregate stability, and plant cover (Quansah 1981; Sharma *et al.* 1991; van Dijk *et al.* 1996). It is also dependent on the layer of water on the surface of soil (Kinnell 1991; Richter 1998), and on the presence

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of stones, clods, and crop residues at the soil surface (Wainwright 1996; Morgan 2005).

Generally, it is believed that reducing the maize lines width contributes to water erosion risk reduction (Uppenkamp 2007; Nübel 2008; Mohammadi *et al.* 2012). In Germany, crops grown in row spacings ≤ 0.45 m, including maize, are not considered as wide-row crops. Then, they apply the less stringent criteria for growing on land at risk of erosion (LfL 2010). A narrower line contributes to the increase of soil protection, diminishing water runoff and soil erosion (Mannering & Johnson 1969; Sangoi & Salvador 1998). Corn row spacing (0.51, 0.76, and 1.02 m) had little effect on ground cover or erosion during the first 5 weeks after planting. At 7 to 8 weeks, ground cover was increased slightly and the narrow (0.51 m) line spacing reduced erosion (Mannering & Johnson 1969). Zábranský *et al.* (2013) proved that lines width reduction in maize from 0.75 to 0.45 m resulted in a decrease in throughfall values, and can contribute to the elimination of splash erosion. Brückler *et al.* (2004) determined the highest values of throughfall (under natural and artificial conditions – precipitation/irrigation) in the half distance only between the lines of corn cultivated in 0.75 m rows. The authors further state that the highest values of infiltration were measured directly in the rows of plants, the lowest at the distance of 70–136 mm from the lines of plants. Dekker and Ritsema (1997) point out the significant variability of soil volumetric water content in maize crops cultivated in 0.75 m rows. Due to interception and stem flow, water is funnelled towards the roots, and thus concentrates in the maize rows. However, distinctive wetting patterns were also formed between the maize rows, caused by rainwater dripping to the ground from overhanging leaves. The influence of distribution of rainfall on the soil volumetric water content in maize crops was also confirmed by Hupet and Vanclooster (2005) and Martello *et al.* (2015). Micro-topographical depressions further concentrate dripping water. The difference in the elevation between the top of the row and the bottom of the inter-row was about 70 mm (Dekker & Ritsema 1997). Miole *et al.* (2011) reported that depths of stemflow and throughfall were slightly higher in the narrow spacing treatment. Mean ratios of throughfall to incident precipitation or irrigation are highly variable depending on the crop variability (Quinn & Laflen 1983; Parkin & Codling 1990; Bui & Box 1992; Paltineanu & Starr 2000). De Moraes Frasson and Krajewski (2011, 2013) state that knowledge of the concentration of drops and their size distribution on the throughfall is also important in the future development of microwave-based sensors to measure the evolution of plant water storage and soil moisture during storms.

In addition to throughfall, the erosion processes are influenced by the stem flow (Neave & Abrahams 2002). According to Bui and Box (1992), up to one-third of the stem flow may contribute to the formation of surface runoff. A positive correlation was confirmed between the amount of rainfall (independent variable) and throughfall and the stem flow values of corn plants (Paltineanu & Starr 2000). These authors also point out the fact that at lower precipitation, the ratio of stem flow to throughfall increases. Hence, with an increase in precipitation the value of this ratio decreases. The stemflow of maize increases linearly with the total rainfall amount (Liu *et al.* 2015).

The aim of the study was to assess the effects of different row-spacing on the splash erosion and throughfall in maize crops. Data on the determination of the dependence between the values of throughfall and splash erosion are very limited in the scientific literature. The following objectives were set: (a) to determine the effect of different maize row width on the value of splash erosion during the vegetation period, (b) to determine the variability of throughfall within the rows, (c) to determine the relationship between the splash erosion and throughfall, (d) to determine the effect of the crop height and leaf area index on throughfall.

MATERIAL AND METHODS

Field experiments were carried out in 2012–2014 at Budihostice locality, Central Bohemia (50°04'34.45''N, 14°09'22.351''E; 220 m a.s.l.; soil type Haplic Chernozem). In the normal period (1961–1990) potential evapotranspiration slightly exceeded the precipitation totals (P/E_0 was around 0.7–0.8) for the Budihostice locality (Pivec *et al.* 2006). Average soil texture of the experimental plots measured in spring 2012 was as follows: soil particles < 0.01 mm 24.74%, 0.01–0.05 mm 13.05%, 0.05–0.1 mm 9.48%, and 0.1–2 mm 52.73%. Silage maize crops (hybrid PR38N86) with row width of 0.45 and 0.75 m were evaluated. The size of the experimental plot was 0.5 ha. The basic technology of soil cultivation in the experimental plots comprised of autumnal plowing. Seedbed preparation was carried

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Table 1. Terms of maize seeding, average number of plants per ha, and average distance between plants three weeks after seeding in 2012–2014

Year	Terms of seeding	Row width (m)	No. of plants per ha	Average distance between plants (m)
2012	19.4.	0.45	88 889	0.271
		0.75	89 333	0.151
2013	19.4.	0.45	87 778	0.259
		0.75	89 333	0.156
2014	15.4.	0.45	85 556	0.266
		0.75	86 667	0.154

out using a shallow cultivator in one day of sowing. The sowing dates, number of plants per ha, and average distance between plants are documented in Table 1. A six-line seed driller (Kverneland Accord Optima HD; Kverneland Group, Klepp Stasjon, Norway) was used for sowing (row width 0.45 and 0.75 m). Plant protection and fertilization were identical on both surfaces. The plots were not irrigated.

Values of splash erosion were monitored using a method according to Bollinne (1975). Funnels with collection bottles (volume 0.5 l) were installed in the centre of maize inter-rows. Plastic funnels (body diameter 125 mm, outlet diameter 25 mm) were placed 4 mm above the soil surface (flooding prevention) as shown in Figure 1. A sieve (mesh size of 2 × 2 mm) eliminating the trapping of small mammals and insects into the container was placed between the bottle and the funnel. After every rainfall event with precipitation totals exceeding 2 mm soil sampling followed. Captured suspension was filtered and dried to constant weight. The soil in the funnel was then expressed as a real number of spray per unit area of soil (*MSR* g/m^2), using the algorithm according to Poesen and Torri (1988). Five collection funnels for the evaluation of splash erosion were located on each plot. At the end of the vegetation period, the stability of soil aggregates in trial plots (*SAS*) was also assessed using a wet sieving apparatus (Ejkelkamp, Giesbeek, NL) according to the manufacturer's methodology. An 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.

Throughfall (P_{th}, mm) was measured with collecting funnels identical to those for the splash measuring (without a sieve between funnel and bottle) – Figure 1. The amount of captured water was determined by weight, and subsequently expressed in mm of water column. Plastic tubes that hold the bottles with the funnel were placed 200 mm above the soil surface. Three drop zones (depending on the location within the line) were evaluated within each line (Figure 2). Seven collection funnels (a total of 21 funnels per each variant) were installed for each assessed drop zone; their distribution in measuring plots with corn line spacings of 0.45 and 0.75 m is displayed in Figure 2. Two collection funnels were placed at a height of 3.5 m (upper edge of the funnel) above ground. These funnels were used to determine the aerial precipitation above the crop canopy (P, mm). The reason was for the comparison of P_{th} and P using the same collecting devices. Values of P and P_{th}, and

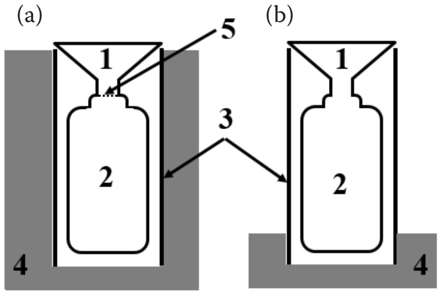

Figure 1. Measuring scheme of the splash erosion (a) and throughfall (b); 1 – funnel; 2 – bottle; 3 – tube; 4 – soil; 5 – sieve

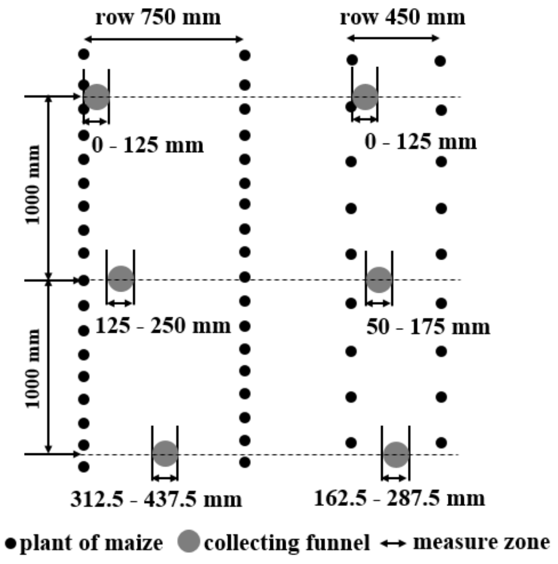

Figure 2. Scheme of the funnel location for the throughfall measurements in maize crop with the 0.75 m and 0.45 m wide rows

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similarly *MSR*, were determined for the measured period, depending on the duration of the precipitation.

Verification of the accuracy of P measurement using the collection device above the crop canopy was made by comparing the average values of P precipitation with standard precipitation values (P_{rg}, mm) measured by the standard tipping bucket rain gauge SR 03 (Meteoservis, Vodňany, CZ). The dependency between P and P_{rg} in 2012 can be described by the following model: $P = 0.849 \times P_{rg}$, correlation coefficient (r) = 0.996, in 2013 the same dependency by the model: $P = 0.939 \times P_{rg}$, $r = 0.993$, and finally in 2014 by the model: $P = 0.947 \times P_{rg}$, $r = 0.997$.

As an observed subject within the development of vegetation, the BBCH growth stages for the crops (according to Meier (2001)) and the plant length (L, m) were monitored weekly. Twenty plants from each variant were evaluated. Plant length was measured from the base of the plant up to the end of the most developed stretched leaf (since the stage of BBCH 61), then from the base to the top of inflorescence after stage BBCH 61.

Values of photosynthetically active leaf area (expressed by *LAI*) in the ten plants for each variant were measured in fortnight intervals. Plants for the determination of L and *LAI* were taken diagonally on the plot. *LAI* was determined destructively, followed by the infrared image analysis. Plant leaves were separated and placed on a 0.6 × 0.6 m black plate. The leaves were laid on the plate whole or dissected according to their size. Infra-red photographs (8 Mpx resolution) of the leaves were taken from the height of 1.2 m and converted into a black (for background) and white (for leaves) format. Following the circumference of the plates, all images were cropped in the Photoshop program. Subsequently, the percentage of the white and black pixels from the cropped photographs was determined. The percentage of white colour was used to calculate the leaf surface in the image area of the plate. Using the number of plants per unit area, *LAI* was determined. A Nikon Coolpix 995 digital camera (Nikon Corporation, Tokyo, Japan) was modified by changing the NIR-blocking filter for an Infrared R72 filter (Hoya, Tokyo, Japan) mounted in front of the lens. The images were processed with the analytical tool in Adobe Photoshop CS5 (Adobe Systems Software, Dublin, Ireland).

To determine the dependency of P_{th} on the values of L and *LAI*, daily values of plant length (L_{cal}, m) and leaf area index (LAI_{cal}) were calculated. Finally, the dependency between the values of P (mm)/P_{th} (mm) ratio (dependent variable) for the actual precipitation event and L_{cal} (m) and LAI_{cal} values (independent variable) for the same event were estimated. The computational algorithms and parameter values of equations for L_{cal} and LAI_{cal} are documented in Table 2. The values of L_{cal} were calculated for the whole vegetation period within the years evaluated,

Table 2. Values of parameters for the plant lengths calculation (L_{cal}, m) and for leaf area index calculation (LAI_{cal}) (years 2012–2014)

Year	Row width (m)	par1	par2	par3	*r*	*n*
L_{cal}						
2012	0.45	0.0024	0.0009	–65.30	0.998*	18
	0.75	0.0013	0.0005	–62.03	0.999*	18
2013	0.45	0.0009	0.0003	–64.20	0.998*	20
	0.75	0.0010	0.0003	–64.77	0.998*	20
2014	0.45	0.0021	0.0008	–66.67	0.995*	15
	0.75	0.0023	0.0009	–66.99	0.997*	15
LAI_{cal}						
2012	0.45	1.9929E-4	4.1752E-5	53.4183	0.999*	9
	0.75	2.6034E-5	5.9823E-6	48.9556	0.995*	9
2013	0.45	5.0684E-8	1.1738E-8	40.6758	0.999*	9
	0.75	7.3460E-7	1.5360E-7	44.0716	0.999*	9
2014	0.45	7.6714E-5	2.2084E-5	52.3402	0.998*	9
	0.75	3.8263E-5	1.0029E-5	51.8555	0.993*	9

Models: L_{cal} = par1/(par2 + exp (– (*DOY*/par3)^2)); LAI_{cal} = par1/(par2 + exp (– (*DOY*/par3)^2)); *DOY* – day of year; *r* – correlation coefficient L vs L_{cal} or *LAI* vs LAI_{cal}; *confidence level 95.0%; *n* – sample size

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the values of LAI_{cal} were calculated for the individual years within the periods 19/4–30/7 2012, 19/4–20/8 2013, and 15/4–17/8 2014.

Statistical analyses were carried out in Statgraphics®*Plus* 4.0 (Statgraphics, Warrenton, USA). The analysis of variance (ANOVA, Tukey's test, $\alpha = 0.05$) and simple regression were used. The program Mini32 Version 403.18 (EMS, Brno, Czech Republic) was used for the determination of the calculated values of plant length L_{cal} and LAI_{cal}.

RESULTS

Precipitation and throughfall. The size and number of the evaluated rainfall events from 2012 to 2014 and the average P/P_{th} ratios (mm; the average value from assessed area), depending on the precipitation totals are documented in Table 3. Values fluctuated within the range of 1.44–6.75 (Table 1). The measurements (2012–2014) in both stands showed a close correlation between the values of aerial precipitation (P, mm) and the mean throughfall (P_{th}, mm) (Figure 3). With increasing P-value, higher levels of P_{th} were proved in the 0.75 m compared with the 0.45 m row spacing (Figure 3). For the observed period, the highest average proportion of P_{th} (%) (P = 100%) was established in the 0.75 m rows. This proportion is the highest in the centre of the inter-row, and decreases toward the plant row (Figure 4). In the case of the 0.45 m row spacing, the proportions of P_{th} (%) on P were lower than in the 0.75 m rows in all of the assessed areas (Figure 4). In the case of the 0.75 m wide rows, the average value of the proportion of P/P_{th} (2012–2014) was 35.9% in the 0–125 mm zone, 47.6% in the 125–250 mm zone, and 53.8% in the 312.5–437.5 mm zone. In the case of the 0.45 m row spacing, average P/P_{th} was 33.1% in the 0–125 mm zone, 33.5% in the 50–175 mm zone, and 32.3% in the 162.5–278.5 mm zone.

Splash erosion, precipitation, and throughfall. The values of splash erosion (MSR, g/m^2) in crops with the 0.75 and 0.45 m row spacing within the observation periods from 2012–2014 are documented in Table 4. Statistically significant lower values of splash erosion were observed in the 0.45 m wide rows compared with the 0.75 m wide rows, especially within the years 2012 and 2014 (Table 4). The positive influence of narrower rows on the MSR elimination was not clear in 2013 (Table 4).

The absolute values of MSR fluctuated between 11.8–557.8 g/m^2 (2012), 8.1–2630.8 g/m^2 (2013), and 44.0–839.9 g/m^2 (2014). Figure 5 illustrates a positive correlation of splash erosion (MSR, g/m^2) and aerial precipitation (P, mm) during the years 2012–2014. Positive correlation was also determined between splash erosion (MSR, g/m^2) and the throughfall values (P_{th}, mm) – Table 5. The closest dependency between P_{th} and MSR was observed within the 0.45 m wide rows in 2012–2013 in the 0–125 mm zone, rather than in 2014 in the 50–175 mm zone, as it is evident from

Table 3. Number of events selected by totals and the average P/P_{th} proportion (precipitation/throughfall) in maize crops with 0.45 m and 0.75 m row spacing in 2012–2014

Precipitation totals (mm)	No. of events selected			P/P_{th}					
				2012		2013		2014	
	2012	2013	2014	row width (m)					
				0.75	0.45	0.75	0.45	0.75	0.45
0 ≤ 2	2	0	1	1.44	3.48			4.07	6.75
2 ≤ 5	5	1	5	1.48	2.52	4.14	1.99	2.85	3.21
5 ≤ 10	5	4	3	2.32	4.13	1.99	3.06	2.55	2.71
10 ≤ 15	2	3	0	2.58	4.88	3.36	4.91		
15 ≤ 20	0	1	1			3.73	4.52	1.54	2.18
20 ≤ 25	0	0	0						
25 ≤ 30	0	1	0			3.58	5.19		
30 ≤ 35	1	1	1	2.31	3.38	4.16	4.63	2.61	3.42
> 35	0	1	2			1.33	1.65	2.93	2.86
Sum	15	12	13						

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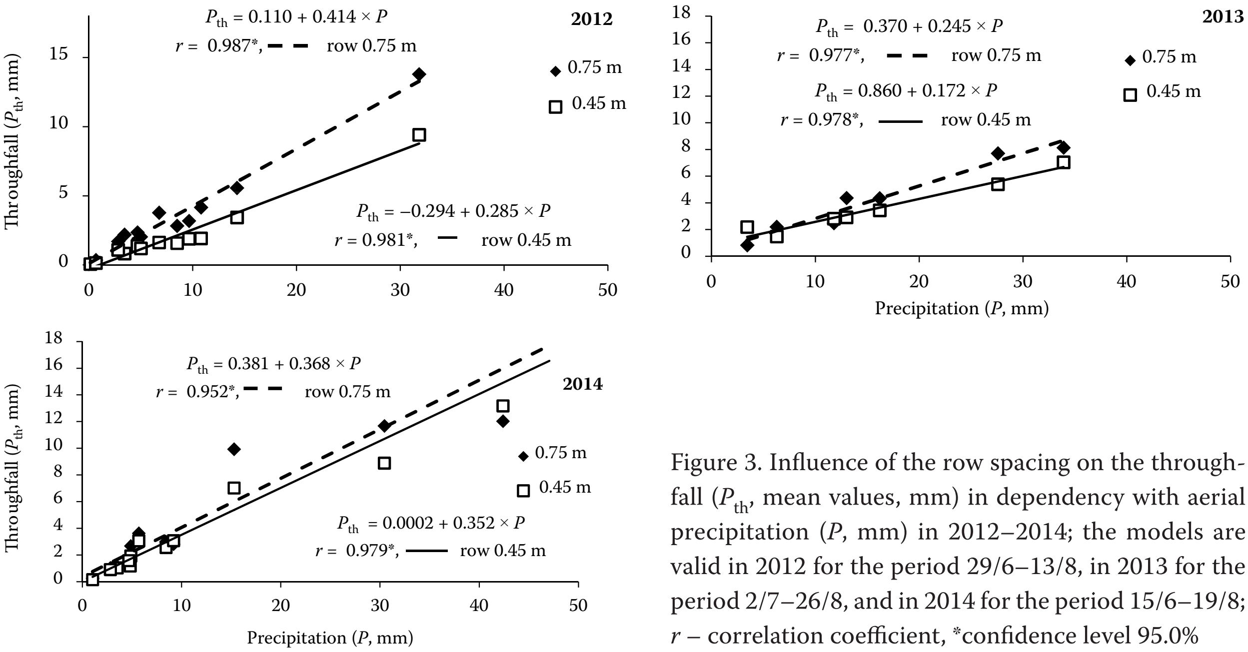

Figure 3. Influence of the row spacing on the throughfall (P_{th}, mean values, mm) in dependency with aerial precipitation (P, mm) in 2012–2014; the models are valid in 2012 for the period 29/6–13/8, in 2013 for the period 2/7–26/8, and in 2014 for the period 15/6–19/8; r – correlation coefficient, *confidence level 95.0%

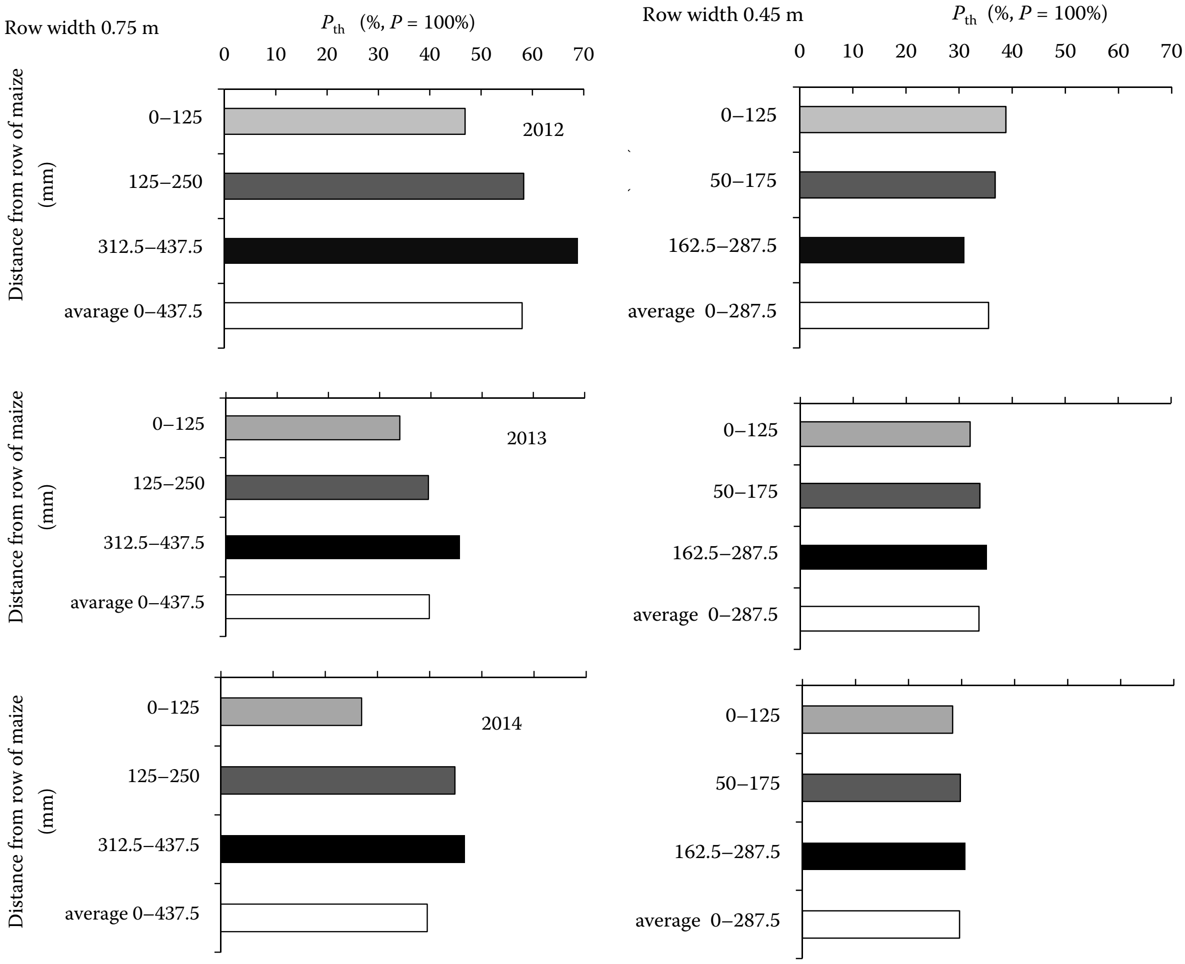

Figure 4. Influence of row spacing on throughfall (P_{th}, %) within the inter-row in 2012–2014; aerial precipitation (P, mm) represents 100%

Table 4. Values of splash erosion (MSR, g/m^2) in maize crops with different row spacing during estimated periods in 2012–2014

Row width (mm)	Period													
2012	21/5–23/5	23/5–1/6	1/6–4/6	4/6–11/6	11/6–12/6	12/6–21/6	21/6–29/6	29/6–1/7	1/7–2/7	2/7–3/7	3/7–5/7	5/7–9/7	9/7–16/7	18/7–23/7
450	271.1^{a}	166.8^{a}	158.7^{a}	20.6^{a}	45.6^{a}	108.4^{a}	11.8^{a}	65.3^{a}	55.5^{a}	487.3^{a}	51.1^{a}	154.7^{a}	45.0^{a}	58.1^{a}
750	280.5^{a}	225.9^{a}	223.1^{b}	35.5^{a}	77.8^{b}	158.4^{b}	26.0^{a}	84.7^{b}	88.2^{b}	557.8^{a}	48.1^{a}	175.6^{a}	42.3^{a}	44.2^{a}
2013	15/5–20/5	20/5–23/5	23/5–27/5	27/5–31/5	31/5–5/6	5/6–10/6	10/6–11/6	24/6–25/6	25/6–26/6	26/6–3/7	26/7–30/7	30/7–5/8	5/8–7/8	7/8–13/8
450	970.6^{a}	56.8^{a}	418.6^{a}	627.4^{a}	886.2^{a}	2622.6^{a}	50.2^{a}	279.7^{a}	8.1^{a}	230.4^{b}	99.4^{a}	113.1^{a}	73.9^{a}	22.9^{a}
750	800.5^{a}	49.5^{a}	381.2^{a}	559.4^{a}	892.4^{a}	2630.8^{a}	81.0^{b}	282.4^{a}	12.2^{a}	166.0^{a}	91.0^{a}	97.3^{a}	74.1^{a}	28.2^{a}
2014	19/5–22/5	22/5–26/5	26/5–28/5	28/5–30/5	30/5–26/6	26/6–30/6	30/6–9/7	9/7–15/7	15/7–22/7	22/7–28/7	28/7–6/8			
450	309.8^{b}	604.4^{a}	789.4^{a}	244.3^{a}	124.3^{a}	75.3^{a}	322.7^{a}	53.8^{a}	152.3^{a}	198.5^{a}	44.0^{a}			
750	257.5^{a}	598.6^{a}	839.9^{a}	283.5^{a}	238.1^{b}	88.9^{a}	705.2^{b}	102.7^{b}	347.4^{b}	488.6^{b}	62.4^{b}			

Indexes a, b in the individual rows document statistically significant differences ($\alpha = 0.05$)

Table 5. Influence of throughfall (P_{th}, mm) on the splash erosion (MSR, g/m^2, measured in the centre of the inter-row) in different parts of inter-rows of maize crop (0.45 m and 0.75 m row spacing) in 2012–2014

Row width (mm)	Distance from maize row (mm)	2012		2013		2014	
		MSR	r	MSR	r	MSR	r
450	0–125	$-38.932 + 43.303 \times P_{th}$	0.937	$10.278 + 13.448 \times P_{th}$	0.948	$23.463 + 16.282 \times P_{th}$	0.968
	50–175	$-48.279 + 46.288 \times P_{th}$	0.875	$25.422 + 12.301 \times P_{th}$	0.934	$32.597 + 14.208 \times P_{th}$	0.995
	162.5–287.5	$-40.597 + 55.690 \times P_{th}$	0.867	$16.979 + 12.084 \times P_{th}$	0.919	$32.513 + 13.246 \times P_{th}$	0.983
	average	$-44.193 + 48.405 \times P_{th}$	0.901	$17.113 + 12.684 \times P_{th}$	0.937	$28.8448 + 14.5919 \times P_{th}$	0.987
750	0–125	$-53.086 + 47.654 \times P_{th}$	0.946	$2.762 + 14.920 \times P_{th}$	0.869	$83.508 + 2.712 \times P_{th}$	0.792
	125–250	$-73.629 + 42.928 \times P_{th}$	0.971	$15.019 + 10.296 \times P_{th}$	0.941	$-37.442 + 32.372 \times P_{th}$	0.974
	312.5–437.5	$-77.233 + 37.281 \times P_{th}$	0.958	$14.280 + 8.781 \times P_{th}$	0.926	$16.900 + 24.739 \times P_{th}$	0.958
	average	$-70.885 + 42.626 \times P_{th}$	0.963	$8.749 + 11.169 \times P_{th}$	0.934	$-13.450 + 34.680 \times P_{th}$	0.969

r – correlation coefficient (confidence level 95.0%)

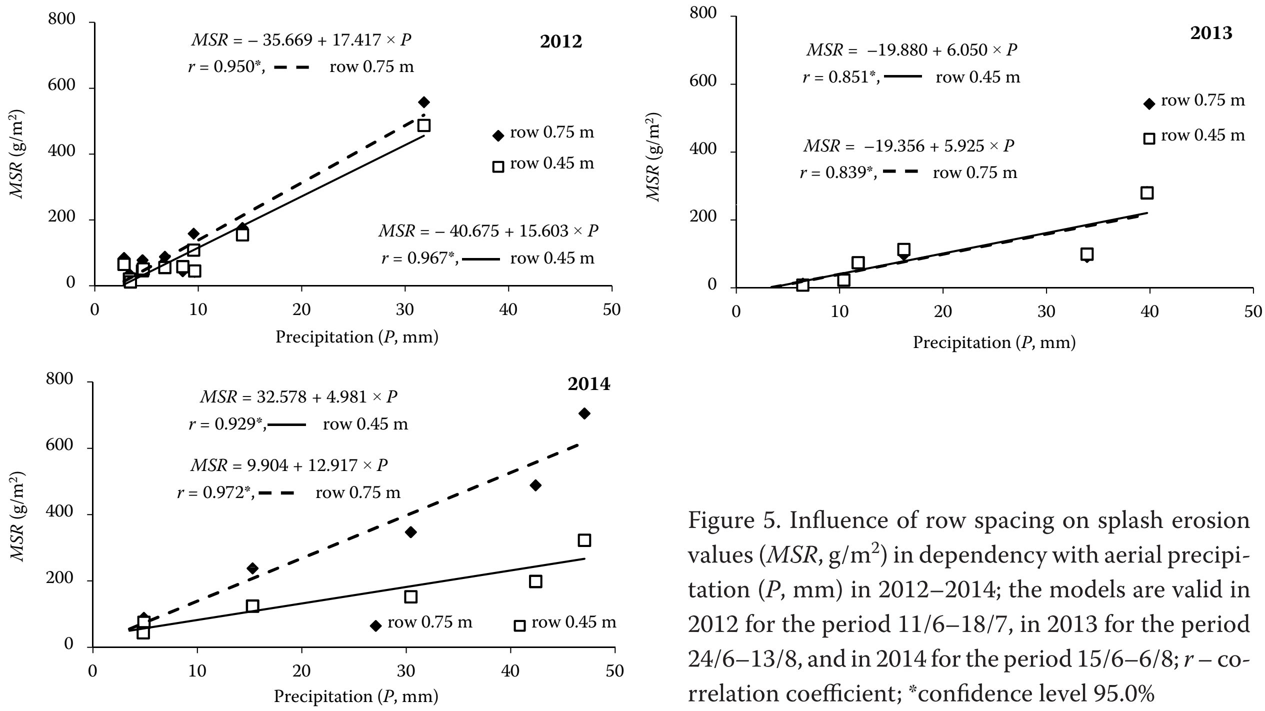

Figure 5. Influence of row spacing on splash erosion values (*MSR*, g/m^2) in dependency with aerial precipitation (*P*, mm) in 2012–2014; the models are valid in 2012 for the period 11/6–18/7, in 2013 for the period 24/6–13/8, and in 2014 for the period 15/6–6/8; *r* – correlation coefficient; *confidence level 95.0%

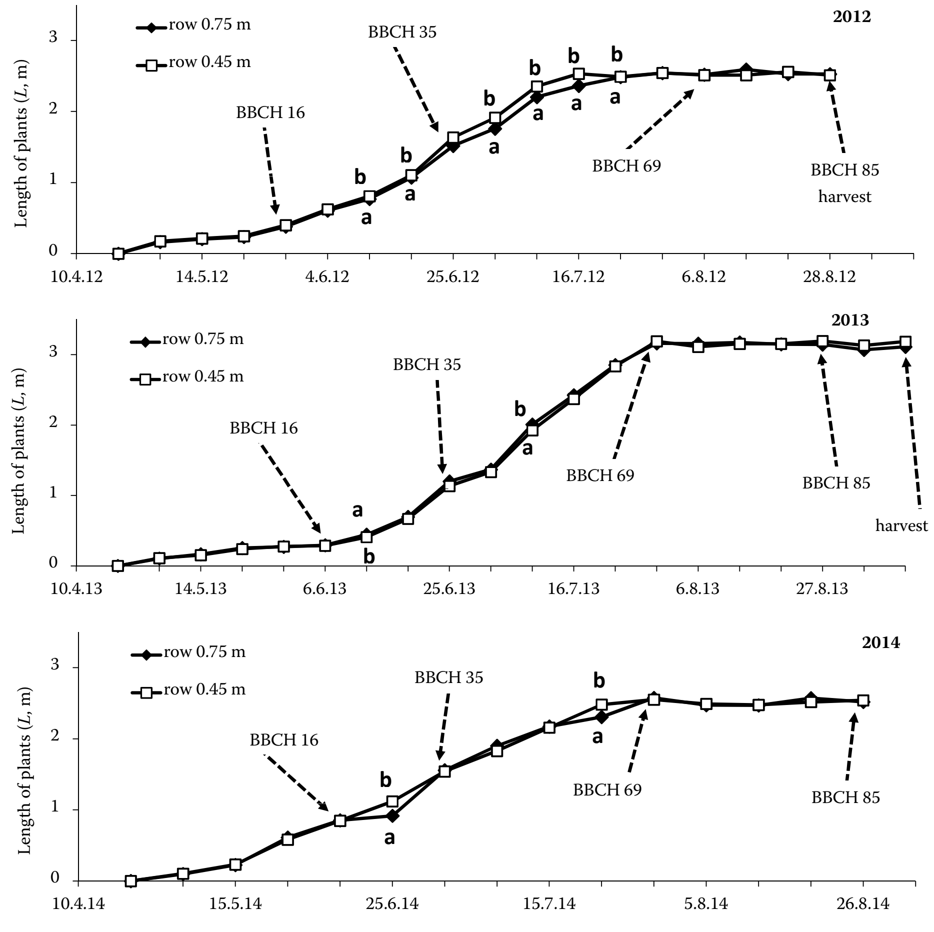

Figure 6. Average values of the length of maize plants (*L*, m) and BBCH stages in 0.45 m and 0.75 m row spacing within the years 2012–2014; indexes a/b indicate statistically significant differences (α = 0.05)

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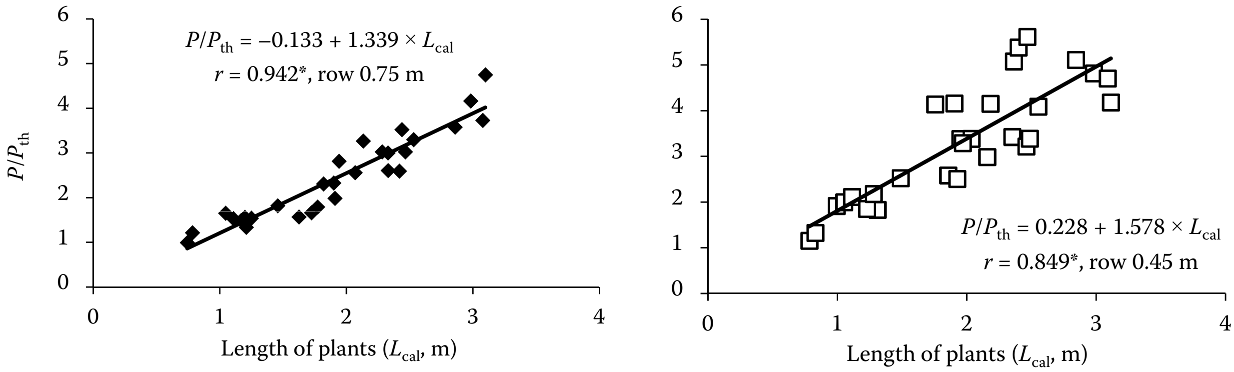

Figure 7. Dependency of the proportion of the aerial precipitation (P, mm) and throughfall (P_{th}, mm) on the calculated length of plants (L_{cal}, m); values of L_{cal} and P/P_{th} used in the models were derived from the periods when the plants were within the phase BBCH 30–70; data from years 2012–2014; r – correlation coefficient; *confidence level 95.0%

Table 6. Stability of soil aggregates (*SAS*, stable share) at the end of the vegetation period during 2012–2014

Row width (mm)	*SAS*		
	2/9/2012	13/9/2013	9/9/2014
450	0.29^b	0.24^a	0.38^a
750	0.25^a	0.26^a	0.36^a

Different letters document statistically different averages (α = 0.05)

Table 5. In the case of the 0.75 m wide rows, the closest dependency between P_{th} and *MSR* was observed always in the 125–250 mm zone, in contrast to the soft dependency in the 0–125 mm zone (Table 5).

The mass proportion of the stable aggregates on the total mass of aggregates (*SAS*) during 2012–2014 years is documented in Table 6. When compared with the 0.75 m wide rows, statistically significant higher values of *SAS* were observed in the 0.45 m wide rows in 2012. No statistically significant differences were observed between *SAS* values in 2013 and 2014.

Plant cover and throughfall. Table 4 illustrates the dynamics of the lengths of plants and BBCH phases during the years 2012–2014. The statistically significant differences in the plants length between the 0.45 and the 0.75 m wide rows are noticeable from Figure 6 in 2012 only. Significantly longer plants in the 0.45 m wide rows from the beginning of the growth elongation phase (BBCH 30) up to the phase of complete flowering (BBCH 67) were observed. The positive correlation between plant length (L_{cal}, m) and P/P_{th} proportion is documented in Figure 7. Values of L_{cal} and P/P_{th} for the season when the plants were in the BBCH phase 30–70 (2012–2014 average) were used in the model. During this period of vegetation, the highest level of dependency between variables was determined. A closer dependency between L_{cal} and P/P_{th} was according to the correlation coefficients estimated in the 0.75 m wide rows. The measured values of *LAI* for the crops

Table 7. Values of *LAI* during 2012–2014

Year 2012	Row width (mm)		Year 2013	Row width (mm)		Year 2014	Row width (mm)	
	450	750		450	750		450	750
19/4	0	0	19/4	0	0	15/4	0	0
7/5	0.020	0.018	7/5	0.015	0.013	1/5	0.016	0.011
21/5	0.145	0.108	21/5	0.091	0.106	28/5	0.197	0.203
4/6	0.902	0.778	6/6	0.168	0.255	10/6	0.763	0.738
18/6	2.289	1.932	12/6	0.336	0.462	25/6	2.150	1.597
2/7	4.118	4.117	25/6	2.568	2.621	9/7	3.193	3.604
16/7	4.608	4.118	9/7	4.093	4.432	23/7	3.599	3.642
30/7	4.054	3.828	23/7	4.415	5.043	5/8	3.306	3.724
13/8	3.469	3.904	6/8	4.502	4.635	19/8	3.486	3.764
28/8	2.509	2.619	20/8	4.109	4.714	2/9	3.590	3.198

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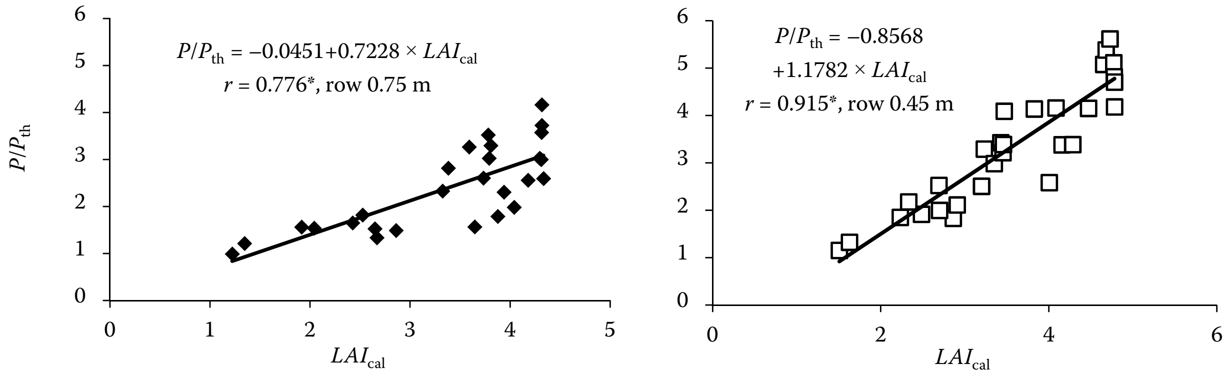

Figure 8. Dependency of the proportion of the aerial precipitation (P, mm) and throughfall (P_{th}, mm) on the calculated values of the leaf area index (LAI_{cal}); values of LAI_{cal} and P/P_{th} used in the models were derived from the periods when the plants were within the phase BBCH 30–70; data from years 2012–2014; r – correlation coefficient; *confidence level 95.0%

evaluated within the years 2012–2014 are included in Table 7. The positive correlation between daily values of LAI_{cal} and P/P_{th} proportion is documented in Figure 8. In this case, the tightest dependency between the variables was according to the correlation coefficients estimated within the BBCH phase 30–70 (2012–2014 average). A closer dependency between LAI_{cal} and P/P_{th} was estimated in the 0.45 m wide crop rows (Figure 8).

DISCUSSION

Precipitation and throughfall. A positive correlation between P/P_{th} (row width 0.45 as well as 0.75 m) was determined in accordance with the results of Paltineanu and Starr 2000 (Figure 3). P_{th} values in the 0.45 m wide rows were reduced in comparison with the 0.75 m wide rows (Figure 3), especially under the higher precipitation totals. Measurements did not prove the dependency between the P/P_{th} proportion and the precipitation totals (Table 3). However, it is necessary to take into account if this is possible under the conditions of the natural precipitation, incontinuous precipitation data recording, and continuously changing parameters of growth. The highest P/P_{th} proportions were estimated in the centre of inter-rows in the 0.75 m wide row crops, in accordance with Bruckler *et al.* 2004. The P/P_{th} proportion decreased toward the row (Figure 4). This fact was probably due to the occurrence of the free inter-row space as a result of the free growing crop, and due to the water drip from leaves in the centre of the inter-row. The effect of the water drip from leaves on the water concentration in the centre of inter-rows and on the increasing splash erosion is pointed out by Brandt (1989), Bruckler *et al.* (2004), and Morgan (2005).

In the case of the 0.45 m wide rows, these phenomena were not so clearly noticeable (Figure 4). Stands are substantially closed; stem flow plays a crucial role in the rainwater distribution.

Zábranský *et al.* (2013) proves this fact, introducing higher values of the stem flow in the 0.45 m wide rows compared with the 0.75 m row spacing in maize crops. Under the lower precipitation totals, the proportion of stem flow on the total precipitation is increasing; greater precipitation, *vice versa*, tends to lower the proportion of the stem flow.

Based on the P/P_{th} proportion, a great variability of the actual throughfall as well as of the average values within the inter-rows is noticeable during the evaluated years (Figure 4).

The estimated proportion of P_{th} and P corresponds with the results reported in the literature, whereby this ratio lays within the interval of 34–84%, depending on different sources (Quinn & Laflen 1983; Parkin & Codling 1990; Bui & Box 1992; Paltineanu & Starr 2000). According to these authors, the variability of crops is the main factor influencing the variability of the throughfall. The variability of P_{th} and P proportion (%) may also be explained by the different totals of precipitation and numbers of precipitation in the individual size category (Table 3). The other factors will certainly include the rain intensity, drops dimension, angle of rain incidence, etc. Paltineanu and Starr (2000) point out the fact that in maize crop under less intense rain, the proportion of stem flow on the throughfall is increasing. Under more intense rain this proportion is decreasing.

Splash erosion, precipitation, and throughfall. A positive correlation between the precipitation totals (Figure 5), throughfall (Table 5), and MSR values was proved. The positive influence of the narrower line on the elimination of erosion processes was also determined, due to the estimation of lower *MSR* values on the 0.45 m wide compared with the 0.75 m wide rows (Uppenkamp 2007; Nübel 2008; Mohammadi *et al.* 2012). It is explainable by probably higher soil coverage by the leaves and by a greater proportion of stem flow (Bui & Box 1992; Zábranský *et al.* 2013). Lower *SAS* values on the 0.45 m compared with 0.75 m rows are highly possible because of high precipitation in the beginning of the vegetation period (5–7 leaf phases), resulting in areal soil loss and its subsequent deposition in the inter-rows. This effect was greater in the 0.45 m than in the 0.75 m rows, and subsequently influenced the evaluation of *SAS*. For this reason, this fact cannot be associated with the influence of vegetation.

Plant cover and throughfall. The experiments proved the positive influence of the length of plants as well as of *LAI* on P/P_{th} values. Throughfall P_{th} in relation to the precipitation P values decreased with increasing plant height and *LAI* (Figure 7). This dependency was then proved from the beginning of the stem elongation (BBCH 30) to the end of flowering (BBCH 70). This fact is explainable by the increase of the crop cover from phase BBCH 30, because of intensive leaf growth and greater soil coverage. From the end of flowering, the leaves arrangement changed (the angle of leaf blade increased) and the upper half of leaves bent toward the soil surface. Simultaneously, necrosis may result in the death of lower leaves of plants from this stage. These facts are likely to have a subsequent influence on the overall soil coverage and the proportion of the water drip from leaves and the stem flow. Finally, all of this modifies the influence of the crop on the rain water distribution.

According to the estimation of the influence of the crop, closer dependency between L_{cal} and P/P_{th} was proved in the 0.75 m wide crop rows (Figure 7). In the 0.45 m wide rows, a greater influence of LAI to P/P_{th} ratio was observed (Figure 8). This fact could be explained by a probably higher soil coverage by leaves in the 0.45 m wide rows. The length of plant may be the factor strongly influencing the angle of the precipitation incidence in the case of the 0.75 m row spacing.

CONCLUSIONS

The presented results may be summarized as follows:

- For the 0.45 m wide compared to the 0.75 m wide crop rows, a decrease of throughfall in the BBCH phase 30–70 was observed.
- Reduction of lines width from 0.75 m to 0.45 m in maize resulted in decreasing splash erosion.
- Narrower lines (0.45 m) did not provably impact the splash erosion in the beginning of the vegetation period if compared with wider lines (0.75 m).
- In general, in both evaluated crops the protective influence of vegetation was decreased with the beginning of the senescence phase.

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