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Soil-conservation effect of intercrops in silage maize

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Abstract: More than 50% of agricultural land is threatened by water erosion in the Czech Republic. With respect to soil erosion, maize (*Zea mays* L.) belongs to the most problematic crops; one of the possibilities to increase protection against erosion is intercropping. In this study, we attempted to find out the effects of individual intercrops and their mixtures (sown 4–6 weeks after sowing maize) or a mixed culture (maize plus lupine) on the soil losses and surface runoff in the period 2019–2021. The study was realised in a sugar beet growing region (Haplic Luvisol); a field rainfall simulator was used. From the used variants with *Lolium perenne* L., *Trifolium repens* L., *Vicia villosa* Roth, *Lolium multiflorum* Lam., *Festuca arundinacea* Schreb., *Triticum aestivum* L. or a mixture (*Vicia villosa* plus a *Trifolium* hybrid diploid), the variants with *Lolium perenne*, *Lolium multiflorum*, *Vicia villosa* or *Vicia villosa* plus the *Trifolium* hybrid diploid, established between the maize rows (hybrid maize, cultivar Walterinio) on May 27, were the most efficient in case of both the soil losses and runoff reductions in the year 2019. For example, *Triticum aestivum* between the maize rows mostly reduced the soil losses and the surface runoff was similar (or higher) compared with the control (maize without any intercrop). The variant with *Trifolium repens* had mostly higher (or similar) soil loss values (compared with the control); in this variant, the runoff was lower compared with the control. We proved our hypothesis with regards to the higher reduction in the soil losses than with the runoff in the variant with *Lolium perenne*. The results from the years 2020 (the used variants with *Lolium multiflorum*, *Secale cereale* L., *Trifolium incarnatum* L., *Phacelia tanacetifolia* Benth., *Lolium multiflorum* plus *Trifolium incarnatum*, *Lolium multiflorum* plus *Vicia pannonica* Crantz) and 2021 (the variants with *Lolium multiflorum*, *Lolium multiflorum* – early sowing, *Secale cereale*, *Trifolium incarnatum*, *Phacelia tanacetifolia*, *Lolium multiflorum* plus *Trifolium incarnatum*, a mixed culture = maize plus *Lupinus albus* L.) showed the variants with *Trifolium incarnatum*, the mixture (*Lolium multiflorum* plus *Trifolium incarnatum*), *Phacelia tanacetifolia* (in the year 2020) or the mixture (*Lolium multiflorum* plus *Trifolium incarnatum*) and a mixed culture (maize plus *Lupinus albus*) (2021) had the most positive effect – the soil loss and surface runoff values were lower when the maize was > 2 m compared with the maize < 1 m. The results obtained in the period 2019–2021 showed the grasses were the most efficient in decreasing the soil losses when the maize was < 1 m and when the maize was > 2 m with the used mixtures.

Keywords: black fallow; erodibility; growth stage; ryegrass; slope; throughfall

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In the Czech Republic, more than 50% of agricultural land is threatened by water erosion (and approximately 10% of agricultural land is threatened by wind erosion) – see Janeček et al. (2002); it is also stated, for example, the first soil erodibility maps (in the Czech Republic) were constructed in the 1960s – water and wind. In the Czech Republic, specific conditions for the occurrence of water erosion are given by the largest land blocks in Europe (thanks to the intensification of agricultural production in the former Czechoslovakia) as well as balks or dirt road ploughing, etc., and interest in investing in soil conservation measures (Karásek et al. 2019; Janeček et al. 2002; Boardman & Poesen 2006). Water erosion causes topsoil losses, the deposition of eroded soil in river beds and reservoirs, etc.; lower crop yields due erosion have been described in different publications (loss of the rooting depth, decrease in the plant-available water, etc.) – see Frye et al. (1982), Becher et al. (1985), Lal and Moldenhauer (1987), Mokma and Sietz (1992), Tengberg et al. (1997), Zhang et al. (2021), etc.

Runoff and soil erosion are influenced by many factors including the vegetation cover (Gyssels et al. 2005; Zuazo & Pleguezuelo 2008). The aboveground and underground biomass (roots) play a role in reducing soil erosion (De Baets et al. 2011; Sinohara et al. 2016); plant roots have an effect on the soil porosity, aggregate stability, infiltration capacity, etc. (Angers & Caron 1998; Bacq-Labreuil et al. 2019). The effects of plant roots on the soil bulk density have been described by Liu et al. (2015). Different crops differ in their effect on soil erosion, for example, Gao et al. (2020) reported soybeans had a better effect on the soil erosion compared to maize. According to Lin et al. (2019), soil erosion processes are also influenced by both the slope gradient and rainfall intensity. One of the most problematical crops is maize (*Zea mays* L.) – see Laloy and Bielders (2010). Maize has a high energy value and starch concentration or yield potential, thus it is easy to ensile. Concerning maize yield trends in the Czech Republic (and the effects of precipitation, temperature, water deficit) – see Maitah et al. (2021). For example, maize belongs to narrow-leaf crops and intercepts most rainwater at the bottom of the leaves, where the water is transferred along the plant stems (Martello et al. 2015). Becher et al. (1985) studied the effect of water erosion on silage maize yields. Herout et al. (2018) studied three technologies of tillage (maize) – disc cultivator, strip-till, no-till. The authors found out that no-till technology gave the lowest soil loss. One of the possibilities to increase the protection against erosion is intercropping – growing of two or more crops simultaneously on the same field (Jamriška 2002; Kintl et al. 2018, 2020). For example, intercrops can be established between maize rows using different methods (together with maize or later; concerning the later term, both hoeing and intercrop sowing can be realised). Shaw et al. (2009), for example, endeavoured to study when different intercrops should be sown (at maize sowing, eight weeks after maize sowing or soon after silage maize harvest). Lima et al. (2014) found the intercropping of maize with jack beans reduced the soil erosion compared with the use of maize or jack beans by themselves.

In this study, we attempted to determine how different intercrops and their mixtures (sown 4–6 weeks after sowing the maize) or a mixed culture (maize plus lupine) influence the soil losses and surface runoff measured in the third and fourth growth periods (concerning the definition of the periods – see Janeček et al. 2002 or Kabelka et al. 2019, 2021). We hypothesised the use of selected grasses, clovers, cereals or mixtures between the maize rows will lead to lower soil losses (Zhou & Shangguan 2008; Hůla et al. 2011; Sinohara et al. 2016; Lin et al. 2019). We also hypothesised a higher reduction in the soil losses than the runoff in the case of *Lolium perenne* (Zhou & Shangguan 2008).

MATERIAL AND METHODS

Plot 1. In 2019, one experimental plot (49°39'48.955"N, 16°43'27.390"E, 355 m a.s.l., Haplic Luvisol – IUSS Working Group WRB 2015) was selected near Jevíčko (the cadastral area of Chornice) in the Svitavy district in the Czech Republic (sugar beet growing region). This area is characterised by a mean annual air temperature of 7.4 °C and by a mean annual precipitation of 545 mm (the given climatic region of the Czech Republic – see Table I in the publication by Podhrázská et al. 2013). In the 2019 vegetation season, the sum of the precipitation and the mean air temperature were slightly higher (13.8 mm and 1.3 °C) compared with the long-term average from 1981 to 2010. In 2018, silage maize was cultivated on the experimental plot (an average slope of 6.6%). After the harvest in the autumn of 2018, an application of manure (25 t/ha) with consequent incorporation into the soil was realised. In the spring of 2019, both soil loosening and the incorporation of a digestate (20 m^3/ha) into

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the soil were also performed as well as an application of urea (100 kg/ha) and its incorporation during the seedbed preparation. In the middle of April, hybrid maize (cultivar Walterinio) was sown using a Horsch Maestro 8.70 CC (HORSCH, Germany) (99 thousand individuals per hectare) with a row spacing of 0.75 m; at the same time, Amofos (PhosAgro, Russia) (mineral fertiliser) was applied (150 kg/ha). The used intercrops (*Lolium perenne* Double (LPD), *Trifolium repens* Klondike (TRK), *Vicia villosa* Latigo (VVL), *Lolium multiflorum* Svatava (LMS), *Festuca arundinacea* Finelawn (FAF), *Triticum aestivum* Juuf (TRJ)) and a mixture (*Vicia villosa* plus the *Trifolium* hybrid diploid Soufflet Agro (VVTS)) were sown (3–5 leaves, 15–20 cm) using a four-row experimental testing machine (P&L Ltd., Czech Republic) which was used for both the hoeing and sowing (row widths of 0.3 m). All the variants were compared with two control variants (the variant with maize without any intercrop as well as black fallow). Three days after sowing the intercrops, a broadcast and post-emergent application of Laudis (Bayer AG, Germany) (2 L/ha) with an Amazone Pantera 450 (Amazone, Germany) was performed. In the course of the vegetation season, the experimental plot was slightly damaged by rodents; some of the used intercrops were damaged by browsing.

Plot 2. In the spring of 2020, the experimental plot was selected in the cadastral area of Jaroměřice (49°62'39''N, 16°72'87''E, 350–360 m a.s.l.) in the Svitavy district in the Czech Republic (sugarbeet growing region). This area is characterised by a mean annual air temperature of 7.4 °C and by a mean annual precipitation of 545 mm (Haplic Luvisol – IUSS Working Group WRB 2015). In the 2020 vegetation season, the sum of the precipitation was higher (119 mm), and the mean air temperature was similar compared with the long–term average from 1981 to 2010. In 2019, silage maize was cultivated on the plot with an average slope of 8.7%. After the harvest (mulched stubble), an application of 20 m^3 liquid manure/ha with shallow incorporation into the soil and 25 t/ha of manure incorporated into the soil (25 cm) using a cultivator was realised. Before sowing, both soil loosening plus the incorporation of a digestate (20 m^3/ha) were realised. Also, Super Hume (UAS of America, Inc., USA) (5 L/ha) and urea (100 kg N/ha) were applied and incorporated during the seedbed preparation. In the middle of April, hybrid maize (cultivar Walterinio) was sown using a Kinze 3500 Interplant (Kinze Manufacturing, USA) (80 thousand individuals per hectare, 0.75 m). In the first half of July 2020, an aerial application of the biopesticide *TrichoLet*® (Biocont Laboratory Ltd., Czech Republic) was performed in two terms. The used intercrops (*Lolium multiflorum* (LM), *Secale cereale* (SC), *Trifolium incarnatum* (TI), *Phacelia tanacetifolia* (PT)) and their mixtures (*Lolium multiflorum* plus *Trifolium incarnatum* (LMTI), *Lolium multiflorum* plus *Vicia pannonica* (LMVP)) were sown (3–4 leaves) using a four–row experimental (multifunctional) testing machine (P&L Ltd.). All the variants were compared with two control variants (the variant with maize without any intercrop as well as black fallow). No damage to the plants by game was found in the course of the 2020vegetation season.

Plot 3. In the spring of 2021, the experimental plot was selected in the cadastral area of Jaroměřice approximately 200 m from experimental plot 2. In the 2021vegetation season, the sum of the precipitation and the mean air temperature were similar compared to the long-term average. Silage maize was cultivated on the plot in 2020 with an average slope 10%. After the harvest (mulched stubble), there was a postharvest application of 20 m^3 digestate/ha with shallow incorporation and an application of manure (25 t per ha) with its incorporation to a depth of 25 cm using a cultivator. In the spring of 2021, an application of 30 m^3 digestate/ha was performed; Super Hume (5 L/ha) and urea (100 kg/ha) were applied during the seedbed preparation. At the end of April, hybrid maize (cultivar Walterinio) was sown using a Kinze 3500 (80 thousand individuals per hectare, 0.75 m). An aerial application of biopesticide *TrichoLet*® was performed in July. The used intercrops (*Lolium multiflorum* (LM), *Lolium multiflorum* – early sowing (LMES), *Secale cereale* (SC), *Trifolium incarnatum* (TI), *Phacelia tanacetifolia* (PT)) and their mixtures (*Lolium multiflorum* plus *Trifolium incarnatum* (LMTI)) were sown (the end of May, 3–4 leaves) using a four–row experimental (multifunctional = hoeing between maize rows, intercrop sowing, additional fertilisation of maize and a strip application of herbicide on the maize rows) testing machine (P&L Ltd.). Also, a mixed culture (maize plus *Lupinus albus* Zulika) was established (Kinze 3500 Interplant) in 2021; in this variant, two rows of maize alternated with two rows of lupine (0.375 m). All the variants were compared with two control variants (the variant with maize without any intercrop and black fallow). No damage to the crop by game was found in the course of the 2021vegetation season.

Measurements. The used field rainfall simulator (the rainfall simulation area = 21 m, with a rainfall

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intensity of 1.2 mm/min) plus the principles of measurement are described in different publications (e.g., Kabelka et al. 2019, 2021; Kincl et al. 2021). All the rainfall simulations were performed twice consecutively (the first measurement = 30 min of simulated rainfall on the soil with natural moisture; after a 15 min technological break, a second rainfall simulation for 15 min was performed on the same saturated soil). In the case of all the plots, the measurement was performed in the third cropstage period (the period from the end of the first month after sowing the maize to the end of second month after sowing the maize) and the fourth cropstage period (from the end of the third cropstage period to harvest) – see Janeček et al. (2002). The measurements were realised at the end of June and at the end of July when the maize was 0.5–0.9 m (5–7 leaves) or 2.3–3.4 m (12–13 leaves) tall in the years 2019 (plot 1), 2020 (plot 2) and 2021 (plot 3).

RESULTS AND DISCUSSION

In 2019, when the height of maize was 0.8–0.9 m (plot 1), the values of the soil loss were the lowest in the variants with *Lolium perenne* and *Lolium multiflorum* or *Triticum aestivum* (the first rainfall simulation = 30 min). These values were by 73.3% and 48.9% or 26% lower, respectively, compared with the variant with maize and without any intercrop. The highest values (by 89.3% or 42.7% higher compared with the variant without the intercrop) were found in case of the variants with *Trifolium repens* or *Festuca arundinacea*, respectively (see Figure 1). In the case of the second simulation (15 min), the values of the soil loss were the lowest in the variants with *Vicia villosa*, *Lolium multiflorum* and *Lolium perenne* (58.6%, 61.4% and 62.9%, respectively, of the value from the variant with the maize and without any intercrop) – see Figure 1. The highest soil loss (by 3.6% higher compared with the variant without the intercrops) was in the case of *Triticum aestivum*. The values of the soil loss were the highest in the variant with black fallow (both rainfall simulations). The values of the surface runoff (the year 2019, plot 1, 0.8–0.9 m, 6–7 leaves) were reduced by 66.2% (LPD) < 57.4% (VVL) < 45.2% (LMS) < 27% (TRK) < 22.8% (VVTS) < 1.1% (TRJ) or increased by 0.8% (FAF) compared to the control variant without the intercrops (the first rainfall simulation); in the case of the second simulation, the surface runoff decreased by 45.4% (VVL) < 26% (LMS) < 24.2% (LPD) < 20.7% (FAF) < 19.8% (VVTS) < 14.5% (TRK) < 13.2% (TRJ). The highest runoff was determined in the variant with the black fallow (both rainfall simulations). In 2019, when the height of the maize was 2.5–2.6 m (12–13 leaves) (plot 1), the value of the soil loss decreased in all the variants compared with the variant with the maize and without any intercrop (the first rainfall simulation) – see Figure 1. The soil loss was the lowest in the variants with a mixture of *Vicia villosa* plus the *Trifolium* hybrid diploid Soufflet Agro (36.3% of the value from the variant without the intercrops) and *Vicia villosa* (39.2%) or *Lolium perenne* (58.8%). The surface runoff was 58.4% (TRK), 75.6% (LMS and VVTS), 82.7% (LPD), 87.3% (VVL), 90.9% (FAF) or 139.1% (TRJ) of the value from the control plot. In the case of the second simulation (15 min), the lowest soil loss 25%, 35.5% or 56.6% was found

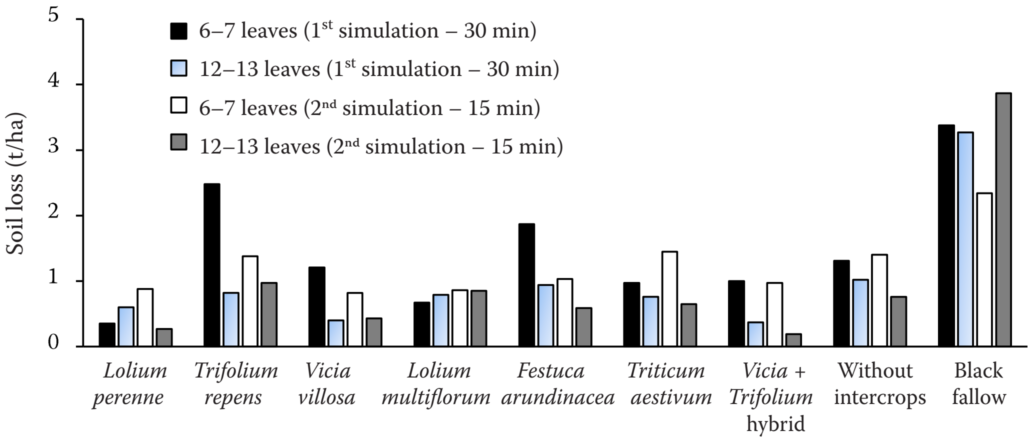

Figure 1. The values of the soil loss in the case of the individual intercrops (and *Vicia villosa* plus *Trifolium* hybrid diploid) in the silage maize in 2019

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in the variants with a mixture (*Vicia villosa* plus *Trifolium* hybrid diploid), *Lolium perenne* or *Vicia villosa*, respectively; in the variants with *Trifolium repens* and *Lolium multiflorum*, the loss was higher compared with the control (Figure 1). The surface runoff was 51.8% (LPD), 73.4% (VVL), 75.2% (TRK), 79.8% (VVTS), 89% (FAF), 97.7% (LMS) or 104.1% (TRJ) of the value from the control plot (maize). The soil loss and surface runoff were the highest on the black fallow plot (both rainfall simulations).

In 2020 (June 24–25, plot 2), the highest decrease in the soil loss was seen in the variant with *Trifolium incarnatum* (by 67.2% compared with the control), *Lolium multiflorum* + *Trifolium incarnatum* (54.7%) or *Secale cereale* (50%) – the first rainfall simulation (Figure 2). The surface runoff was in a range from 86.7% (LMTI) to 95.2% (LM) of the value from the control variant without any intercrop. Concerning the second simulation, the soil loss was the lowest in the variant with *Trifolium incarnatum* or *Phacelia tanacetifolia* (38.2% or 41.2% of the control, respectively); the highest loss (76.5%) was in the variants with *Lolium multiflorum* + *Trifolium incarnatum* and *Lolium multiflorum* + *Vicia pannonica* (Figure 2). The surface runoff values decreased by 7.6% (LM and SC) – 11.2% (PT) compared with the control without intercrops. On July 27–29 (2.3–2.4 m plus 12–13 leaves, plot 2), the soil loss and surface runoff were relatively low compared with the previous measurements in 2020. No soil loss was found in the variants with *Lolium multiflorum*, *Trifolium incarnatum*, *Phacelia tanacetifolia* or *Lolium multiflorum* + *Trifolium incarnatum* (the first rainfall simulation); in the variants with *Secale cereale* or *Lolium multiflorum* + *Vicia pannonica*, the soil loss was 14.3% of the control value (Figure 2). The surface runoff was 1.2% (LM), 3.1% (PT), 6.1% (LMTI), 12.3% (TI), 21.5% (LMVP) or 47.2% (LM) of the control value – the control value was lower (by 66%) compared with the control value from June. The use of the second simulation (15 min) showed no soil loss in the variants with *Trifolium incarnatum* or *Lolium multiflorum* + *Trifolium incarnatum*; in the variant with *Lolium multiflorum* + *Vicia pannonica*, the soil loss was 28.6% of the control value (Figure 2). The runoff values were 22.5% (LMTI), 35.5% (LM), 36% (PT), 43% (TI), 69% (SC) and 77.5% (LMVP) of the control value (maize). The soil loss and runoff in the variant with the black fallow were the same or similar (June) or higher (July) compared with the control without the intercrops (in 2020).

In 2021 (at the end of June, plot 3, 6–7 leaves), the lowest soil loss value (15.4% of that from the control variant) was in the mixed culture of maize plus *Lupinus albus* (the first rainfall simulation = 30 min); as shown in Figure 3, < 50% of the control was from the variants with *Lolium multiflorum* plus *Trifolium incarnatum* (23.1%), *Lolium multiflorum* – early sowing (30.8%) or *Trifolium incarnatum* (43.6%). The value of the surface runoff was 12.7% (maize plus *Lupinus albus*), 46.5% (LMTI), 63.7% (TI), 64.3% (LM), 66.2% (LMES), 74.5% (PT) or 79% (SC) of the value from the control plot without the intercrops. The use of intercrops (except for *Phacelia tanacetifolia*) or the

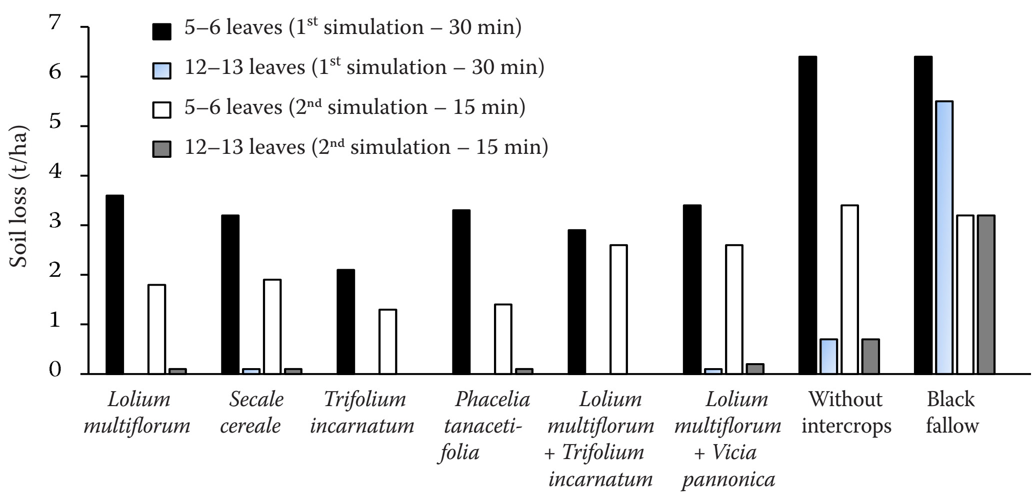

Figure 2. The values of the soil loss in the case of the individual intercrops (and *Lolium multiflorum* plus *Trifolium incarnatum* or *Lolium multiflorum* plus *Vicia pannonica*) in the silage maize in 2020

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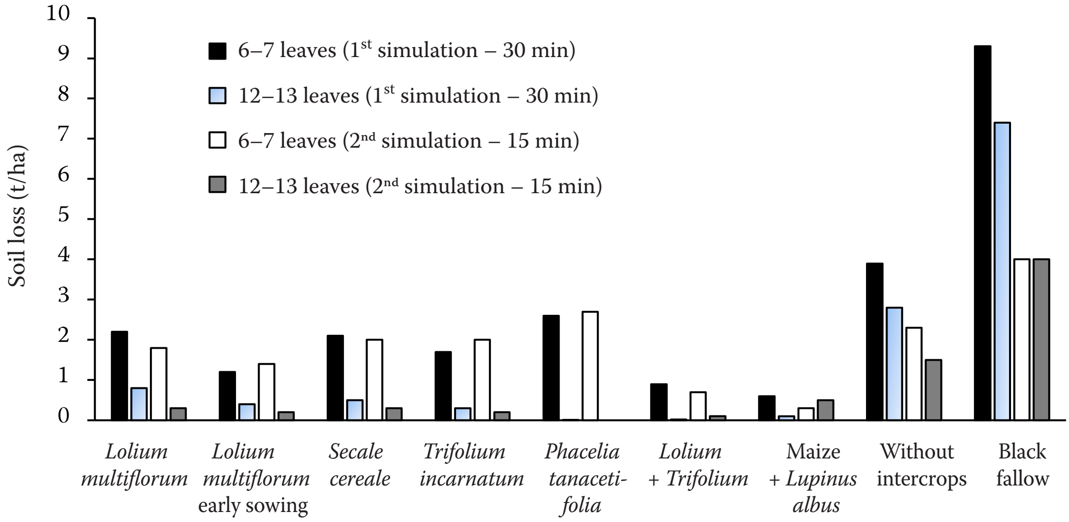

Figure 3. The values of the soil loss in the case of the individual intercrops (or *Lolium multiflorum* plus *Trifolium incarnatum*) in the silage maize or mixed culture (maize plus *Lupinus albus*) in 2021

mixed culture led to lower soil losses in the second simulation (Figure 3); 13% (or 30.4%) of the control value was found in the variant with maize plus *Lupinus albus* (or *Lolium multiflorum* plus *Trifolium incarnatum*). The runoff was 23% (maize plus *Lupinus albus*), 49.3% (LMTI), 80.4–84.5% (LM, TI, LMES, PT) or 89.9% (SC) of that from the control (maize without the intercrops). At the end of July (the year 2021, plot 3, 12–13 leaves), the soil loss values were lower compared with the previous measurements in 2021. As shown in Figure 3, the use of *Phacelia tanacetifolia* or *Lolium* plus *Trifolium* led to the lowest soil loss (< 1% of the value from the control plot). In the case of the maize plus lupine, the loss was 3.6% of the control value (30 min rainfall simulation). The runoff was 0.53% (PT), 10.6% (LMTI), 13.8% (maize plus lupine), 31.9% (TI), 41% (SC), 70.7% (LM) and 119% (LMES) of the control (maize). In the case of the second simulation, the soil loss ranged from 0 to 33.3% of the control; no soil loss (or 6.67% of the control value) was found out in the variant with *Phacelia tanacetifolia* (or *Lolium* plus *Trifolium*) – see Figure 3. The values of the runoff were 24.8% (PT), 47.7% (TI), 49% (LMTI), 54.2% (SC), 59.5% (LM), 69.3% (maize plus lupine) and 99.3% (LMES) of the control variant value. In 2021, the soil loss and runoff were higher in the variant with the black fallow compared with the control (maize). The results obtained in this study are also summarised in Table 1. As shown in Table 1, the highest reduction in the soil losses was in the case of the used grasses (June) or mixtures (July). Concerning the soil losses in the two months after the used cereal, clover, grass, and phacelia sowing in 2020–2021, see the fitted curves in Figure 4 and 5. As shown in Figure 4 and 5, the soil loss was 51.9, 38.2, 56.3 and 59.1% (*Secale cereale*, *Trifolium incarnatum*, *Lolium multiflorum* and *Phacelia tanacetifolia*, respectively) (30 min) and 71.4, 62.6, 65.6 and 79.3% (*Secale cereale*, *Trifolium incarnatum*, *Lolium multiflorum* and *Phacelia tanacetifolia*, respectively) (15 min) of the control (1 month after sowing); 2 months after sowing, the

Table 1. A summary of the results (soil losses) obtained in the period of 2019–2021

Crops	3rd cropstage period		4th cropstage period	
	1st simulation (30 min)	2nd simulation (15 min)	1st simulation (30 min)	2nd simulation (15 min)
Cereals	61	82	44	50
Clovers	56	71	42	64
Grasses	42	59	59	60
Mixtures	58	74	22	20

The values represent the amount of soil loss related to the control – maize without intercrops (%)

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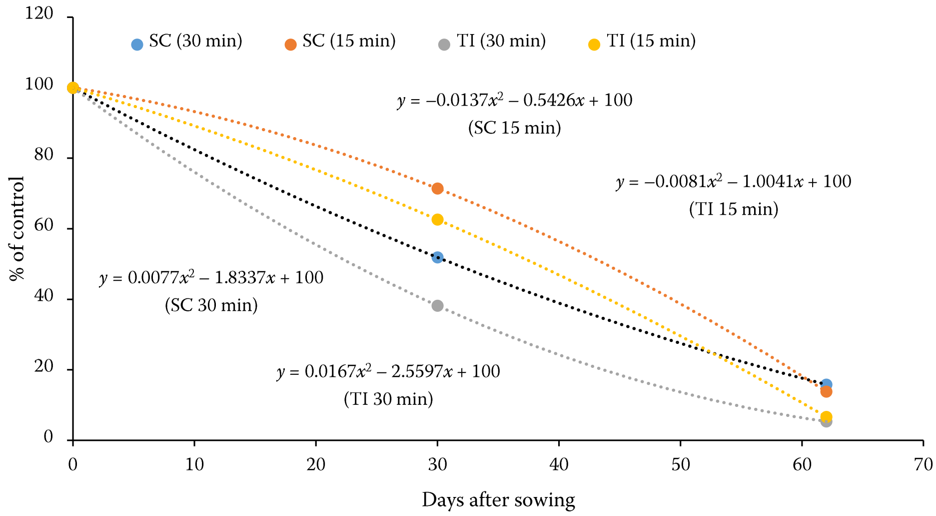

Figure 4. Soil losses in the two months after sowing the intercrops
SC – *Secale cereale*; TI – *Trifolium incarnatum*; 30 min – the first simulation; 15 min – the second simulation

soil losses were 15.8, 5.4, 14.3 and 0.18% (*Secale cereale*, *Trifolium incarnatum*, *Lolium multiflorum* and *Phacelia tanacetifolia*, respectively) (30 min) and 13.8, 6.7, 17.1 and 7.15% (*Secale cereale*, *Trifolium incarnatum*, *Lolium multiflorum* and *Phacelia tanacetifolia*, respectively) (15 min) of the control.

The results from 2019 indicate that the variant with *Lolium perenne* (*Lolium multiflorum* or *Vicia villosa*) was one of the most efficient (soil losses and surface runoff). Zhou and Shangguan (2008) studied the effects of canopies and living roots (*Lolium perenne* L.) on the sediment yields and runoff; the experiments (conducted at 5-week intervals) started 12 weeks after planting. The authors showed that the runoff and sediment yields decreased with the plant growth; the reduction in the runoff was lower than the sediment reduction. In our study, we also found higher reductions in the soil losses than in the runoff in the variant with *Lolium perenne*. According to Zhou and Shangguan (2008), both the roots and canopies contributed to the soil erosion reductions. Nevertheless, ryegrass canopies contributed more to the reduction in the runoff (the effect of interception plus prolonged infiltration time) and the roots

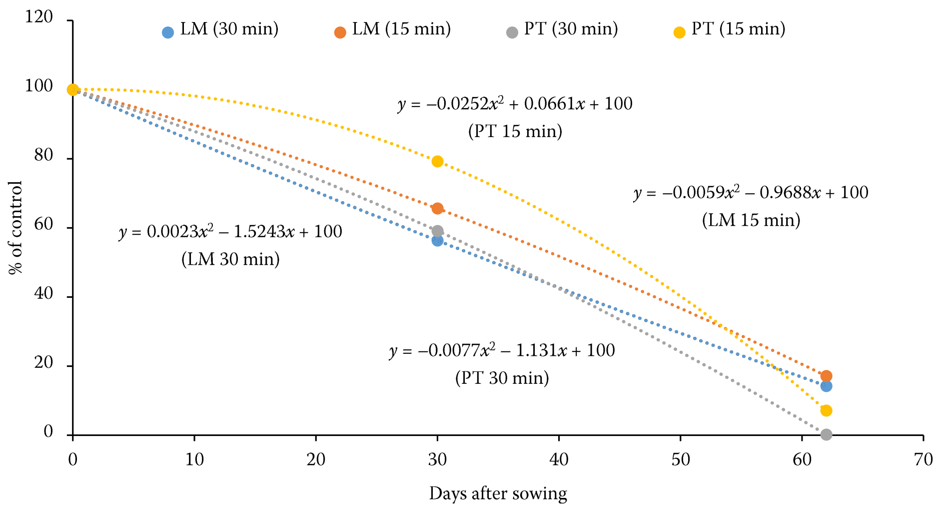

Figure 5. Soil losses in the two months after sowing the intercrops
LM – *Lolium multiflorum*; PT – *Phacelia tanacetifolia*; 30 min – the first simulation; 15 min – the second simulation

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contributed more to the reduction in the sediment yield because of their effect on the aggregate stability and soil anti-erodibility (Zhou & Shangguan 2008). Also, Katuwal et al. (2013), for example, studied the effects of *Lolium perenne* roots on the soil erosion. Their experiments were realised 4, 8 and 12 weeks after sowing. The authors, for example, state that the splash and wash erosion decreased exponentially with an increasing root density; no effects of the roots on the values of the bulk density and saturated hydraulic conductivity were observed. De Baets et al. (2011), for example, state plants with fine-branched root systems (such as *Lolium perenne*) are more effective in reducing the concentrated flow erosion rates compared with plants with tap root systems. The authors also mentioned differences in the aboveground biomass development of the studied plants (*Sinapis alba*, *Scale cereale*, *Phacelia tanacetifolia*, *Lolium perenne*, *Raphanus sativus* subsp. *oleiferus* or *Avena sativa*). Lin et al. (2019) stated that wheat (and stubble) was more effective in reducing the sediment loss than the runoff; wheat stubble reduced 35.7% of the runoff and 68.2% of the sediment loss compared with the bare soil. In this study, the use of wheat between maize rows mostly led to lower values in the soil losses (except for the second simulation – 0.8–0.9 m) and similar or higher values of surface runoff compared with the control variant (only maize without the intercrops). Huang et al. (2013) state that the vegetation cover (ryegrass, purple medic or spring wheat) decreased the runoff intensity compared with the bare ground. Sinohara et al. (2016) studied the effects of *Trifolium repens* and *Avena sativa* on the erosion; according to the authors, clover is commonly used to revegetate slopes. The authors found a significant effect of the aboveground biomass on the soil erosion (a negative relationship between the percent of vegetation cover and the soil erosion rate); nevertheless, plant roots had no effect on the erosion. In this study (in 2019), the values of the soil loss in the variant with *Trifolium repens* were mostly higher (or similar) compared with the variant with maize without the intercrops; in the case of the runoff, the values were lower compared with the control variant. Wall et al. (1991) studied the effects of intercropping red clover with silage maize on the soil erosion as well as the silage maize yields. The authors stated that the intercropping led to runoff and soil loss reductions without any significant effect on the silage maize yields. In this study, the variants with *Trifolium incarnatum*, *Phacelia tanacetifolia* or a mixed culture (maize plus lupine) were also among the most efficient; the different effects of *Phacelia tanacetifolia* on the aggregate size distribution and porosity were found to be dependent on the soil texture (Bacq-Labreuil et al. 2019). Jørgensen and Møller (2000) found that phacelia was one of the suitable crops for intercropping in maize as it suppressed weeds without any significant reductions in the maize yields. Concerning erosion, Malik et al. (2000) state that ryegrass and crimson clover were able to provide the best protection. Hůla et al. (2011) studied the effects of maize or oat cultivation (different variants) on the water runoff and soil losses during intensive rainfalls. As the authors presented in the figures, the loss of soil was mostly lower in the variant with triticale plus maize compared with maize (the variants with tillage plus seedbed preparation). As found in this study, the values of the soil losses and runoff were lower when the maize was > 2 m. Rain (or irrigation) partitioning by the maize (interception, throughfall and stemflow) varies across the crop growth stages (changes in the maximum water storage capacity, etc.) as reported by Ma et al. (2014), Zheng et al. (2018, 2021), Lin et al. (2020), etc.; the greatest effect on the splash erosion was reported in the case of throughfall. The width of the maize rows is also one of the factors influencing the throughfall and soil erosion. For example, Brant et al. (2017) proved the used 0.45 m wide silage maize rows (compared with 0.75 m rows) led to a decrease in the splash erosion in most of the studied years; the authors state positive correlations between the splash erosion values and the aerial precipitation (or throughfall). In the case of 0.75 m rows, the closest dependency between the throughfall and splash erosion was observed in the 125–250 mm zone of inter-rows. The authors also state that the values of the throughfall/aerial precipitation above the canopy ratio decreased from the centre of the inter-rows (the average value = 53.8%) toward the plant rows (the effect of water drip from leaves) – see also Martello et al. (2015); Brant et al. (2017) proved the ratio was influenced by both the plant length and the leaf area index. In case of maize, large fractions of rainfall can reach the soil as stemflow and concentrate in near-stem soils (e.g., Lin et al. 2020). The stemflow can enhance the erosion caused by the throughfall; it can lead to better crop growth or fertiliser losses (Parking & Codling 1990). The influence of the throughfall as well as the stemflow on the soil erosion (different

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physical processes) is discussed by Lin et al. (2020). As stated by Nazari et al. (2020) in the introductory part of their publication, 15–57% (and 35–84%) of the incident rainfall can reach the soil as throughfall (and stemflow) in the case of maize; some other authors reported 11.5–78% in the case of stemflow (Parking & Codling 1990; Martello et al. 2015; Liu et al. 2017 etc.). Non-uniform splash erosion determined mainly between the rows (maize) and directly under the leaf margins was reported by Ma et al. (2014); the effect of the rainfall intensity on the splash erosion differs according to the crop (see Ma et al. 2014). Haynes (1940) reported 7, 22 and 15% of precipitation intercepted by alfalfa, maize and soybeans, respectively.

CONCLUSION

From the intercrops established between the maize rows on May 27 (*Lolium perenne* L., *Trifolium repens* L., *Vicia villosa* Roth, *Lolium multiflorum* Lam., *Festuca arundinacea* Schreb., *Triticum aestivum* L. or the mixture of *Vicia villosa* plus *Trifolium* hybrid diploid), the variants with *Lolium perenne*, *Lolium multiflorum*, *Vicia villosa* or *Vicia villosa* plus the *Trifolium* hybrid diploid were the most efficient in the case of both the soil losses and runoff reductions in 2019. We proved our hypothesis and found higher reductions in the soil losses than in the runoff in the variant with *Lolium perenne*. *Triticum aestivum* between the maize rows mostly reduced the soil losses; the surface runoff was similar (or higher) compared with the control. Mostly higher (or similar) soil loss values and lower runoff values were seen in the variant with *Trifolium repens* compared with the control. In 2020, the variants with *Lolium multiflorum*, *Secale cereale* L., *Trifolium incarnatum* L., *Phacelia tanacetifolia* Benth., *Lolium multiflorum* plus *Trifolium incarnatum*, *Lolium multiflorum* plus *Vicia pannonica* Crantz were established; the obtained results indicate that *Trifolium incarnatum*, the mixture (*Lolium multiflorum* plus *Trifolium incarnatum*) and *Phacelia tanacetifolia* (the year 2020) had the most positive effect. From the variants established in 2021 (*Lolium multiflorum*, *Lolium multiflorum* – early sowing, *Secale cereale*, *Trifolium incarnatum*, *Phacelia tanacetifolia*, *Lolium multiflorum* plus *Trifolium incarnatum*, the mixed culture = maize plus *Lupinus albus* L.), the mixture of *Lolium multiflorum* plus *Trifolium incarnatum* and the mixed culture (maize plus *Lupinus albus*) were the most efficient. The soil losses and surface runoff were lower when the maize was > 2 m compared with the maize < 1 m. The summary of the results obtained in the period 2019–2021 showed the grasses were the most efficient (soil losses) when the maize was < 1 m and the mixtures were most efficient when the maize was > 2 m.

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