https://doi.org/10.17221/43/2024-SWR

Impact of intercrops on soil loss and surface runoff from sloping maize fields

Jan Gregar[1]*, *Jan Petrů*[1], *Jana Kalibová*[1], *Věra Ürge*[1], *David Kincl*[1,2], *Jan Vopravil*[1,2]

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

**Corresponding author: gregarj@fzp.czu.cz*

Citation: Gregar J., Petrů J., Kalibová J., Ürge V., Kincl D., Vopravil J. (2024): Impact of intercrops on soil loss and surface runoff from sloping maize fields. Soil & Water Res., 19: 168–175.

Abstract: Water erosion poses a significant threat to more than 50% of agricultural land in the Czech Republic. Maize (*Zea mays* L.) is particularly susceptible to soil erosion, with the bare soil space between maize rows exposed to erosive agents. Intercropping has emerged as a potential solution to mitigate soil erosion risks in maize cultivation. A series of soil erosion field experiments were conducted from 2022 to 2023 using natural rainfall to investigate the influence of selected intercrop mixtures during the growing season on sediment yields and surface runoff volume. The results revealed a gradual decrease in surface runoff volume and sediment yields over the growing season. Significantly reduced surface runoff volume and soil loss were observed in two tested intercropped plots S2 – rye (*Secale cereale*) and incarnate clover (*Trifolium incarnatum*); S3 – ryegrass only (*Lolium*)), compared to a control plot managed conventionally with maize (S1). Surface runoff volume and soil loss from S2 and S3 reached 2.57–43.5% and 1.26–11.65% of the control plot, respectively. These findings highlight the soil conservation effect of intercrop technologies (S2 and S3) in mitigating soil erosion in maize cultivation. The importance of vegetation cover in reducing soil erosion intensified over time. Intercropping holds promise as a sustainable agricultural management strategy for sloping maize fields.

Keywords: agricultural management; corn; maize; soil conservation; soil erosion; water erosion

Soil erosion in agricultural areas poses significant environmental challenges, impacting economic development and food security (Luo et al. 2019). Maize cultivation, a substantial portion of arable land in the Czech Republic, faces challenges due to its susceptibility to erosion, especially on sloping lands, exacerbated by the increase in maize cultivation for biomass fuel production (Martinát et al. 2016). Long-term shallow tillage has further degraded soil structure, hindering maize yield enhancement efforts in various countries (Luo et al. 2019; Yu et al. 2023). Extensive research has explored the influence of different tillage practices on soil hydraulic properties under various conditions, including maize cultivation (Strudley et al. 2008; Alletto et al. 2015; Villarreal et al. 2017; Skaalsveen et al. 2019; Šípek et al. 2019; Kabelka et al. 2021; Kincl et al. 2022). To mitigate water erosion, strategies involve reducing the kinetic energy of raindrops and preventing surface runoff formation (Kalibová et al. 2016; Petrů

Supported by National Agricultural Research Agency – Research Project No. QK22020053 „Conditions of growing maize on highly erosive threatened soil".

https://doi.org/10.17221/43/2024-SWR

& Kalibová 2018). Alternative cultivation practices such as residue application, crop cover, or reduced tillage have been effective in minimizing negative impacts (Josa & Hereter 2005; Vlček et al. 2022). Living plants and roots contribute to runoff and erosion reduction (Zhou & Shangguan 2008). Implementing reduced tillage, narrow sowing rows, or cover crops in conventionally tilled plots has proven beneficial for erosion mitigation, reducing flash flood occurrences, and promoting groundwater recharge (Malik et al. 2000; Hangen et al. 2002; Vlček et al. 2022).

MATERIAL AND METHODS

In order to investigate changes in surface runoff volume and sediment yield across various intercropped maize fields in the Czech Republic, three experimental plots were set up in an erosion-threatened area within the municipality of Petrovice, Skoupý cadastral territory (772241), Příbram district (49.5765108N, 14.3537778E). This location was selected due to its suitability for trial plots, situated directly on a slope with the ability to delineate equal-sized areas oriented at approximately a 1° slope to the contours. Additionally, the site allows for surface drainage towards the lowest point of the plot, where the sedimentation pit is situated (Figure 1).

The first plot served as a control, sown conventionally with maize (scenario S1). The second (S2) and third (S3) plots employed soil conservation technologies during maize sowing. In 2022, seeding occurred on May 14th using a Vaderstad Tempo V6 seeder (Väderstad, Sweden), employing CAMPINOS FAO 200 variety at a seeding rate of 90 000 seeds/ha and a depth of 5 cm. Sowing followed a fallow period, with the control plot conventionally prepared through ploughing and compacting. The experimental plots utilized the strip-till method with the SLY Stripcat II (Agrisem, France) ploughing machine. These plots were intercropped with rye (*Secale cereale*) and incarnate clover (*Trifolium incarnatum)* (scenario S2), and ryegrass only (*Lolium*) (scenario S3). Winter barley (*Hordeum vulgare*) served as a pre-crop on plots S2 and S3 (Table 1). Chemical protection included Maister power (1.5 L/ha) and Kelvin duo + Slalom (90 g/ha + 0.3 L/ha), with urea (200 kg/ha) and Explorer (100 kg per ha) for fertilization. Management in 2023 mirrored that of 2022 to maintain consistent conditions.

Each plot, measuring 70 × 80 m, was positioned adjacent to each other on the slope base on the pre-

Figure 1. Study area and experimental plot locations

https://doi.org/10.17221/43/2024-SWR

Table 1. Overview of the crops used in the different experimental scenarios, including the main crop, intercrops and pre-crops

Plot	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Pre-crop		winter barley (*Hordeum vulgare*)	winter barley (*Hordeum vulgare*)
Main crop	maize (*Zea mays* L.)	maize (*Zea mays* L.)	maize (*Zea mays* L.)
Intercrop		rye (*Secale cereale*)	ryegrass (*Lolium*)
Intercrop		incarnate clover (*trifolium incarnatum*)	

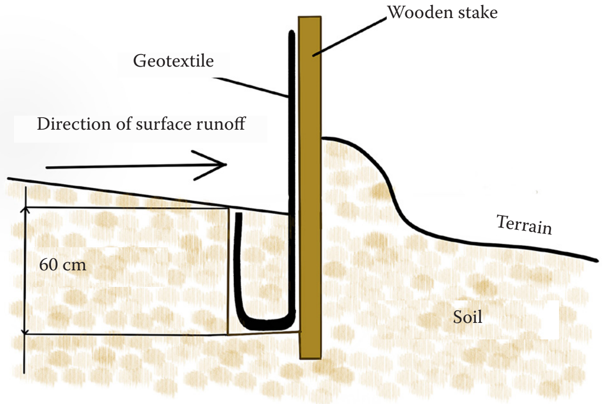

Figure 2. Experimental plot delimitation by a silt-fence technology in order to divert the surface runoff to Parshall flumes

scribed contour line orientation (Figure 1). The slope has a gradient of 17–29 per cent, and a trench has been created above the site to prevent surface runoff from the land above the measured area. They were demarcated at the lower end by a silt fence (Figure 2) to channel surface runoff into sedimentation pools (Figure 3). Rainfall was naturally monitored on-site using an ombrograph (MR Typ2, Ekotechnika, CzechRepublic), while surface runoff was tracked via Parshall flumes (Figure 4). Sediment levels were monitored in sedimentation pools situated at the lowest point of the parcels. Data recording utilized a telemetry station (Figure 5).

After each significant rainfall event (resulting in a minimum surface runoff measured by the Parshall flume of 0.5 mm), the sediment was gathered from the sedimentation pools and weighed. Excess water was permitted to evaporate, and the sediment was then reweighed. Following this, a sample was extracted for laboratory analysis to determine the percentage humidity according to the ASTM D2216-19 standard. By subtracting the water percentage from the sample weight, the total weight of sediment col-

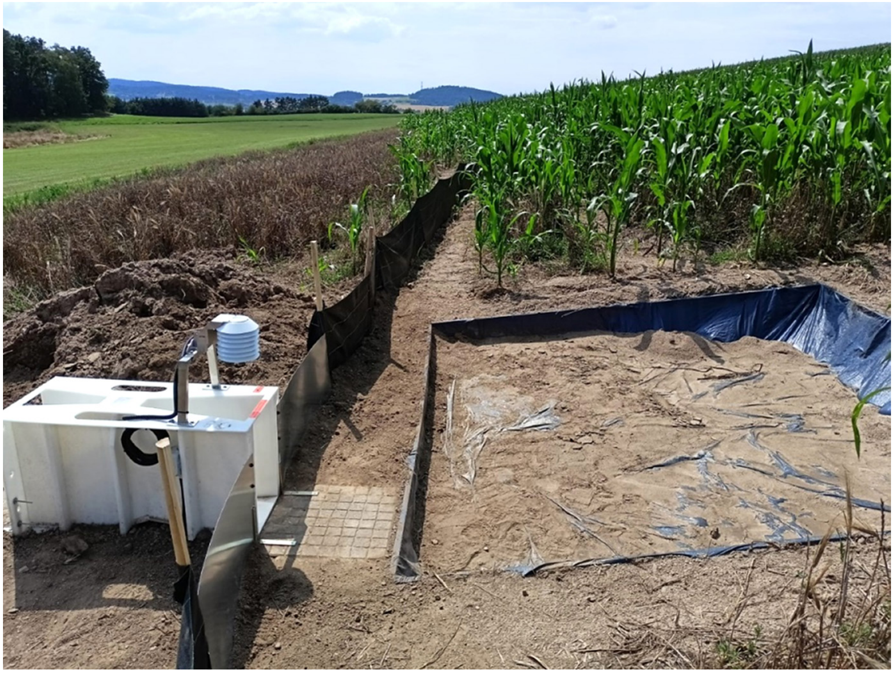

Figure 3. Sedimentation pool with installed Parshall flume

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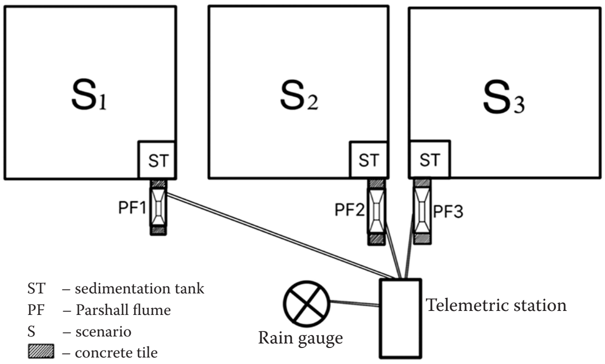

Figure 4. Scheme of technological equipment of the experimental site
For crops used in plots S1, S2 and S3 see Table 1

lected from the pool could be ascertained. Rainfall measurements in millimetres were captured by the ombrograph, while the runoff rate and volume were monitored by the Parshall flume. All data were seamlessly stored and processed online through the telemetry station. In total, three rainfall-runoff events were documented, one in 2022 and two in 2023. The objective of the statistical analysis was to assess the correlation between soil erosion and various soil cultivation methods. Upon testing the data for normality and homogeneity, neither normal distribution nor variance homogeneity was established. Hence, it was imperative to proceed with a nonparametric Kruskal-Wallis test.

Figure 5. Telemetry station for data recording

RESULTS AND DISCUSSION

Sediment yields from three natural rainfall events for three tested scenarios S1 – conventional treatment, S2 – rye and incarnate clover, S3 – ryegrass only are visible in Table 2. Sediment yield is expressed as a percentage of the control area S1 in Table 3. Table 4 shows a summary of the soil loss records provided by Table 2 and confirms the presumption that average soil loss is lower when intercropping is used than with conventional cultivation.

The boxplot (Figure 6) shows soil losses for individual scenarios. It is evident from the boxplot that the highest

Table 2. Sediment yields from natural rainfall

Rainfall event		Sediment yield (kg)		
		27.06.2023	19.07.2023	19.8.2022
Scenario	S1	1 344	330	519.5
	S2	34.5	65.5	226
	S3	17	7.2	60.5

For crops used in plots S1, S2 and S3 see Table 1

Table 3. Sediment yield expressed as a percentage of the control area S1

Rainfall event		Sediment yield (% of S1)		
		27.06.2023	19.07.2023	19.8.2022
Scenario	S1	100	100	100
	S2	2.57	19.85	43.5
	S3	1.26	2.18	11.65

For crops used in plots S1, S2 and S3 see Table 1

Table 4. Summary of the soil loss records

	Soil loss (kg)		
	S1	S2	S3
Minimum	330.00	34.50	7.20
1st quartile	424.80	50.00	12.10
Mean	731.20	108.70	28.23
3rd quartile	931.80	145.80	38.75
Maximum	1 344.00	226.00	60.50

For crops used in plots S1, S2 and S3 see Table 1

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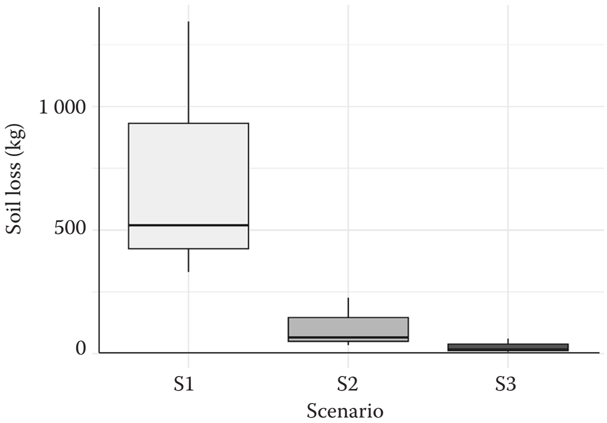

Figure 6. Soil losses for individual scenarios
For crops used in plots S1, S2 and S3 see Table 1

soil loss was recorded from S1 (conventional cultivation – control plot). Scenarios S2 and S3 perform less variance and mean soil loss compared to S1. Figure 7 illustrates the progression of soil loss during the growing season, showing that scenarios S2 and S3 with intercrops (*Secale cereale*, *Trifolium incarnatum*, and *Lolium*) significantly reduce erosion compared to conventional maize cultivation (S1). Figure 8 shows the percentage of soil loss during the growing season, confirming the significance of intercrops in reducing soil erosion. Figure 9 displays an example of the relationship between rainfall events and corresponding surface runoff over time. It illustrates how changes in precipitation levels influence runoff volumes, providing insights into the effectiveness of soil conservation practices.

The Kruskal-Wallis test revealed a statistically significant difference among the different soil cultivation technologies (S1–S3). Subsequently, the Dunn test was employed as a post-hoc analysis, utilizing the same parameters as the Kruskal-Wallis test to assess differences between individual groups. Notably, no statistically significant differences were detected between S2 and S3, while a significant difference was observed between S1 and S3.

Control (S1) exhibited the highest surface runoff and erosion rates, highlighting the necessity for intensive soil conservation efforts.

S2 (rye and crimson clover) demonstrated reduced soil loss compared to the control.

S3 (buckwheat) slightly outperformed S2 in terms of soil loss reduction.

Various studies conducted in different regions highlight the importance of sustainable soil management practices in safeguarding soil health and enhancing agricultural sustainability. Deng et al. (2024) investigated the impact of different tillage practices on surface runoff and soil erodibility, emphasizing the significance of downslope ridge planting and

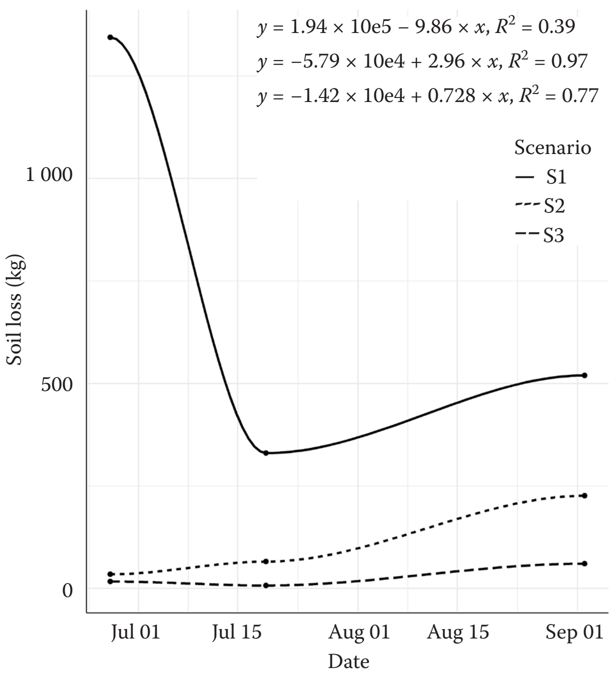

Figure 7. The course of soil loss within the vegetation period
For crops used in plots S1, S2 and S3 see Table 1

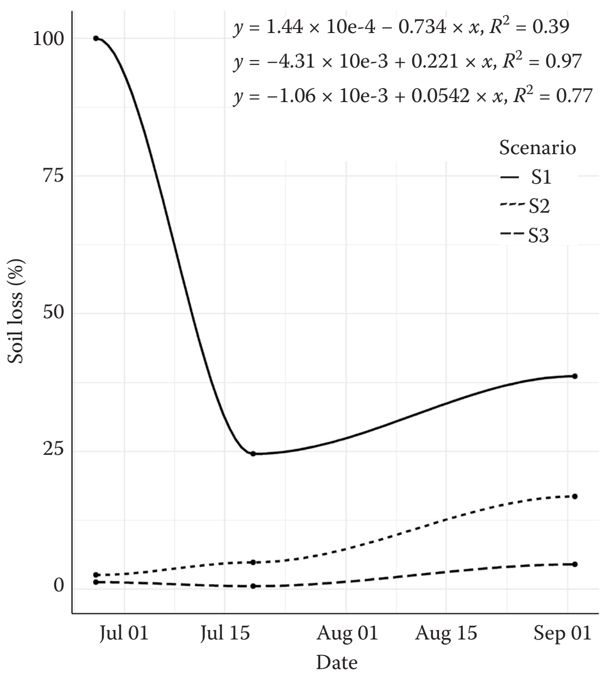

Figure 8. Soil loss in % during vegetation periods
For crops used in plots S1, S2 and S3 see Table 1

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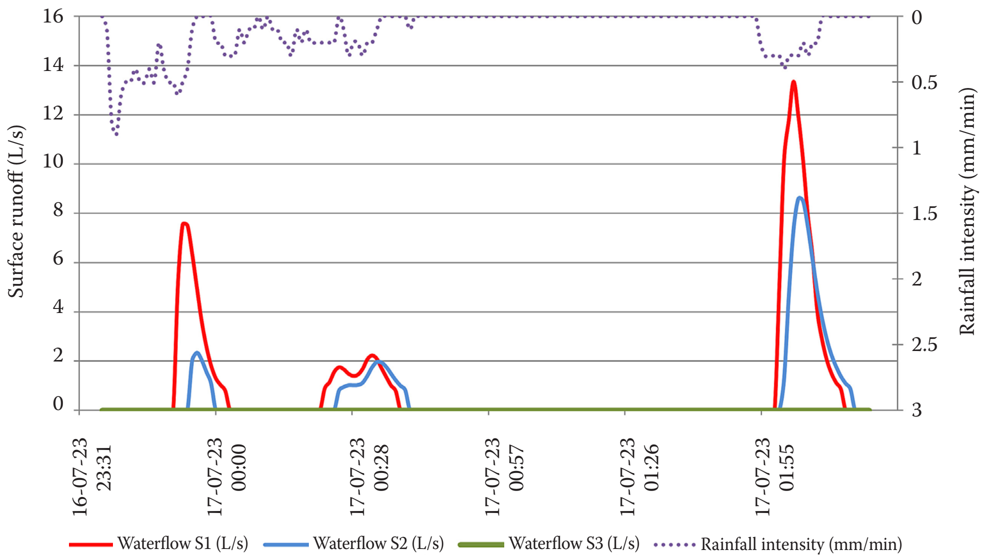

Figure 9. Example of temporal analysis of precipitation and runoff dynamics
For crops used in plots S1, S2 and S3 see Table 1

cross ridge planting in mitigating nitrogen (N) losses in sloping farmlands with yellow soil (He et al. 2022). The findings suggest that controlling N losses from sloping farmlands could effectively reduce non-point source pollution, contributing to the sustainable utilization of such areas. Similarly, Fan et al. (2016) explored the benefits of intercropping maize and potato in reducing surface runoff and soil evaporation on sloping land in China. Their results demonstrate that intercropping significantly decreases accumulative runoff and soil evaporation while increasing soil moisture content and transpiration, thereby enhancing soil moisture retention and crop yield. The capacity of crops to reduce runoff and sediment increases with crop growth and generally peak at the late growth stage (Engel et al. 2009; Chen et al. 2010; Wang et al. 2019). Carvalho et al. (2015) reported that corn development stages reduced surface runoff losses by 0.6%, 7.8% and 51.0% compared with exposed soil, respectively at 30, 60 and 75 days after planting corn rows along contour lines.

Blaise et al. (2021), Fan et al. (2016) and Ibitoye et al. (2024) further emphasize the effectiveness of intercropping and mulching practices in reducing soil erosion and improving soil structure in rain-dependent cotton cultivation in India and Africa, respectively. Intercropping, combined with mulching, not only reduces soil loss but also enhances soil productivity and water retention capacity, thereby promoting sustainable agricultural practices (Javůrek et al. 2008). Moreover, Zhang et al. (2021) highlight the potential of integrated fertilizer management, including biochar and organic fertilizers, in maintaining high farmland productivity while mitigating environmental impacts. By optimizing nutrient regimes and preventing nutrient losses through runoff, such practices contribute to sustainable agricultural development and environmental conservation. Overall, the findings from these studies underscore the importance of adopting sustainable soil management practices, such as conservation tillage, intercropping, and integrated fertilizer management, in mitigating soil erosion, reducing non-point source pollution, and enhancing agricultural sustainability on sloping farmlands worldwide. These practices not only protect soil resources but also contribute to improved water quality, increased crop yield, and long-term agricultural resilience in the face of climate change challenges.

CONCLUSION

In conclusion, this study highlights the effectiveness of intercropping as a sustainable agricultural management strategy for mitigating soil erosion on sloping maize fields. The research clearly demonstrates that intercropping with suitable species such as rye (*Secale cereale*), incarnate clover (*Trifolium incarnatum*), and ryegrass (*Lolium*) results in a significant reduction in both surface runoff volume and soil loss compared to conventional maize cultivation methods. The findings underscore the critical role

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of vegetative cover in minimizing soil erosion. Specifically, Figure 7 illustrates the progression of soil loss over the growing season, revealing that scenarios S2 and S3 with intercrops substantially decrease erosion compared to the control plot (S1). Figure 8 further quantifies the percentage of soil loss during the growing season, reinforcing the value of intercrops in controlling soil erosion. Although the study was based on only three significant erosion events, predictive models indicate a positive impact of intercropping on reducing erosion. These preliminary results suggest that implementing intercrops not only addresses immediate erosion concerns but also contributes to long-term soil health and stability. This approach offers a viable solution for enhancing soil resilience and reducing sediment yield on sloping agricultural lands, thereby promoting sustainable farming practices. However, the findings need to be further validated through additional research efforts. Overall, the evidence supports the adoption of intercropping technologies as an integral component of soil management strategies. By integrating appropriate intercrop species, farmers can effectively combat soil erosion and improve soil conservation. These findings advocate for the broader application of intercropping as a means to advance soil health, ensure sustainable agricultural productivity, and address the challenges posed by erosion in vulnerable landscapes.

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Received: May 2, 2024
Accepted: August 28, 2024
Published online: September 9, 2024