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The Effect of Reservoir Cultivation on Conventional Maize in Sandy-Loam Soil

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Abstract: Maize grown on sloped areas is susceptible to surface runoff and soil erosion, especially if traditional technology with tillage is employed. As a result, other solutions are being sought that address this risk and are acceptable to farmers. The combination of inter-row cultivation with the formation of small reservoirs appears to be a suitable alternative solution applicable in traditional corn cultivation. In the years 2020, 2021, and 2022, three plots of land in southern Bohemia, Czech Republic, were selected for testing, on which this approach was tested. During the field experiments, three variants were compared each year: inter-row cultivation with reservoirs, inter-row cultivation only, and a control without any mechanical intervention. All variants were subjected to rain simulation, from which the surface runoff was evaluated. The highest retention of runoff was manifested with reservoir cultivation by 2.4–4.2 min, compared to the cultivated variant, and 2–4.2 min compared to the control. This result would correspond to a difference of 5.7–9.8 mm retained precipitation and 4.6 to 7.3 mm, respectively. The hydraulic conductivity of the soil was evaluated after canopy closure. The lowest values were invariably reached in the reservoirs, up to 88% lower than with the cultivated variant and 79% lower than the control. The fresh matter yield of forage maize was shown to be inconclusively higher by up to 10% in 2020 and 2022 in cultivation with reservoirs. However, the dry matter yield was always lower in the variant with reservoirs compared to inter-row cultivation only. Overall, reservoir cultivation appears to be an effective method for the retention of rainwater on agricultural land with a slope up to 6° without a significant effect on the yield of maize.

Keywords: diking; tied ridging; surface runoff; inter-row cultivation; corn; erosion; *Zea mays*; yield

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1. Introduction

Currently, mitigating the negative impact of growing wide-row crops on sloping production areas is an ongoing issue due to the danger of excess surface runoff and soil loss [1], and not only in the Czech Republic. Maize or potatoes grown on sloping agricultural land create the highest level of soil erosion. In the Czech Republic, the growing areas planted with maize have increased significantly during the development of biogas production, for which corn silage, in addition to being animal feed, has become one of the main sources of biomass [2].

Surface runoff, together with erosion, represents an environmental risk in crop production, since it results in soil degradation [3], i.e., the loss of the fertile soil layer, together with the loss of organic matter and nutrients and thus a reduction in crop production efficiency. Susceptibility of soils to surface runoff and thus increased water erosion is enabled on sloping land, and it is strongly influenced by the steepness of the slope. Runoff is then more likely to occur when a soil crust forms on the surface after rainfall [4]. As a result, the structure of the soil surface is disturbed by the movement of particles, which affects the soil's infiltration capability and consequently the efficient use of water and nutrients by the plants [5].

In the Czech Republic, roughly 50% of all agricultural soils are at risk of erosion [6,7]. Soil loss is mainly caused by rainfall. The highest incidence of erosion-causing rains in the Czech Republic occurs from April to August, which essentially coincides with the growing season of maize. Maize grown for silage is usually sown during April at the earliest, and the harvest begins usually during September.

Traditionally, maize grown by conventional methods in the Czech Republic will include fertilization by manure, which will be incorporated by plough. In the spring, this step is followed by pre-drilling preparation (planing and cultivation). After drilling, the soil is typically treated with pre-emergent herbicides, or, alternatively, inter-row cultivation is carried out after the plants emerge to reduce weeds [8]. When performed correctly, inter-row cultivation can reduce surface runoff and erosion [9]. Of course, reducing runoff is also important for maintaining good yields in rain-fed maize, especially with the shift to more sparse but extreme rainfall events [10].

Unfortunately, the traditional way of growing maize on slopes does not provide sufficient soil protection. Therefore, there is a need to find and implement alternative methods that are also acceptable to farmers [6,11].

To decrease the erosion risk, many protective measures have been tested [1,12,13] that should prevent the removal of topsoil from agricultural land. The conventional technology of growing corn can be replaced or supplemented by alternative technologies: e.g., strip-till technology, effective on sloping land [14], which, however, requires different technical equipment. Another approach is to use inter-row cover crops [15] or even to grow maize in ridges [16]. However, these alternatives are hard to combine with the conventional approach and need additional equipment.

Another soil protection approach for wide-row crops is to use reservoir cultivation [17]. Reservoir cultivation technologies originally came from the USA, where first, irrigation water was to be retained on land using a system of reservoirs or micro-basins [18,19]. Later, the system of reservoirs or dykes was used to capture precipitation and soil runoff during the cultivation of wide-row plants. The creation of reservoirs, usually called diking or tied-ridging, has been fairly widely used in the cultivation of potatoes in Central Europe in recent years [20]. For maize, however, the use of this technology in production has not been seen in the Czech Republic.

The main working principles behind reservoir creation may depend on a specific machine. Some achieve it by simply pushing an implement into the soil; some scoop soil using a blade pulled through it [21]. Some use a combination of these principles, as is the case with traditional dikers with paddle wheels [22]. This method creates retention spaces in the soil that are able to retain runoff and eroded soil up to a certain level of rainfall. During heavy rains, however, there is a possibility of the dikes between reservoirs failing, which can potentially cause a cascade reaction and result in increased erosion [23]. At the bottom of the reservoirs, crust will form, and sometimes algae can grow, which may cause a gradual deterioration of the infiltration capacity at their bottom. At the same time, it has already been proven in previous studies that the formation of dykes may have the effect of an increased yield [23,24].

Machines for the creation of reservoirs or dikes are often designed to be used in a separate operation, which is counterproductive against minimizing both costs and field traffic. The trend of combining field operations is strongly preferred for reducing the negative effects of traffic on soil compaction [25–27] and for reducing energy consumption [28]. From this preference follows the necessity of merging the reservoir formation with another operation, e.g., ideally, inter-row cultivation.

The aim of this study was to evaluate the effectiveness of inter-row reservoirs introduced within the conventional maize-growing system, i.e., in combination with inter-row cultivation, within the conditions of the Czech Republic. The effect of reservoirs on surface runoff and on maize yields was followed.

2. Materials and Methods

2.1. Design of Field Trials

The testing took place on sloping plots of land located in the area of southern Bohemia on production plots sown with maize (*Zea mays* L.) with a seeding rate of 80,000 grains/ha and a row spacing of 0.75 m. Every year, there were three variants of approx. 100 m^2 each. Each variant was established in three repetitions. The first variant was a control (C), which was left without any further intervention. In the second variant (CU), the inter-rows were cultivated to a depth of 8 cm. The third variant was reservoir cultivation (RC), in which the inter-rows were cultivated as in CU, and additionally, reservoirs with a volume of approx. 2 L were established to the depth of cultivation and were arranged as in Figure 1. For all repetitions, the variants were established on a site with a slope as close as possible to 5° and separated from the rest of the production area so that they would not be affected by runoff from it. Establishment of the variants, i.e., CU and RC, was carried out at times that would be viable based on the conditions in each given year. Testing took place over three consequential years, 2020, 2021, and 2022. Maize rows were always drilled across the predominant slope. For testing purposes, both cultivation and reservoir cultivation were performed only once on the respective variants in each season on the same date.

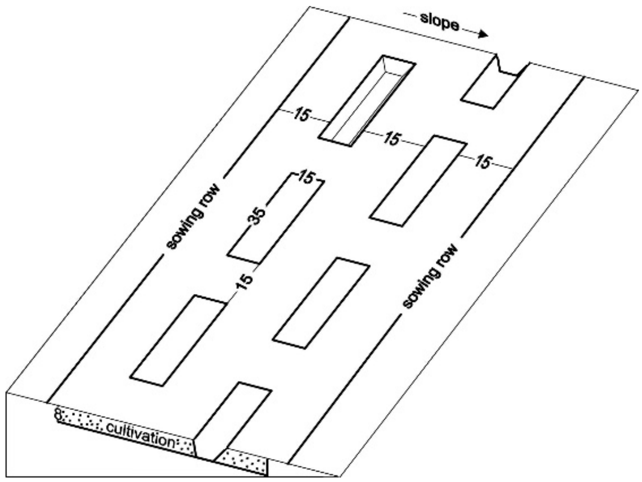

Figure 1. Placement of reservoirs in the inter-row.

2.2. Trial Sites

2020

The land was exposed to the south with an average slope of 4.12° at an altitude of 481 m.a.s.l.; the soil type was modal eubasic cambisol. The pre-crop on the plot in 2019 was spring wheat with straw collection. Next, the plot was disked, followed by an application of manure and deep ploughing. In the spring of 2020, planing and pre-drill preparation followed. On 21 April 2020, maize, Bigbeat variety (FAO 320), was drilled with sub-surface fertilization (Amofos, 150 kg/ha). On 27 April 2020, the plot was treated with pre-emergent herbicide and fertilized with DAM 390. The variants were established on 29 May 2020 The harvest took place on 4 October 2020.

2021

The land was exposed to the north with an average slope of 3.86° at an altitude of 438 m. The soil type was modal eubasic cambisol. The pre-crop on the plot in 2020 was winter wheat with straw collection. Next, disking and application of manure were carried out, followed by deep ploughing. In the spring of 2021, skidding and pre-drill preparation with a combinator machine followed. On 22 April 2021, maize, Zelstar variety (FAO 330), was drilled with subsurface fertilization (NP2614, 200 kg/ha). The plot was treated with pre-emergent herbicide and fertilized with DAM 390 on 29 April 2021. Variants were established on 1 June 2021. The harvest took place on 14 October 2021.

2022

The plot was on a southern slope with an average inclination of 2.91° at an altitude of 435 m.a.s.l. The soil type was modal cambisol. The pre-crop on the plot in 2021 was winter wheat with straw collection. Next, the soil was disked, and manure was applied, followed by ploughing. In 2022, planing and pre-drill preparation was carried out with a combinator. On 30 April 2022, again, silage maize, Zelstar variety (FAO 330), was drilled with fertilization (NPK, 200 kg/ha). The plot was treated with pre-emergent herbicide on 3 May 2022 and fertilized with DAM 390. Variants were established on 2 June 2022. The harvest took place on 26 September 2022.

2.3. Weather Monitoring

During the season, the air temperature and rainfall were monitored at intervals of 15 min using a meteorological station using the shuttle rain gauge made by Libor Daneš (Louňovice, Czechia) with an accuracy of 0.2 mm. Data were recorded by a DN4000 data logger with data transfer via GPRS to a server.

2.4. Rain Simulation

On each variant with a slope between 3.8° and 6°, three plots of 2.1 × 1.4 m were fenced off. Collectors were placed on the lower side of the bed to direct the surface runoff into containers placed on tensometric scales. The weight of the water was recorded at 5 s intervals. The equipment described in [29], equipped with Lechler nozzles with a circular spray pattern, was used to sprinkle each bounded area. The height of the nozzles above the soil surface was 0.8 m, and the spray pressure was 45 kPa. The rain intensity was maintained at 2.35 mm/min over the plots during the whole test.

The slope of the soil surface was measured on the plots with an accuracy of 0.1°. The average slope was found from three repeated measurements using a 2 m long ruler.

2.5. Physical Properties of Soil

Before the rain simulation, disturbed soil samples were taken on the test area for grain size and soil moisture with a groove probe at a depth of 0–250 mm, and intact soil samples were taken at depths of 50–100, 100–150, and 150–200 mm for a total of 10 repetitions. The granular composition of the soil was determined by the densitometric method. The soil type was classified according to the representation of the proportion of grains smaller than 0.01 mm. Physical characteristics were determined using intact soil samples, from which the dry bulk density or total porosity were determined; see Table 1.

Table 1. Soil characteristics of the topsoil.

Year	Depth (cm)	Soil Type	Clay (% wt.)	Silt (% wt.)	Sand (% wt.)	Dry Bulk Density (g/cm^3)	Porosity(%)	Slope for Rain Simulations (°)
2020	0–25	sandy loam–loam	11.8	29.3	58.9	1.36	48.5	4.7–5.9
2021	0–25	sandy loam–loam	14.3	29.1	56.6	1.52	41.2	3.8–5.8
2022	0–25	sandy loam–loam	22.5	49.3	28.2	1.55	41.9	4.2–5.8

2.6. Soil Hydraulic Conductivity Measurement

Determination of saturated hydraulic conductivity (mm/h) was carried out using the single ring infiltration method [30–32]. Before and after infiltration of the set amount of water, 2 L, the volumetric humidity inside the cylinder was measured 3 times using the moisture probe ML3 Theta Probe (Delta-T Devices, Cambridge, UK).

2.7. Soil Surface Roughness

Surface roughness was determined using a traditional method [33] applied on a 3D surface model of soil obtained by a photogrammetric method using the 3DF Zephyr program (Verona, Italy). First, the surface was scanned with a camera, and a 3D model was built [34]; then, the length of the surface roughness was determined in 3 sections.

2.8. Maize Yield

Total yields of fresh and dry matter of the above-ground biomass were compared between the variants. From each variant, five different rows of 2 m length were taken. Plant height and fresh yield were measured immediately after sampling before mechanical harvesting. In order to exclude the influence of the selected variety, soil conditions, and meteorological conditions during the season, yield parameters were expressed in percentage values related to the control variant for each given year. The yield of dry matter was calculated using laboratory-determined moisture from individual rows. Drying took place at a temperature of 105 °C until constant weight.

2.9. Data Curation and Statistical Analysis

The primary data organization and evaluation were carried out in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA), and the statistical analyses were performed in TIBCO Statistica 14.0 (TIBCO Software Inc., Palo Alto, CA, USA). The hydraulic conductivities were compared using the Kruskal–Wallis and multiple comparisons tests at $\alpha = 0.05$. The yields were compared using ANOVA at $\alpha = 0.05$.

3. Results and Discussion

3.1. Weather

The rainfall totals for the growing seasons during the trial are summarized in Table 2 and in Figure 2. The winter of 2019/20 was unusually dry, and even spring did not bring the necessary moisture until the end of April; the total amount of rain was only 162 mm. A period of frequent rainfalls took place on 3 June 2020, and more intense rains came after 7 June 2020. The soil was noticeably dry when inter-rows were cultivated. During June, the precipitation was above the long-term average by 32 mm. This month is the typical period for inter-row cultivation, and the soil is still prone to increased surface runoff, thus emphasizing the role of the reservoirs on the production area. In July, precipitation was well below the long-term average. The amount of precipitation from May to September then amounted to 370 mm, which is 30 mm less than average.

Table 2. Monthly sums of rainfall (mm) in the trial season and the long-term average for the South Bohemian region.

Year	May	June	July	August	September
Long-term average (1991–2020) [1]	75	92	94	85	56
2020	64	130	33	99	44
2021	89	71	98	114	18
2022	70	240	34	92	66

[1] Data from Czech Hydrometeorological Institute.

In 2021, after the dry autumn of 2020, again a below-average winter came. The emergence and further development of the plants were then significantly affected by the unusually low temperatures after drilling, and plant growth was delayed for up to a week. During the growing season, precipitation was mostly above the long-term average; only in June and September was it below the average. However, the establishment of variants took place in June, when a dry period of almost two weeks followed.

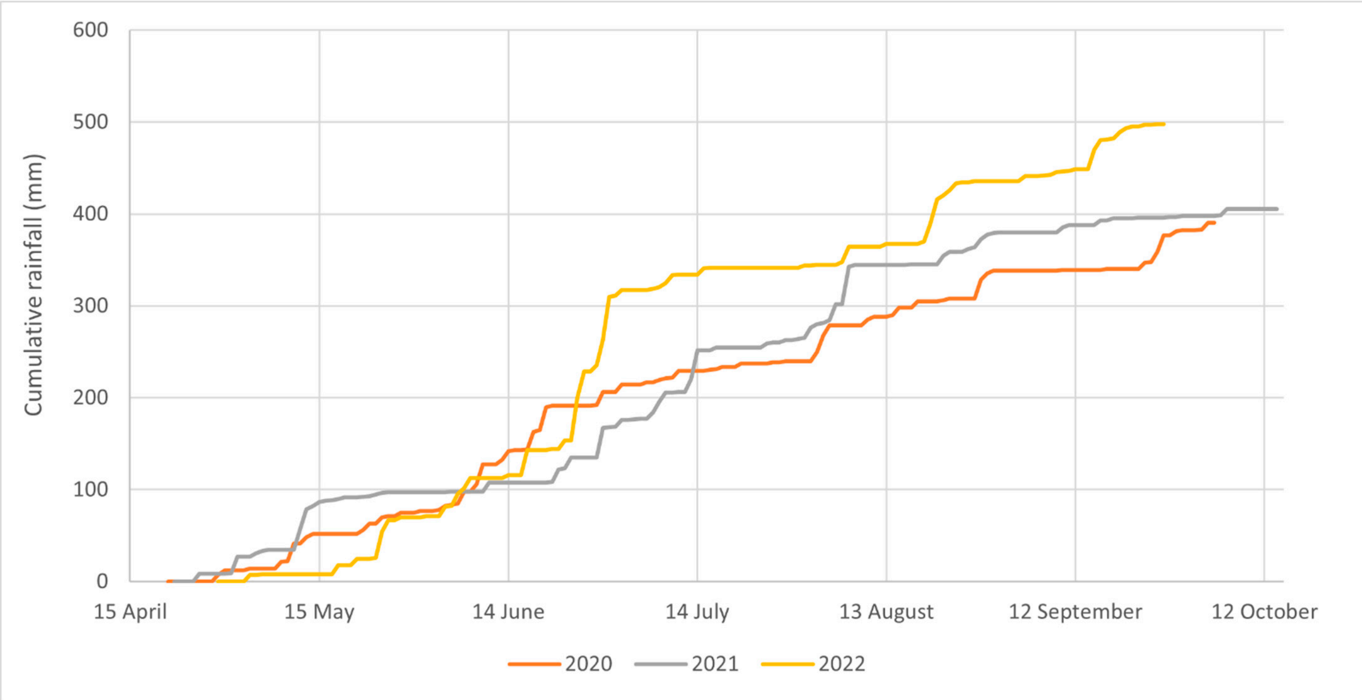

Figure 2. Cumulative rainfall total during the maize growing seasons.

The growing season in 2022 was characterized by significantly above-average rainfall in June, when inter-row cultivation was followed by a very rainy period with a total rainfall more than 2.6 times higher than the long-term average. The amount of precipitation during the growing season from May to September was 25% higher than the average in the same period.

3.2. Rain Simulation

The generation of surface runoff took place in standard phases that would become repeated in all measurements. At the beginning of the simulated rainfall, all of the water infiltrated into the soil. After the surface layer became saturated, the infiltration rate would drop below the rain's intensity. At this point, surface runoff occurred. The retention phase, as shown in Table 3, was longer in the case of the RC variant compared to the CU; water was retained in the reservoirs, and surface runoff was delayed by 2.4–4.2 min, which corresponded to an extra rainfall retention of 5.7 mm to 9.8 mm, compared to the control, for which there was a 2–4.2 min delay in runoff, which corresponded to 4.6–7.3 mm of rain. The year 2020 showed an anomaly caused by continuous depressions that remained in the inter-rows in C after the pre-drilling preparation. This resulted in a delay of surface runoff by 2.2 min more compared to CU. This phenomenon distinguished the 2020 trial compared to 2021 and 2022, as evident from Table 3. However, the reservoirs in the RC variant still managed to delay runoff by an additional 2.1 min compared to C. In both following years, the assumption was fulfilled that the earliest start of runoff would occur in the C variant, then with the CU variant, and the latest with the RC variant. Runoff retention was also positively correlated with soil surface roughness. This effect was described by Jester et al. [35] in laboratory measurements. In a similar manner, surface roughness has been shown to negatively correlate with soil loss [36]. The soil roughness on the tested variants (see Table 3) showed the highest values each year in RC, where reservoirs were included, and then successively for C and CU. Sittig et al. [37] compared surface runoff during the growth season of maize with conventional mechanical cultivation and reservoir cultivation. The latter reduced surface runoff by 27–71%. Sui et al. [38] achieved an average reduction of 78–80% in surface runoff over two trial years by microdams. They also confirmed the effect on delaying the start of surface runoff.

Table 3. Results from simulated rain experiments.

Year	Variant [1]	Soil Roughness (mm)	Runoff Start (min)	Rainfall Retention until Start of Runoff (mm)	Rainfall Retention Compared to Control (mm)	Runoff Stabilization Time (min)	Stabilized Runoff (% of Rainfall Intensity)
2020	C	24.6 ± 2.8	4.3 ± 1.1	10.2 ± 2.6	-	17.7 ± 0.1	43 ± 12
	CU	18.8 ± 0.4	2.1 ± 0.1	5.0 ± 0.1	−5.2	15.2 ± 0.2	70 ± 14
	RC	31.3 ± 2.3	6.3 ± 0.5	14.8 ± 1.2	4.7	20.7 ± 1.3	58 ± 13
2021	C	22.3 ± 2.6	5.5 ± 2.8	12.8 ± 6.5	-	15.9 ± 1.5	74 ± 5
	CU	21.5 ± 0.8	5.8 ± 0.4	13.5 ± 0.9	0.7	12.9 ± 2.4	45 ± 14
	RC	30.4 ± 1.4	8.2 ± 2.9	19.2 ± 6.9	6.5	23.4 ± 6.0	54 ± 10
2022	C	23.5 ± 1.4	4.2 ± 1.1	9.9 ± 2.6	-	15.2 ± 1.1	77 ± 9
	CU	21.4 ± 0.9	5.3 ± 0.8	12.4 ± 1.9	2.6	13.4 ± 1.1	72 ± 11
	RC	27.3 ± 1.6	8.4 ± 1.7	19.7 ± 4.0	9.9	17.2 ± 1.9	68 ± 9

[1] C—control, CU—cultivation, RC—reservoir cultivation.

After a certain time, the runoff rate would stabilize at a value that is dependent on the saturated hydraulic conductivity of the soil. The effect of deep tillage on water uptake has been described in literature, as well as the increased susceptibility to surface runoff with traditional soil tillage when growing maize [12,27]. The start of runoff and the time to stabilization of runoff rate are characteristics affected not only by autumn tillage and physical soil properties but also by cultivation during vegetation season, as shown by the results. Regardless, the formation of reservoirs during the vegetation period will support more even retention of rainfall on the land and thus prevent earlier runoff of water to lower points in the production area, where the soil is often undesirably saturated with water, and anaerobic conditions may be created [20].

The measured data confirmed the effectiveness of reservoir cultivation in terms of surface runoff, which also results in a reduction in soil loss, as described by many studies [24]. Kovář et al. [39] confirmed the existence of a mutual correlation between surface runoff and soil runoff. Luo et al. [40] reported a correlation between surface runoff and sediment content (R^2 = 0.35) and a linear dependence between runoff and sediment yield (R^2 = 0.75), as well as a significant influence of torrential rains, including a reduction in the effects of these rains upon growing plants. Brant et al. [41] explained the relationship of plant height and splash erosion, which decreases with plant age. With increasing canopy closure, the distribution of rain on the plot changes, decreasing the kinetic energy of the drops acting on the soil, where about one third of the precipitation contributes to surface runoff [42]. Carvalho et al. [43] confirmed the fact that surface runoff decreased, and infiltration increased, with gradually increasing the plant canopy area. They reported that, after the canopy closure in the field trial, the reservoirs would not completely fill with sediment. Additionally, the recreation of the reservoirs restored the infiltration capacity of the soil and limited further erosion. Similar conclusions were reached in potato cultivation [17,20], with which restoration has been recommended immediately after the microdams between reservoirs are breached and at the latest before canopy closure. It should be noted that reservoir cultivation for weed control is only effective in the second half of the period of high erosion risk. This can be amended by the creation of reservoirs simultaneously with drilling [37].

3.3. Saturated Hydraulic Conductivity

The differences in hydraulic conductivity between the individual years in Table 4 are closely related to the physical properties of the soils, which are listed in Table 1. The saturated hydraulic conductivity data show a relatively high variability, which is often expected. Since hydraulic conductivity is dependent on multiple physical properties of the soil: the soil structure, capillarity, and moisture content, a reduced accuracy of hydraulic conductivity measurement has been shown in literature [44]. This effect, however, is negligible compared to the high variability measured in agricultural practice.

Table 4. Saturated hydraulic conductivity (mm/h).

	2020			2021			2022		
Variant [1]	C	CU	RC	C	CU	RC	C	CU	RC
Average [2]	70.5 [ab]	82.3 [a]	17.8 [b]	33.1 [a]	56.9 [a]	6.8 [b]	30.8 [a]	40.6 [a]	13.7 [b]
S.D.	49.8	56.0	13.0	27.1	48.6	3.1	19.6	16.5	8.9
C.V. (%)	70.6	68.1	72.7	81.9	85.4	46.1	63.7	40.7	65.3
Max.	142.9	167.8	33.0	98.7	154.1	11.1	72.7	68.5	33.8
Min.	12.6	8.0	3.5	10.0	16.6	3.3	12.6	18.2	5.7

[1] C—control, CU—cultivation, RC—reservoir cultivation. [2] Means with different letters are statistically different based on Kruskal–Wallis and multiple comparisons tests at $\alpha = 0.05$.

During each year, the average hydraulic conductivity between the individual variants behaved according to the expected assumption, i.e., the CU variant showed the highest hydraulic conductivity; next was the control, and the lowest was always the hydraulic conductivity inside the reservoirs. The hydraulic conductivity of the RC variant was on average the lowest compared to the other variants: 66–88% lower than the CU variant and 56–79% lower than the C variants. The differences between C and CU were not conclusive at the 95% confidence level. However, the RC variant was significantly lower than CU in 2020 and lower than both variants in 2021 and 2022.

During the trials, the reservoirs of the RC variant were not restored in any season. At the bottom of the reservoirs, soil particles would settle during the season, which formed a difficult-to-permeate layer with a negative impact on hydraulic conductivity. Even though various studies have reported an increased water infiltration after the formation of reservoirs, this phenomenon is most significant only soon after the formation of reservoirs. With rainfall accumulation, the soil permeability at the bottom of the reservoirs would gradually decrease. A possible cause was explained by Lado & Ben-Hur [45], who described not only the decrease in infiltration during the simulation of rainfall but also the formation of relatively thin impermeable layers on the soil surface. The deterioration in infiltration capacity after rain events is expected; however, the degree also depends on the soil's organic matter, or more precisely on the addition of organic amendments, such as biochar [46]. However, it can be argued that an increased infiltration of water in the reservoirs is supported by the retention of water, which provides sufficient time for the surface water to infiltrate into the soil.

During the growing seasons, due to the gradual impact of rainfall, the reservoirs would become filled with sedimented soil particles, due to the change of inclination [47]. Therefore, the effective volume of the reservoirs would become smaller over the season. Generally, for the best water retention efficiency of reservoirs, it is recommended to recreate them during the season with inter-row cultivation, which can be typically carried out two to three times per season [17].

3.4. Yield of Maize

In the tested years, the yields of both fresh and dry matter were compared. Since the goal was to compare the tested variants, and since the same variety was not grown every year, the yield values were converted to percentages in which the yield of the control variant was set to 100%. The yields are reported in Tables 5 and 6.

Table 5. Fresh matter yield of maize (%); values are reported as percentages of the average in the control variant for each year.

	2020			2021			2022		
Variant [1]	C	CU	RC	C	CU	RC	C	CU	RC
Average	100.0	106.9	108.7	100.0	95.8	94.3	100.0	103.8	109.7
S.D.	10.4	11.3	19.2	3.4	7.4	2.5	8.2	12.2	7.4
C.V. (%)	10.4	10.6	17.7	3.4	7.8	2.7	8.2	11.8	6.8
Max.	111.4	125.4	135.9	102.6	104.3	96.6	110.2	117.3	120.1
Min.	91.0	94.1	88.3	96.2	90.2	91.6	91.7	84.8	95.2
ANOVA		$p = 0.72$			$p = 0.40$			$p = 0.15$	

[1] C—control, CU—cultivation, RC—reservoir cultivation.

Table 6. Dry matter yield of maize (%); values are reported as percentages of the average in the control variant for each year.

	2020			2021			2022		
Variant [1]	C	CU	RC	C	CU	RC	C	CU	RC
Average	100.0	109.2	106.1	100.0	94.4	94.9	100.0	106.7	105.5
S.D.	11.6	10.5	21.2	5.4	9.0	6.0	9.6	12.1	8.0
C.V. (%)	11.6	9.6	20.0	5.4	9.5	6.4	9.6	11.3	7.6
Max.	111.6	126.2	139.1	105.8	104.7	101.8	110.0	122.0	114.9
Min.	88.4	97.5	87.4	95.2	88.0	91.3	87.9	88.3	92.3
ANOVA		$p = 0.72$			$p = 0.58$			$p = 0.43$	

[1] C—control, CU—cultivation, RC—reservoir cultivation.

The comparison of average yields shows that inter-row cultivation and reservoir cultivation in 2020 and 2022 showed an increased yield, in both fresh and dry matter. The highest increase in fresh matter yield, 8–10%, was manifested in RC compared to C. On the other hand, a positive effect on the yield in dry matter was shown in CU compared to C and RC. In all trial years, however, the differences between yields, both in fresh and dry matter, were not statistically significant using ANOVA; see Tables 5 and 6. The tendency to increase yield in the cultivated variant, CU, compared to C is also in agreement with the five-year research of other researchers [48,49] on crust-prone loess clay soil. There, it was shown that inter-row cultivation increased maize yields to the same degree as did increasing soil cover with organic residues from previous crops, and the authors hypothesized that both practices increased the yields due to increased infiltration and reduced water evaporation.

A positive effect of reservoir cultivation on the yield of maize, increased by more than 50% in dry conditions in periods with rainfall, was reported by Mupangwa et al. [24]. This result, however, was in conditions very different from Central Europe. Similarly, Brhane et al. [23] reported that dike formation in grain cultivation significantly increased yields by 42% and 49% compared to conventional tillage, but again in incomparable climatic conditions. Mak-Mensah et al. [15] reported a 47% increase in alfalfa forage with reservoirs compared to traditional cultivation on a slope. A yield increase with tied-ridging, i.e., in potatoes, was reported by Agassi & Levy [22].

Compared to the other years, 2021 showed the opposite effect in the yields for CU and RC, approximately 5% lower than for C. It should be noted that this could have been caused by too early cultivation, which was performed at an early stage of plant development, around the formation of the 4th leaf of the emerging plants, and which also coincided with the beginning of a two-week dry period. During this period, therefore, there may have been a significant decrease in soil moisture in the area of the still undeveloped root system. On the other hand, Werf et al. [50] reported the consequences of inter-row cultivation and its effect on yield and development of the root system and described the insignificant effect of inter-row cultivation (on a weed-free soil) of up to 7 cm depth on plant yield and the possible interruption of the capillary rise of water, including an increase in temperature in the surface layer. Furthermore, they stated the inconclusiveness of whether cultivation increased the dry yield of maize.

4. Conclusions

The system of reservoir cultivation appears to be an effective tool in terms of rainfall retention in soil with a likely positive effect on the erosion control event in maize fields. Rain simulation tests have shown that in the presented setting, it could support the retention of up to an extra 9.8 mm of rainfall. On the other hand, this technology does not solve the problem of the plot's susceptibility to increased surface runoff and associated erosion risk between drilling and a time suitable for inter-row cultivation. During the season, the infiltration capacity in the reservoirs as well as their volume decrease. The ideal solution is the recreation of the reservoirs in combination with inter-row cultivation, which can typically be carried out two to three times per season.

This study showed that the system of reservoir cultivation did not show a negative effect on the yields. On the contrary, there was a tendency to increase the yield of fresh matter on the variants grown with reservoir cultivation, i.e., in 2020 and 2022, albeit this increase was not statistically significant. As a result, there may be an effect on the ideal harvest time, in which dry matter content is an important parameter for the harvest and the quality of the resulting silage.

The experiences from the 2021 trial indicated that reservoir cultivation is likely to be more advantageous in years with a higher number of precipitation events. In that year, the plants were likely stunted by too early cultivation, which decreased soil moisture. The formation of reservoirs at the beginning of the growing season should therefore ideally be carried out before a rainy period. Since the outcomes, i.e., the soil loss prevention and yields, each year depend on weather and soil conditions, further trials would be welcome to verify whether this technology could be widely used to control erosion linked to traditionally cultivated maize.

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References

1. Brant, V.; Kroulík, M.; Pivec, J.; Zábranský, P.; Hakl, J.; Holec, J.; Kvíz, Z.; Procházka, L. Splash Erosion in Maize Crops under Conservation Management in Combination with Shallow Strip-Tillage before Sowing. *Soil Water Res.* **2017**, *12*, 106–116. [CrossRef]
2. Tamelová, B.; Malaťák, J.; Velebil, J.; Gendek, A.; Aniszewska, M. Impact of Torrefaction on Fuel Properties of Aspiration Cleaning Residues. *Materials* **2022**, *15*, 6949. [CrossRef] [PubMed]
3. Alavinia, M.; Saleh, F.N.; Asadi, H. Effects of Rainfall Patterns on Runoff and Rainfall-Induced Erosion. *Int. J. Sediment Res.* **2019**, *34*, 270–278. [CrossRef]
4. Assouline, S.; Ben-Hur, M. Effects of Rainfall Intensity and Slope Gradient on the Dynamics of Interrill Erosion during Soil Surface Sealing. *Catena* **2006**, *66*, 211–220. [CrossRef]
5. Wang, Q.; Li, F.; Zhao, X.; Zhao, W.; Zhang, D.; Zhou, X.; Sample, D.J.; Wang, X.; Liu, Q.; Li, X.; et al. Runoff and Nutrient Losses in Alfalfa (*Medicago Sativa* L.) Production with Tied-Ridge-Furrow Rainwater Harvesting on Sloping Land. *Int. Soil Water Conserv. Res.* **2022**, *10*, 308–323. [CrossRef]

6. Menšík, L.; Kincl, D.; Nerušil, P.; Srbek, J.; Hlisnikovský, L.; Smutný, V. Water Erosion Reduction Using Different Soil Tillage Approaches for Maize (*Zea Mays* L.) in the Czech Republic. *Land* **2020**, *9*, 358. [CrossRef]
7. Gebhart, M.; Dumbrovský, M.; Šarapatka, B.; Drbal, K.; Bednář, M.; Kapička, J.; Pavlík, F.; Kottová, B.; Zástěra, V.; Muchová, Z. Evaluation of Monitored Erosion Events in the Context of Characteristics of Source Areas in Czech Conditions. *Agronomy* **2023**, *13*, 256. [CrossRef]
8. Fogliatto, S.; Milan, M.; De Palo, F.; Ferrero, A.; Vidotto, F. Effectiveness of Mechanical Weed Control on Italian Flint Varieties of Maize. *Renew. Agric. Food Syst.* **2019**, *34*, 447–459. [CrossRef]
9. Pulkrábek, J.; Urban, J.; Dvořák, P.; Bečková, L. Effect of Soil Loosening during Vegetation on Soil Erosion and Sugar Beet Production. *Listy Cukrov. Reparske* **2019**, *135*, 188–195.
10. Reddy, K.S.; Maruthi, V.; Pankaj, P.K.; Kumar, M.; Pushpanjali; Prabhakar, M.; Reddy, A.G.K.; Reddy, K.S.; Singh, V.K.; Koradia, A.K. Water Footprint Assessment of Rainfed Crops with Critical Irrigation under Different Climate Change Scenarios in SAT Regions. *Water* **2022**, *14*, 1206. [CrossRef]
11. Kwaad, F.J.P.M.; Van der Zijp, M.; Van Dijk, P.M. Soil Conservation and Maize Cropping Systems on Sloping Loess Soils in the Netherlands. *Soil Tillage Res.* **1998**, *46*, 13–21. [CrossRef]
12. Dickey, E.C.; Shelton, D.P.; Jasa, P.J.; Peterson, T.; Peterson, T.R.; Asae, M. Soil Erosion from Tillage Systems Used in Soybean and Corn Soil Erosion from Tillage Systems Used in Soybean and Corn Residues Residues Soil Erosion from Tillage Systems Used in Soybean and Corn Residues. *Biol. Syst. Eng.* **1985**, *28*, 1124–1130.
13. Stašek, J.; Krása, J.; Mistr, M.; Dostál, T.; Devátý, J.; Středa, T.; Mikulka, J. Using a Rainfall Simulator to Define the Effect of Soil Conservation Techniques on Soil Loss and Water Retention. *Land* **2023**, *12*, 431. [CrossRef]
14. Adee, E.; Hansel, F.D.; Ruiz Diaz, D.A.; Janssen, K. Corn Response as Affected by Planting Distance from the Center of Strip-till Fertilized Rows. *Front. Plant Sci.* **2016**, *7*, 1232. [CrossRef]
15. Mak-Mensah, E.; Sam, F.E.; Safnat Kaito, I.O.I.; Zhao, W.; Zhang, D.; Zhou, X.; Wang, X.; Zhao, X.; Wang, Q. Influence of Tied-Ridge with Biochar Amendment on Runoff, Sediment Losses, and Alfalfa Yield in Northwestern China. *PeerJ* **2021**, *9*, e11889. [CrossRef] [PubMed]
16. Kovaříček, P.; Marešová, K.; Hůla, J.; Kroulík, M. Use of Ridge Tillage for Growing of Wide Row Crops. *Listy Cukrov. Řepařské* **2010**, *126*, 91–96.
17. Vejchar, D.; Vacek, J.; Hájek, D.; Bradna, J.; Kasal, P.; Svobodová, A. Reduction of Surface Runoff on Sloped Agricultural Land in Potato Cultivation in De-Stoned Soil. *Plant Soil Environ.* **2019**, *65*, 118–124. [CrossRef]
18. Nuti, R.C.; Lamb, M.C.; Sorensen, R.B.; Truman, C.C. Agronomic and Economic Response to Furrow Diking Tillage in Irrigated and Non-Irrigated Cotton (*Gossypium Hirsutum* L.). *Agric. Water Manag.* **2009**, *96*, 1078–1084. [CrossRef]
19. Arlene, M.; Adviento-Borbe, A.; Barnes, B.D.; Iseyemi, O.; Mann, A.M.; Reba, M.L.; Robertson, W.J.; Massey, J.H.; Teague, T.G.; Gan, J. Water Quality of Surface Runoff and Lint Yield in Cotton under Furrow Irrigation in Northeast Arkansas. *Sci. Total Environ.* **2018**, *613*, 81–87. [CrossRef]
20. Lemann, T.; Sprafke, T.; Bachmann, F.; Prasuhn, V.; Schwilch, G. The Effect of the Dyker on Infiltration, Soil Erosion, and Waterlogging on Conventionally Farmed Potato Fields in the Swiss Plateau. *Catena* **2019**, *174*, 130–141. [CrossRef]
21. Nenciu, F.; Oprescu, M.R.; Biris, S.S. Improve the Constructive Design of a Furrow Diking Rotor Aimed at Increasing Water Consumption Efficiency in Sunflower Farming Systems. *Agriculture* **2022**, *12*, 846. [CrossRef]
22. Agassi, M.; Levy, G.J. Effect of the Dyked Furrow Technique on Potato Yield. *Potato Res.* **1993**, *36*, 247–251. [CrossRef]
23. Brhane, G.; Wortmann, C.S.; Mamo, M.; Gebrekidan, H.; Belay, A. Micro-Basin Tillage for Grain Sorghum Production in Semiarid Areas of Northern Ethiopia. *Agron. J.* **2006**, *98*, 124–128. [CrossRef]
24. Mupangwa, W.; Love, D.; Twomlow, S. Soil–Water Conservation and Rainwater Harvesting Strategies in the Semi-Arid Mzingwane Catchment, Limpopo Basin, Zimbabwe. *Phys. Chem. Earth Parts A/B/C* **2006**, *31*, 893–900. [CrossRef]
25. Wortmann, C.S.; Dang, Y.P. Strategic Tillage for the Improvement of No-Till Farming Systems. In *No-Till Farming Systems for Sustainable Agriculture*; Springer: Cham, Switzerland, 2020; pp. 155–171.
26. Haruna, S.I.; Anderson, S.H. No-Till Farming Systems for Enhancing Soil Water Storage. In *BT-No-Till Farming Systems for Sustainable Agriculture: Challenges and Opportunities*; Springer: Cham, Switzerland, 2020; pp. 213–231.
27. Rusu, T. Energy Efficiency and Soil Conservation in Conventional, Minimum Tillage and No-Tillage. *Int. Soil Water Conserv. Res.* **2014**, *2*, 42–49. [CrossRef]
28. Moitzi, G.; Neugschwandtner, R.W.; Kaul, H.P.; Wagentristl, H. Comparison of Energy Inputs and Energy Efficiency for Maize in a Long-Term Tillage Experiment under Pannonian Climate Conditions. *Plant Soil Environ.* **2021**, *67*, 299–306. [CrossRef]
29. Novák, P.; Kovaříček, P.; Hůla, J.; Buřič, M. Surface Water Runoff of Different Tillage Technologies for Maize. *Agron. Res.* **2019**, *17*, 754–760. [CrossRef]
30. Bagarello, V.; Iovino, M.; Elrick, D. A Simplified Falling-Head Technique for Rapid Determination of Field-Saturated Hydraulic Conductivity. *Soil Sci. Soc. Am. J.* **2004**, *68*, 66–73. [CrossRef]
31. Bagarello, V.; Elrick, D.E.; Iovino, M.; Sgroi, A. A Laboratory Analysis of Falling Head Infiltration Procedures for Estimating the Hydraulic Conductivity of Soils. *Geoderma* **2006**, *135*, 322–334. [CrossRef]
32. Reynolds, W.D.; Elrick, D.E. Ponded Infiltration From a Single Ring: I. Analysis of Steady Flow. *Soil Sci. Soc. Am. J.* **1990**, *54*, 1233–1241. [CrossRef]

33. Kamphorst, E.C.; Jetten, V.; Guérif, J.; Pitkänen, J.; Iversen, B.V.; Douglas, J.T.; Paz, A. Predicting Depressional Storage from Soil Surface Roughness. *Soil Sci. Soc. Am. J.* **2000**, *64*, 1749–1758. [CrossRef]
34. Herodowicz-Mleczak, K.; Piekarczyk, J.; Kaźmierowski, C.; Nowosad, J.; Mleczak, M. Estimating Soil Surface Roughness With Models Based on the Information About Tillage Practises and Soil Parameters. *J. Adv. Model Earth Syst.* **2022**, *14*, e2021MS002578. [CrossRef]
35. Jester, W.; Klik, A.; Hauer, G.; Hebel, B.; Truman, C.C.; Jester, W.; Klik, A.; Professor, A.; Hauer, G. Rainfall and Surface Roughness Effects on Soil Loss and Surface Runoff. In Proceedings of the Soil Erosion Research for the 21st Century Symposium, Honolulu, HI, USA, 3–5 January 2001; pp. 463–466.
36. Zheng, Z.C.; He, S.Q.; Wu, F.Q. Changes of Soil Surface Roughness under Water Erosion Process. *Hydrol. Process* **2014**, *28*, 3919–3929. [CrossRef]
37. Sittig, S.; Sur, R.; Baets, D. Runoff Mitigation via Micro-Dams and Conservation Tillage—Numerical Modeling of Runoff and Erosion from Maize Field Trials. *Integr. Environ. Assess Manag.* **2022**, *18*, 1348–1363. [CrossRef] [PubMed]
38. Sui, Y.; Ou, Y.; Yan, B.; Xu, X.; Rousseau, A.N.; Zhang, Y. Assessment of Micro-Basin Tillage as a Soil and Water Conservation Practice in the Black Soil Region of Northeast China. *PLoS ONE* **2016**, *11*, 0152313. [CrossRef]
39. Kovář, P.; Vaššová, D.; Janeček, M. Surface Runoff Simulation to Mitigate the Impact of Soil Erosion, Case Study of Třebsín (Czech Republic). *Soil Water Res.* **2012**, *7*, 85–96. [CrossRef]
40. Luo, J.; Zhou, X.; Rubinato, M.; Li, G.; Tian, Y.; Zhou, J. Impact of Multiple Vegetation Covers on Surface Runoff and Sediment Yield in the Small Basin of Nverzhai, Hunan Province, China. *Forests* **2020**, *11*, 329. [CrossRef]
41. Brant, V.; Zábranský, P.; Škeříková, M.; Pivec, J.; Kroulík, M.; Procházka, L. Effect of Row Width on Splash Erosion and Throughfall in Silage Maize Crops. *Soil Water Res.* **2017**, *12*, 39–50. [CrossRef]
42. Bui, E.N.; Box, J.E. Stemflow, Rain Throughfall, and Erosion under Canopies of Corn and Sorghum. *Soil Sci. Soc. Am. J.* **1992**, *56*, 242–247. [CrossRef]
43. Carvalho, D.F.d.; Eduardo, E.N.; De Almeida, W.S.; Santos, L.A.F.; Alves Sobrinho, T. Water Erosion and Soil Water Infiltration in Different Stages of Corn Development and Tillage Systems. *Rev. Bras. Eng. Agrícola Ambient.* **2015**, *19*, 1072–1078. [CrossRef]
44. Elrick, D.E.; Reynolds, W.D.; Geering, H.R.; Tan, K.-A. Estimating Steady Infiltration Rate Times for Infiltrometers and Permeameters. *Water Resour. Res.* **1990**, *26*, 759–769. [CrossRef]
45. Lado, M.; Ben-Hur, M. Soil Mineralogy Effects on Seal Formation, Runoff and Soil Loss. *Appl. Clay Sci.* **2004**, *24*, 209–224. [CrossRef]
46. Xuan, K.; Li, X.; Zhang, J.; Krasilnikov, P.; Taboada, M.A.; Xuan, K.; Li, X.; Zhang, J.; Jiang, Y.; Ma, B.; et al. Effects of Organic Amendments on Soil Pore Structure under Waterlogging Stress. *Agronomy* **2023**, *13*, 289. [CrossRef]
47. Asadi, H.; Moussavi, A.; Ghadiri, H.; Rose, C.W. Flow-Driven Soil Erosion Processes and the Size Selectivity of Sediment. *J. Hydrol.* **2011**, *406*, 73–81. [CrossRef]
48. Doren, D.M. Van Influence of Plowing, Disking; Cultivation, Previous Crop and Surface Residues on Corn Yield. *Soil Sci. Soc. Am. J.* **1965**, *29*, 595–597. [CrossRef]
49. Van Doren, D.M.; Triplett, G.B. Mulch and Tillage Relationships in Corn Culture. *Soil Sci. Soc. Am. J.* **1973**, *37*, 766–769. [CrossRef]
50. van der Werf, H.M.G.; Klooster, J.J.; Van der Schans, D.A.; Boone, F.R.; Veen, B.W. The Effect of Inter-Row Cultivation on Yield of Weed-Free Maize. *J. Agron. Crop Sci.* **1991**, *166*, 249–258. [CrossRef]