agronomy

Article

Effect of Mulching on Soil Quality in an Agroforestry System Irrigated with Reused Water

Ágnes Kun [1,*], Barbara Simon [2], Mihály Zalai [3], Ildikó Kolozsvári [1], Csaba Bozán [1], Mihály Jancsó [1], János Tamás Körösparti [1], Gergő Péter Kovács [4], Csaba Gyuricza [4] and Beatrix Bakti [5]

[1] Research Center for Irrigation and Water Management, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Anna-Liget Str. 35., H-5540 Szarvas, Hungary; kolozsvari.ildiko@uni-mate.hu (I.K.); bozan.csaba@uni-mate.hu (C.B.); jancso.mihaly@uni-mate.hu (M.J.); korosparti.janos.tamas@uni-mate.hu (J.T.K.)

[2] Department of Soil Science, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Páter Károly Str. 1., H-2100 Godollo, Hungary; simon.barbara@uni-mate.hu

[3] Department of Integrated Plant Protection, Institute of Plant Protection, Hungarian University of Agriculture and Life Sciences, Páter Károly Str. 1., H-2100 Godollo, Hungary; zalai.mihaly@uni-mate.hu

[4] Institute of Agronomy, Hungarian Agricultural and Life Science University, Páter Károly Str. 1., H-2100 Godollo, Hungary; kovacs.gergo.peter@uni-mate.hu (G.P.K.); gyuricza.csaba@uni-mate.hu (C.G.)

[5] Department of Plantation Forestry, Forest Research Institute, University of Sopron, H-4150 Puspokladany, Hungary; bakti.beatrix@uni-sopron.hu

* Correspondence: kun.agnes@uni-mate.hu

Abstract: In this study, a special rice-energy willow/poplar agroforestry system was used to analyze the effects of reused water irrigation and mulching on soil salinity, earthworm biomass and abundance, soil organic matter (SOM) content and weed coverage in treerow-dependent habitats. After three-year-irrigation, we investigated the woody line (WL), the buffer zone (BZ) and the crop line habitats (CL). Between 2019 and 2021, we collected data on the distribution of soil-specific electrical conductivity (EC), ammonium-lactate soluble sodium (AL-Na) and exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and soil $NO_2^- + NO_3^-$-N contents from CL habitats irrigated with effluent water from an intensive catfish farm. Based on our results, significantly greater earthworm abundance (274 pc m^{-2}) and earthworm biomass (54.0 g m^{-2}) values were measured in WL than in BZ or CL habitats. There was no significant difference in weed coverage between the CL (0.61%) and BZ (1.91%), but weeds were significantly denser on the WL (12.3%). In the third year, the EC, AL-Na and ESP values were lower, but the SOM was higher in mulched soil (183.1 mS cm^{-1}, 253.1 mg kg^{-1}, 4.4 ESP% and 4.597%, respectively) than in un-mulched soil.

Keywords: agro-forestry; irrigation; reused water; mulch; rice; poplar; willow; weed composition; habitat

check for updates

Citation: Kun, Á.; Simon, B.; Zalai, M.; Kolozsvári, I.; Bozán, C.; Jancsó, M.; Körösparti, J.T.; Kovács, G.P.; Gyuricza, C.; Bakti, B. Effect of Mulching on Soil Quality in an Agroforestry System Irrigated with Reused Water. *Agronomy* **2023**, *13*, 1622. https://doi.org/10.3390/agronomy13061622

Academic Editors: Xiangyang Fan and Erping Cui

Received: 27 May 2023
Revised: 13 June 2023
Accepted: 15 June 2023
Published: 16 June 2023

1. Introduction

Global warming and population growth increase the pressure on renewable natural resources, and especially on freshwater. The UN World Water and Development Report 2017 reports that 70% of the world's water demand is for use as irrigation water for crop production [1]. The predictions showed that agricultural activities will suffer from severe droughts, mainly in arid and semi-arid regions. Even in temperate regions, where crop production is significantly dependent on the natural precipitation, a supplemental irrigation will be important as a climate risk management measure [2].

Reclaimed water can be a sustainable source of irrigation water to support the food supply of a rapidly growing population [3]. However, the successful reuse of reclaimed water is not possible without public acceptance [4]. The policies and the international standards of water reclamation are gradually improving and supporting the reutilization processes [4].

Agricultural effluent water, even with higher salinity, can be an important component of water conservation to alleviate freshwater scarcity [5]. Cavalcante et al. [6] showed that during drought periods, supplementary irrigation with saline water can reduce plants' water stress levels and increase the physical productivity of water. However, the higher salt content in the soil hinders the growth of plants, and among other things inhibits the uptake of nutrients, and causes an ion imbalance, thereby reducing the crop yield. Hasamuzzam et al. [7] showed that after irrigation with 0, 30, 60, 90, 120 and 150 mM NaCl-containing water, in the case of the highest dose, the grain yield of rice decreased by 36–50%. In addition, irrigation with saline water for several years can increase the content of exchangeable sodium in the soil, which affects the physicochemical properties of the soil, such as soil bulk density, conductivity, and soil organic carbon content decrease, which also has a negative effect on rice production [8,9]. Consequently, the accumulation of soil salts should be considered when using saline water as an alternative source for agricultural irrigation.

Mulching is the common practice of placing materials such as plastic material, crop residues, livestock manure, sands rocks and cement on the soil surface before, during, or soon after sowing [10]. The covering of the soil surface can limit evaporation and erosion, improve the available water capacity of soil, regulate soil temperature and suppress weed development [11]. Clare et al. [11] reported that straw also improved soil fertility and had a rich mineral element content, especially of macro elements (nitrogen (N), phosphorus (P), potassium (K)) and organic carbon content. When returned to the soil, all of these elements promote the growth of the cultivated plant culture. The content of excess nutrients improves the soil's microbial activity [12]. In a potato cultivation experiment, Sarangi et al. [13] reported that the salinity in the soil of the mulched plantation decreased from 5 to 3 dS m^{-1}, and the soil moisture content increased by 4–8%, thereby inducing a higher yield.

Earthworms are important elements of the soil ecosystem because they increase diversity, physicochemical properties and nutrient availability in soils due to their distribution, diversity and abundance [14]. Land use systems affect earthworm communities significantly [15], and earthworm density was mainly influenced by aboveground vegetation [16]. In natural and artificial forests, earthworms' distribution is mainly influenced by the trees, as they provide protection from direct sunlight and affect the temperature, moisture content, pH and organic matter content of soils [17,18]. Earthworms' overall density and abundance were found to be positively correlated with the age of the forests because of the longer period of organic matter accumulation [19].

Agroforestry can be considered a sustainable form of land use that combines different plant species to fully use natural resources [20]. Due to the spatial distribution of species and their different growth patterns, the system breaks up monoculture structures, creating new interactions between different species. In terms of resource use, plant species compete for resources and complement each other. For this reason, reducing resource competition between trees and plants is at the heart of efficient agroforestry systems [21].

Weed composition is affected by different tillage and weed control practices of woody and non-woody lines of agroforestry, similar to orchards and vineyards. According to Mainardis et al. [22], tillage is the most effective non-chemical control and results in a less diverse weed composition in vineyards, and a special weed flora can appear on non-tillage strips under the trees [23]. In the case of cultivation systems, which Schumacher et al. [24] highlighted, the position can be more varied, at the border of tilled and untilled habitats, because weeds are affected by both habitats. Schumacher et al. [24] highlighted that the border line is weedier than arable habitats with different ranges of frequent weeds.

However, organic mulching is most common in vegetable and fruit production; it can also be effective in agroforestry, because it can also highly affect the extent of weediness and weed composition. Petrikovszki et al. [25] found that mulching is the third most important factor for weeds, besides seasonality and margin, and mulch could decrease weed cover on most species except perennial *Convolvulus arvensis*.

Our research includes two main objectives: (1) on the one hand, research into the possibilities of irrigation water utilization with a high sodium content to preserve the quality of the soil through mulching, and (2) on the other hand, the examination of the ecological role of the agroforestry system from the point of view of the biological properties of the soil (earthworm numbers and biomass) and the weed coverage of the different ground covers.

2. Materials and Methods

2.1. Site Description and Climatic Conditions

The experiment was set up at the agroforestry research site (0.3 ha) of the Hungarian University of Agriculture and Life Sciences (MATE), Institute of Environmental Sciences (IES), Research Center for Irrigation and Water Management (ÖVKI), in Szarvas, Hungary (Figure 1)

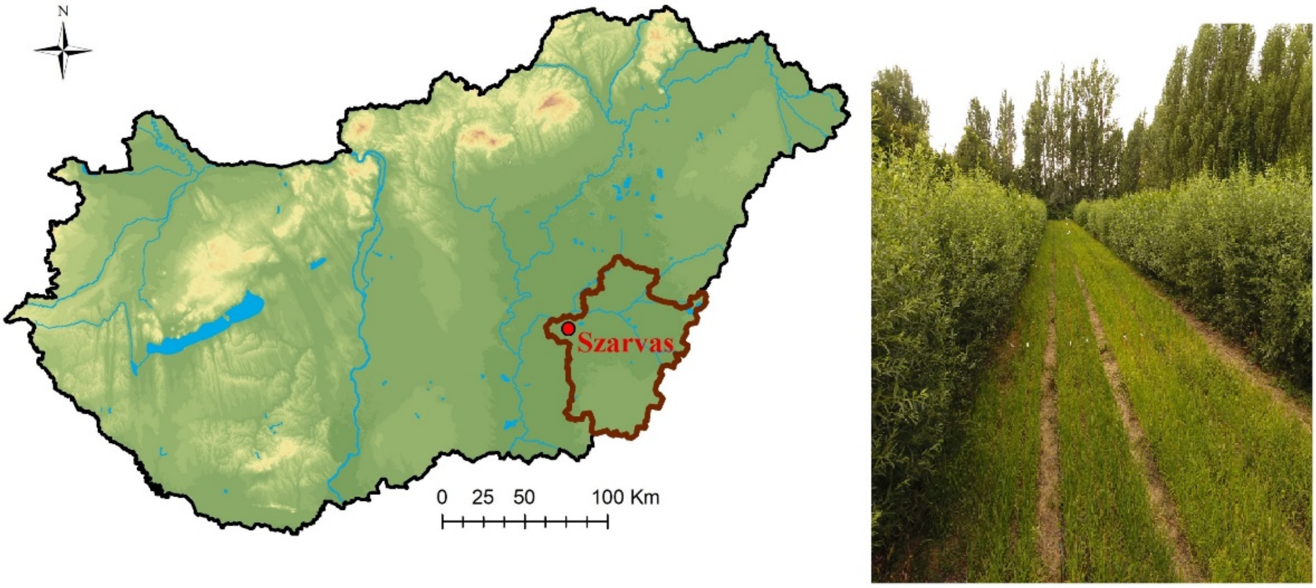

Figure 1. Localization map of the experimental site: Szarvas, Hungary.

Hungary has a temperate continental climate; the specific area of the experimental site is described as a warm and dry climate region. Meteorological data from the three-year experiment (2019, 2020 and 2021) were collected at an automatic weather station (Agromet Solar, Boreas Ltd., Érd, Hungary) 1600 m from the experimental site (Figure 2). The precipitation was 516.4 mm, 611.4 mm and 433.9 mm in the consecutive experimental years. There was also a significant difference between the years in the annual average mean temperature values; the warmest year was 2019, with 13.8 °C, and the second (12.1 °C) and third year (11.6 °C) were cooler.

Before the present experiment, there was an energy plantation (*Salix alba L.* and *Populus alba*) in the research field for five years, for experimental purposes with irrigation. In 2018, the plantation was transformed into an agroforestry system. Now, there are six rows of trees in the area (two single rows at the borders, two double rows in the middle) and 3 fields for intercrop cultivation (10 m width) (Figures 1 and 3). The soil type is Vertisols [26], with a clay texture, 8.3 pH, 5.4% total carbonate and 2.4% total organic carbon.

2.2. Quality of Irrigation Water

Effluent water from an intensive fish farm, producing African catfish (*Clarias gariepinus*), was used as irrigation water, hereafter referred to as wastewater. The source of wastewater was the first stabilization pond of a constructed wetland. This wetland was established in order to pretreat the water before it is released into the oxbow lake of Körös. The wetland was located 150 m from the experimental site. The effluent is characterized by a high concentration of sodium and bicarbonates due to the geothermal origin of the water, and relatively high nutrient content because of the remaining material after fish production (Table 1). This wastewater contains large amounts of debris, such as fish feces and organic materials [27,28]. According to the irrigation water classification of USDA [29], the wastewater belongs to the C3-S2 group, with high salinity and medium sodium hazard.

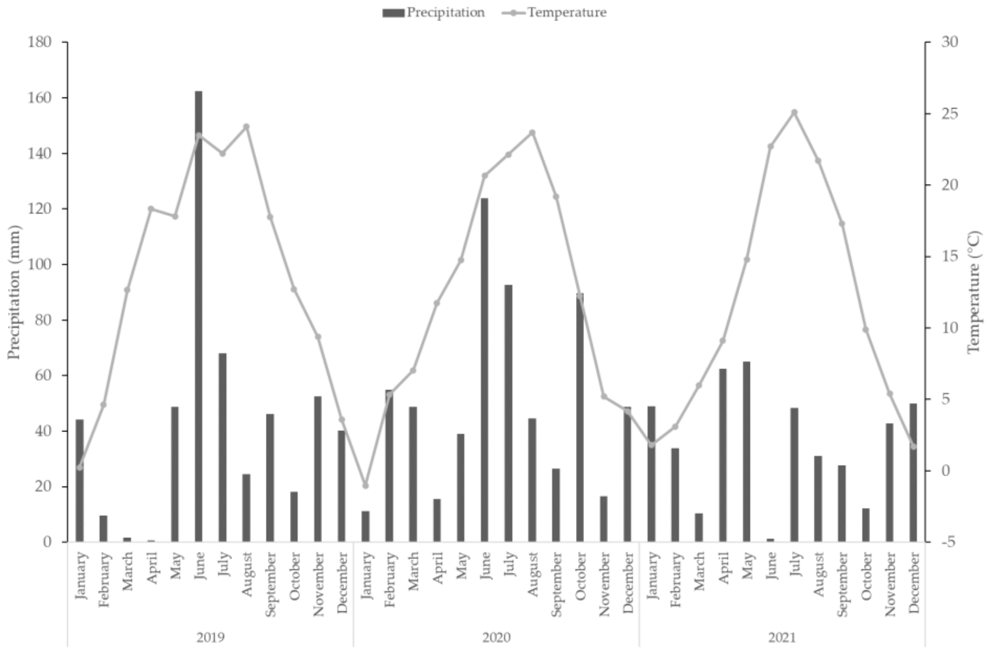

Figure 2. Monthly precipitation amount and average monthly temperature of experimental years (2019, 2020 and 2021).

Figure 3. Drawing of the experimental area in cross-section.

2.3. Mulching

Winter wheat straw (0.25 kg m^{-2}) was applied for mulching (71% soil cover). The mass of mulch material was calculated according to the following equation:

$$F_c = 1 - e^{-A_m * M} \quad (1)$$

where F_c: ratio of covered soil (%), A_m: area: mass of the mulch material (constant, for winter wheat 5 m^2 kg^{-1}) and M: mass of the mulch (kg m^{-2}) [30].

2.4. Treatments

The experimental site (80 × 10 m) was divided into two parts; on one we used mulch (400 m^2), and on the other (400 m^2) there was no ground cover. Both were irrigated with wastewater. The irrigation method was micro sprinkler irrigation. In each experimental year (2019, 2020 and 2021) the irrigation water amount was 150 mm/year. Irrigation was carried out five times each year for 30 mm.

Table 1. Average chemical properties of irrigation water used under experiment (*n* = 5).

		Wastewater
pH		7.81
EC	μS cm^{-1}	1215
HCO_3^-	mg dm^{-3}	853.5
NH_4^+	mg dm^{-3}	27.8
NO_3^-	mg dm^{-3}	0.557
NO_2^-	mg dm^{-3}	0.256
Total inorganic N	mg dm^{-3}	21.65
Total organic N	mg dm^{-3}	10.39
Total N	mg dm^{-3}	32.05
PO_4^{3-}	mg dm^{-3}	4.99
Total P	mg dm^{-3}	3.14
Cl^-	mg dm^{-3}	36.2
SO_4^{2-}	mg dm^{-3}	51.25
Total suspended solids	mg dm^{-3}	54.3
Ca^{2+}	mg dm^{-3}	27.15
Mg^{2+}	mg dm^{-3}	9.15
K^+	mg dm^{-3}	5.81
Na^+	mg dm^{-3}	240.5
SAR		10.57

SAR: sodium adsorption ratio, SAR = Na/((Ca + Mg)/2)1/2 [29].

2.5. Sampling and Analytics

Composite soil samples were taken from 0 to 15 and 15 to 30 cm depths. Regarding the applied treatments, soil samples were taken from *mulched* (straw) and *un-mulched* areas in four repetitions. The soil carbon content was determined using a CNS analyzer (Elementor, Vario MAX Cube), and the soil organic matter was calculated by multiplying the result with 1.74 [31].

Disturbed soil samples were collected before the first irrigation of the three-year experiment (2019 spring), and then each autumn after the irrigations in four repetitions from mulched and un-mulched areas. The sampled soil depths were 0–30 cm and 30–60 cm; however, we did not differentiate between soil depths during the statistical analysis.

The soil's specific electrical conductivity (EC) was measured from saturated soil paste (according to Hungarian standard MSZ-08-0206-2:1978). The available nitrogen content of the soil was characterized by the sum of the nitrite and nitrate contents of the soil (KCL-NO_2^- + NO_3^-–N). Nitrite and nitrate were extracted with potassium chloride and the concentration was measured using FIA spectrophotometer (according to Hungarian standard MSZ 20135:1999). The sodium (AL-Na) concentration was measured after ammonium-lactate extraction with AAS flame photometry (according to Hungarian standard MSZ 20135:1999).

Exchangeable cations (K, Na, Ca, and Mg) were extracted with barium-chloride + triethanolamine and their concentrations were measured using atomic adsorption spectrophotometer (AAS) (according to Hungarian standard MSZ-08-0214-2:1978).

$$ESP(exchangeable\ sodium\ percantage,\ \%) = \frac{Na}{(Na + K + Ca + Mg)} * 100 \tag{2}$$

where Na^+, K and Mg^{2+} concentrations are expressed in milliequivalents per 100 g of soil [29].

Concerning the earthworm sampling, the habitats that were sampled were the following: (a) crop line (CL): in the middle of the interrow section, where soil disturbance, sowing and crop production occurred; (b) buffer zone (BZ): beside the crop line, which did not receive any soil disturbance, or crop production; and (c) woody line (WL): area under the tree line, where no soil disturbance or agricultural cropping occurred. The samples were collected in four repetitions, using the hand-sorting method (ISO 23611-1:2018). Soil blocks (25 × 25 × 25 cm) were excavated onto a plastic sheet, then searched carefully for earthworms. The earthworms were killed in 70% ethanol, transported to the laboratory and fixed in 4% formalin. The number of earthworms (pc m^{-2}) and biomass (g m^{-2}) were determined. The earthworm sampling was carried out in April 2022.

Weed composition was surveyed by recording weed cover expressed in the percentage of the total area of 1 m^2 micro-plots on un-mulched area in April 2022. Data collection included all non-crop plants with four replications of all habitats.

2.6. Statistical Analyses

Statistical analyses were performed in IBM SPSS statistics 27 software. To model the change in soil parameters affected by mulching (factorial variable: yes or no) and irrigation between 2019 and 2021 (survey period; factorial variable: 2019 Spring, 2019 Autumn, 2020 Autumn or 2021 Autumn), variables were tested using Multi-Way Analysis of Variance (Multi-Way ANOVA). Additionally, the sole effect of irrigation between 2019 and 2021 was tested with One-Way Analysis of Variance (ANOVA) separated by mulched and unmulched conditions, too. In significant cases, explanatory variables were tested with a two-samples T-test for mulching variable and a Tukey comparison for habitat variable.

To model data collection in 2022, both mulching and habitat (factorial variable: WL, BZ or CL) variables were tested with Multi-Way Analysis of Variance (MANOVA) in the case of earthworm abundance, earthworm biomass and soil organic matter. Habitat was tested with Analysis of Variance (ANOVA) in the case of total weed coverage. In significant cases, explanatory variables were tested with a two-samples T-test for mulching and with a Tukey comparison for survey period variable.

3. Results

3.1. The Effect of Mulching and Irrigation on Soil Parameters

Due to the high sodium content of the irrigation water, we investigated the salinization of the soil. Due to the presence of excess organic matter spread with mulch, we also examined the nitrogen content of the soil. EC values were significantly higher in unmulched soil (185.9 mS cm^{-1}) than in mulched soil (177.0 mS cm^{-1}) (Table 2). The EC value in the unmulched soil increased year by year: the lowest values were measured during the spring sampling before irrigation (2019), and the highest in the last year of the experiment (2021) (Table 3). The lowest value could also be measured in the soil of the mulched plots in the first experimental year, but there was no significant difference between the values of the autumn sampling of the experimental years (Table 4). The nitrogen content of the soil was significantly higher in the mulched soil (9.0 mg kg^{-1}) than in the unmulched one (7.0 mg kg^{-1}) (Table 2), but irrigation had no significant effect on this parameter (Tables 3 and 4). The accumulation of sodium in the soil was examined based on three parameters: ammonium-lactate soluble sodium (AL-Na), exchangeable sodium ($Na_{(BaCl2)}$) and exchangeable sodium percentage (ESP); all three were lower in the mulched soil than in the unmulched soil, but the difference was only significant in the case of the AL-Na values (Table 2). An increase in sodium due to irrigation could be observed in mulched and unmulched soil. In both treatments, the highest values for all three parameters were measured in the second and third year of the experiment (Tables 3 and 4).

Table 2. Effect of mulching and irrigation between 2019 spring and 2021 autumn based on Multi-Way Analysis of Variance in an agro-forestry experiment (Szarvas, Hungary, 2022).

Soil Parameter	**Mulching**				**Period ***	
	MANOVA		**Mean ± SD**		**MANOVA**	
	F Value	***p* Value**	**Unmulched**	**Mulched**	**F Value**	***p* Value**
EC 1:5 [mS cm^{-1}]	9.595	0.003	185.9 ± 16.6	177.0 ± 14.6	26.127	<0.001
Nitrite + Nitrate Nitrogen (KCl) [mg kg^{-1}]	4.512	0.038	7.0 ± 3.3	9.0 ± 4.5	4.013	0.012
Na (AL) [mg kg^{-1}]	6.596	0.013	293.0 ± 75.0	260.4 ± 64.6	18.212	<0.001
Na (BaCl$_2$) [mg kg^{-1}]	1.858	n.s.	406.3 ± 165.5	362.0 ± 142.0	9.949	<0.001
Na (BaCl$_2$) [mEq 100 g^{-1}]	1.864	n.s.	1.77 ± 0.72	1.57 ± 0.62	9.954	<0.001
K (BaCl$_2$) [mg kg^{-1}]	2.673	n.s.	181.4 ± 42.7	169.0 ± 34.1	13.566	<0.001
K (BaCl$_2$) [mEq 100 g^{-1}]	2.707	n.s.	0.46 ± 0.11	0.43 ± 0.09	13.641	<0.001
Ca (BaCl$_2$) [mg kg^{-1}]	0.825	n.s.	6269 ± 1104	5997 ± 1399	1.882	n.s.
Ca (BaCl$_2$) [mEq 100 g^{-1}]	0.831	n.s.	31.3 ± 5.5	29.9 ± 7.0	1.885	n.s.
Mg (BaCl$_2$) [mg kg^{-1}]	0.744	n.s.	1220 ± 231	1261 ± 208	8.261	<0.001
Mg (BaCl$_2$) [mEq 100 g^{-1}]	0.706	n.s.	10.0 ± 1.9	10.4 ± 1.7	8.349	<0.001
ESP [%]	0.679	n.s.	4.13 ± 1.64	3.85 ± 1.63	11.353	<0.001

* See detailed results and post hoc test in Tables 3 and 4. n.s.: non-significant.

Table 3. Effect of irrigation on unmulched conditions between 2019 spring and 2021 autumn in an agro-forestry experiment (Szarvas, Hungary, 2022).

Soil Parameter	**ANOVA**		**Survey Period (Mean ± SD; Tukey Post Hoc Test)**			
	F Value	***p* Value**	**2019 Spring**	**2019 Autumn**	**2020 Autumn**	**2021 Autumn**
EC 1:5 [mS cm^{-1}]	17.058	<0.001	168.9 ± 10.4 a	177.8 ± 10.0 ab	189.0 ± 8.8 b	204.1 ± 12.2 c
Nitrite + Nitrate Nitrogen (KCl) [mg kg^{-1}]	1.907	n.s.	8.1 ± 4.8	5.5 ± 1.6	8.5 ± 3.1	5.7 ± 2.2
Na (AL) [mg kg^{-1}]	6.764	0.001	249.9 ± 87.7 a	240.9 ± 65.8 a	345.1 ± 40.2 b	336.1 ± 28.4 b
Na (BaCl$_2$) [mg kg^{-1}]	5.609	0.004	318.8 ± 71.2 ab	295.0 ± 105.9 a	505.4 ± 58.8 b	506.1 ± 236.7 b
Na (BaCl$_2$) [mEq 100 g^{-1}]	5.612	0.004	1.39 ± 0.31 ab	1.28 ± 0.46 a	2.20 ± 0.25 b	2.20 ± 1.03 b
K (BaCl$_2$) [mg kg^{-1}]	5.424	0.005	147.2 ± 36.4 a	174.1 ± 46.1 ab	186.1 ± 38.0 ab	218.3 ± 14.9 b
K (BaCl$_2$) [mEq 100 g^{-1}]	5.470	0.004	0.38 ± 0.09 a	0.45 ± 0.12 ab	0.48 ± 0.10 ab	0.56 ± 0.04 b
Ca (BaCl$_2$) [mg kg^{-1}]	1.659	n.s.	6804 ± 1516	5671 ± 1280	6118 ± 658	6485 ± 466
Ca (BaCl$_2$) [mEq 100 g^{-1}]	1.661	n.s.	33.9 ± 7.6	28.3 ± 6.4	30.5 ± 3.3	32.4 ± 2.3
Mg (BaCl$_2$) [mg kg^{-1}]	5.671	0.004	1331 ± 252 bc	1385 ± 176 c	1059 ± 140 a	1107 ± 184 ab
Mg (BaCl$_2$) [mEq 100 g^{-1}]	5.684	0.004	11.0 ± 2.1 bc	11.4 ± 1.4 c	8.7 ± 1.2 a	9.1 ± 1.5 ab
ESP [%]	4.606	0.010	3.1 ± 1.2 a	3.3 ± 1.6 a	5.3 ± 0.6 b	4.8 ± 1.9 ab

a, b, c: means homogenous subset of Tukey post hoc test. n.s. = no significant.

3.2. Earthworm Abundance and Biomass

According to the statistical analysis (MANOVA) we used (Figure 4A; Table 5), the earthworm samples that were taken from the WL (264 pc m^{-2}) and the BZ (172 pc m^{-2}) habitats showed significantly greater earthworm abundance compared to the CL (84 pc m^{-2}) under mulched treatments. As for the un-mulched treatments, the tendency was similar, with WL: 284, BZ: 200 and CL: 60 pc m^{-2}, respectively. Thus, the effect of mulching was not significant.

Table 4. Effect of irrigation on mulched conditions between 2019 spring and 2021 autumn in an agro-forestry experiment (Szarvas, Hungary, 2022).

Soil Parameter	**ANOVA**		**Survey Period (Mean ± SD; Tukey Post Hoc Test)**			
	F Value	***p* Value**	**2019 Spring**	**2019 Autumn**	**2020 Autumn**	**2021 Autumn**
EC 1:5 [mS cm^{-1}]	12.665	<0.001	158.9 ± 8.2 a	178.9 ± 7.3 b	187.3 ± 7.0 b	183.1 ± 15.2 b
Nitrite + Nitrate Nitrogen (KCl) [mg kg^{-1}]	2.186	n.s.	10.9 ± 6.6	7.2 ± 2.3	10.9 ± 4.1	6.9 ± 2.7
Na (AL) [mg kg^{-1}]	18.716	<0.001	204.3 ± 52.1 a	239.5 ± 35.1 a	344.9 ± 27.1 b	253.1 ± 38.2 a
Na ($BaCl_2$) [mg kg^{-1}]	4.642	0.009	260.6 ± 51.6 a	308.3 ± 73.0 ab	459.4 ± 50.8 b	419.6 ± 221.6 ab
Na ($BaCl_2$) [mEq 100 g^{-1}]	4.643	0.009	1.13 ± 0.22 a	1.34 ± 0.32 ab	2.00 ± 0.32 b	1.83 ± 0.96 ab
K ($BaCl_2$) [mg kg^{-1}]	11.382	0.000	133.4 ± 9.8 a	183.3 ± 38.4 bc	159.9 ± 24.6 ab	199.4 ± 12.2 c
K ($BaCl_2$) [mEq 100 g^{-1}]	11.417	0.000	0.34 ± 0.02 a	0.47 ± 0.10 bc	0.41 ± 0.06 ab	0.51 ± 0.03 c
Ca ($BaCl_2$) [mg kg^{-1}]	2.322	n.s.	6459 ± 1405	6684 ± 2104	5135 ± 603	5710 ± 418
Ca ($BaCl_2$) [mEq 100 g^{-1}]	2.329	n.s.	32.2 ± 7.0	33.4 ± 10.5	25.6 ± 3.0	28.5 ± 2.1
Mg ($BaCl_2$) [mg kg^{-1}]	3.096	0.043	1353 ± 236 ab	1368 ± 107 b	1202 ± 178 ab	1125 ± 212 a
Mg ($BaCl_2$) [mEq 100 g^{-1}]	3.155	0.040	11.1 ± 1.9 ab	11.3 ± 0.9 b	9.9 ± 1.5 ab	9.2 ± 1.7 a
ESP [%]	7.078	0.001	2.6 ± 0.8 a	3.1 ± 1.3 ab	5.3 ± 0.4 c	4.4 ± 2.1 bc

a, b, c: means homogenous subset of Tukey post hoc test. n.s. = no significant.

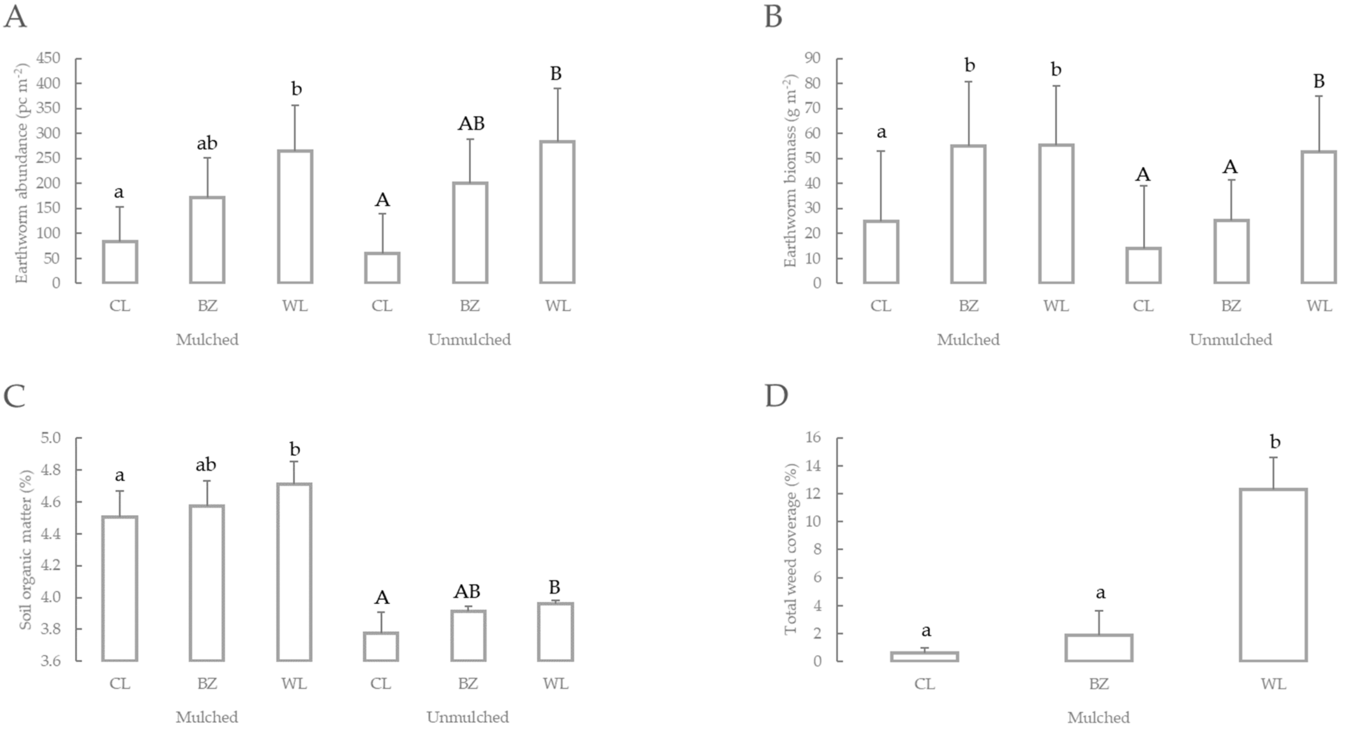

Figure 4. Effect of mulching and habitat on earthworm abundance (pc m^{-2}) (**A**), earthworm biomass (g m^{-2}) (**B**), soil organic matter (%) (**C**) and total weed coverage (%) (**D**) in an agro-forestry experiment (Szarvas, Hungary, 2022).

Regarding the earthworm biomass (Figure 4B; Table 5), the values were significantly the greatest under WL (55.4 g m^{-2}) as compared to CL (24.6 g m^{-2}) treatment in mulched treatments, while a similar tendency was found under unmulched treatments, where WL (52.6 g m^{-2}) gave significantly greater biomass than CL (14.1 g m^{-2}) treatment.

Table 5. Effect of mulching and habitat on earthworm abundance (pc m^{-2}), earthworm biomass (g m^{-2}), soil organic matter (%) and total weed coverage (%) in an agro-forestry experiment (Szarvas, Hungary, 2022).

Earthworm Abundance

Variable	**df**	**MANOVA**		**Tukey Comparison**		
		F	***p*-Value**	**Group**	**Avg Value (pc m^{-2})**	**Sign. Class**
Mulching	1	0.051	ns	-		
Habitat	2	10.825	0.001	WL	274.00	b
				BZ	186.00	b
				CL	72.00	a

Earthworm Biomass

Variable	**df**	**MANOVA**		**Tukey Comparison**		
		F	***p*-Value**	**Group**	**Avg Value (g m^{-2})**	**Sign. Class**
Mulching	1	1.849	ns	-		
Habitat	2	3.573	0.049	WL	54.00	b
				BZ	40.01	ab
				CL	19.39	a

Soil Organic Matter

Variable	**df**	**MANOVA**		**Tukey Comparison/*t*-Test**		
		F	***p*-Value**	**Group**	**Avg Value (%)**	**Sign. Class**
Mulching	1	155.451	<0.001	mulched	4.597	b
				un-mulched	3.883	a
Habitat	2	3.879	0.050	WL	4.336	b
				BZ	4.244	ab
				CL	4.140	a

Total Weed Coverage

Variable	**df**	**ANOVA**		**Tukey Comparison**		
		F	***p*-Value**	**Group**	**Avg Value (%)**	**Sign. Class**
Habitat	2	6.184	0.020	WL	12.303	b
				BZ	1.913	a
				CL	0.608	a

a, b: means homogenous subset of Tukey post hoc test. ns = no significant.

3.3. Soil Organic Matter Content and Total Weed Coverage

Concerning the soil organic matter (SOM) content, we took soil samples from the above-mentioned three habitats (CL, BZ, and WL), and the effect of mulching was statistically significant (Figure 4C; Table 5). Significantly greater values were obtained in the mulched locations under WL (4.7%) treatment compared to CL (4.5%). As for the unmulched treatments, lower values were gained with the following decreasing order: 4.0 (WL), 3.9 (BZ) and 3.8% (CL).

As for the total weed coverage (Figure 4D; Table 5), only the mulched plots were examined. We found the greatest weed coverage values in the case of the WL (12.3%), as compared to BZ (1.9%) and CL (0.6%) locations. WL was significantly greater than BZ and CL.

4. Discussion

4.1. Anthropogenic Soil Salinization due to Irrigation Water Quality

The possible mechanisms for restraining salt accumulation via straw-returning under saline water irrigation included (a) inhibiting the upward movement of salts due to soil water evaporation, and (b) promoting salt leaching by improving the soil properties [32,33]. According to Zhang et al. [32], within each saline water irrigation treatment (I0: 0.47 dS m^{-1}, I1: 3.25 dS m^{-1}, and I2: 6.75 dS m^{-1}), the application of straw-returning resulted in a lower soil salt content compared with the no-straw control, because straw mulching formed a physical barrier on the soil surface, which reduced the energy exchange between the soil and atmosphere. Straw mulching also reduces the soil bulk density [32], and it may promote the leaching of soil salts due to an increase in soil pore space [34]. In our experiment, only in the third year were the EC, AL-Na, Na_{BaCl2} and ESP values lower in mulched soil (183.1 mS cm^{-1}, 253.1 mg kg^{-1}, 419.6 mg kg^{-1} and 4.4 ESP%, respectively) than in un-mulched soil (204.1 mS cm^{-1}, 336.1 mg kg^{-1}, 506.1 mg kg^{-1} and 4.8 ESP%, respectively).

4.2. Relationship between Earthworm Abundance, Biomass and Soil Organic Matter Content and Total Weed Coverage

Organic mulching materials (straw, compost, plant leaves, etc.) generally increase water retention ability, soil health and fertility, provide protection against harsh environmental effects (e.g., erosion) for soil [34–37] and offer habitat, carbon input and food sources for soil fauna [38,39]. In our case, however, mulching treatments did not have any significant effect on earthworm abundance in any of the examined habitats (CL, BZ and WL), even though several researchers reported [40–42] greater earthworm abundance under mulched treatments compared to unmulched areas.

Therefore, the earthworm abundance values from the mulched and unmulched habitats were pooled for the analyses. Based on our results, significantly greater earthworm abundance was gained under the WL (274 pc m^{-2}) and the BZ (186 pc m^{-2}) compared to the CL (72 pc m^{-2}) (Figure 4A). The reason for this might be the fact that the soil disturbance in the BZ and WL habitat was very low or none, and the natural input of raw organic matter (leaves, twigs, bark, etc.) was already provided in those zones; thus, the soil environment was constant, undisturbed and more favorable for earthworms. This resulted in the growth of the earthworm population. This finding was in line with Norgrove et al. [43], who also found greater earthworm abundance in tropical agrisilvicultural systems under undisturbed timber plantations, compared to cropped plots.

The earthworm biomass values (Figure 4B; Table 5), however, gave almost similar results for BZ (54.9 g mm^{-2}) and WL (55.4 g mm^{-2}) habitats under the mulched treatments, suggesting that these individuals had greater biomass, even if their abundance (BZ: 172 pc mm^{-2}) was not so high. This suggests that mulching supported their weight growth as a food source. However, as mulching did not show any significant difference, we also pooled these values. As a result, WL was only significantly different from CL (Table 5) in earthworm biomass.

As for soil organic matter (SOM), the mulched habitats gained significantly greater values (Table 5), suggesting the positive effect of organic mulching on soils. The significantly greater SOM content under WL habitat could be due to the greater raw organic debris input compared to CL habitat. In CL, greater disturbance resulted in a lower SOM content.

The differences in weed composition were highly collated to the intensity of tillage and the coverage of trees. There was no significant difference in weed coverage between the tilled CL (0.61%) and the non-tilled BZ (1.91%), but weeds were significantly denser in WL (12.3%) than in either uncovered habitat (CL and BZ).

5. Conclusions

In conclusion, this study demonstrated the beneficial effects of straw mulching in reducing soil salinity and improving soil health indicators. The woody line (WL) and buffer zone (BZ) habitats showed a higher earthworm abundance compared to other areas. Additionally, mulching positively influenced earthworm biomass and soil organic matter content. Weed coverage was found to be influenced by tillage intensity and tree cover, with higher weed density observed in the woody line habitat. These findings emphasize the potential advantages of reused water irrigation, mulching, and agroforestry systems in promoting soil health and effective weed control. Overall, this research contributes to our understanding of sustainable soil management practices and provides insights for the implementation of agroforestry systems with reused water irrigation in similar contexts. Further research is warranted to explore the long-term effects and scalability of these practices. Agroforestry systems have the potential to enhance soil biodiversity and microbial activity, which play crucial roles in nutrient cycling and soil health. By studying the effects of agroforestry practices on soil biology, we can provide valuable insights into the mechanisms underlying soil quality enhancement in these systems.

Author Contributions: Conceptualization, Á.K., C.G. and B.B.; Data curation, Á.K., M.Z., B.S. and M.J.; Formal analysis, Á.K. and M.J.; Funding acquisition, C.G.; Supervision, C.B.; Methodology, I.K., J.T.K. and G.P.K.; Writing—original draft preparation, Á.K., M.Z., B.S. and B.B.; Writing—review and editing, C.B. and M.J. All authors contributed critically to the drafts and gave final approval for publication. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Hungarian Ministry of Agriculture under Project no. OD001 "Irrigation utilization of agricultural waste water in different crop cultures".

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UNESCO The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. *Future Food J. Food Agric. Soc.* **2017**, *5*, 80–81.
2. Ward, F.A. Enhancing Climate Resilience of Irrigated Agriculture: A Review. *J. Environ. Manag.* **2022**, *302*, 114032. [CrossRef] [PubMed]
3. Khan, M.M.; Siddiqi, S.A.; Farooque, A.A.; Iqbal, Q.; Shahid, S.A.; Akram, M.T.; Rahman, S.; Al-Busaidi, W.; Khan, I. Towards Sustainable Application of Wastewater in Agriculture: A Review on Reusability and Risk Assessment. *Agronomy* **2022**, *12*, 1397. [CrossRef]
4. Liu, X.; Li, L.; Wang, M. Analysis on the Knowledge Evolution Path of Public Acceptance of Reclaimed Water Research. *Water* **2022**, *14*, 2300. [CrossRef]
5. Hussain, M.I.; Farooq, M.; Muscolo, A.; Rehman, A. Crop Diversification and Saline Water Irrigation as Potential Strategies to Save Freshwater Resources and Reclamation of Marginal Soils—A Review. *Environ. Sci. Pollut. Res.* **2020**, *27*, 28695–28729. [CrossRef]
6. Cavalcante, E.S.; Lacerda, C.F.; Mesquita, R.O.; De Melo, A.S.; Da Silva Ferreira, J.F.; Dos Santos Teixeira, A.; Lima, S.C.R.V.; Da Silva Sales, J.R.; De Souza Silva, J.; Gheyi, H.R. Supplemental Irrigation with Brackish Water Improves Carbon Assimilation and Water Use Efficiency in Maize under Tropical Dryland Conditions. *Agriculture* **2022**, *12*, 544. [CrossRef]
7. Hasamuzzaman, M.; Fujita, M.; Islam, M.N.; Ahamed, K.U.; Nahar, K. Performance of Four Irrigated Rice Varieties under Different Levels of Salinity Stress. *Int. J. Integr. Biol.* **2009**, *6*, 85–90.
8. Liu, B.; Wang, S.; Kong, X.; Liu, X.; Sun, H. Modeling and Assessing Feasibility of Long-Term Brackish Water Irrigation in Vertically Homogeneous and Heterogeneous Cultivated Lowland in the North China Plain. *Agric. Water Manag.* **2019**, *211*, 98–110. [CrossRef]
9. Sun, G.; Zhu, Y.; Ye, M.; Yang, J.; Qu, Z.; Mao, W.; Wu, J. Development and Application of Long-Term Root Zone Salt Balance Model for Predicting Soil Salinity in Arid Shallow Water Table Area. *Agric. Water Manag.* **2019**, *213*, 486–498. [CrossRef]
10. El-Beltagi, H.S.; Basit, A.; Mohamed, H.I.; Ali, I.; Ullah, S.; Kamel, E.A.R.; Shalaby, T.A.; Ramadan, K.M.A.; Alkhateeb, A.A.; Ghazzawy, H.S. Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. *Agronomy* **2022**, *12*, 1881. [CrossRef]
11. Clare, A.; Shackley, S.; Joseph, S.; Hammond, J.; Pan, G.; Bloom, A. Competing Uses for China's Straw: The Economic and Carbon Abatement Potential of Biochar. *GCB Bioenergy* **2015**, *7*, 1272–1282. [CrossRef]
12. Akter, M.; Oue, H. Effect of Saline Irrigation on Accumulation of Na^+, K^+, Ca^{2+}, and Mg^{2+} Ions in Rice Plants. *Agriculture* **2018**, *8*, 164. [CrossRef]
13. Sarangi, S.K.; Maji, B.; Sharma, P.C.; Digar, S.; Mahanta, K.K.; Burman, D.; Mandal, U.K.; Mandal, S.; Mainuddin, M. Potato (*Solanum Tuberosum* L.) Cultivation by Zero Tillage and Paddy Straw Mulching in the Saline Soils of the Ganges Delta. *Potato Res.* **2021**, *64*, 277–305. [CrossRef]
14. Römbke, J.; Jänsch, S.; Didden, W. The Use of Earthworms in Ecological Soil Classification and Assessment Concepts. *Ecotoxicol. Environ. Saf.* **2005**, *62*, 249–265. [CrossRef]
15. Ahmed, S.; Marimuthu, N.; Tripathy, B.; Julka, J.M.; Chandra, K. Earthworm Community Structure and Diversity in Different Land-Use Systems along an Elevation Gradient in the Western Himalaya, India. *Appl. Soil Ecol.* **2022**, *176*, 104468. [CrossRef]
16. Lavelle, P.; Blanchart, E.; Martin, A.; Spain, A.V.; Martin, S. Impact of Soil Fauna on the Properties of Soils in the Humid Tropics. In *SSSA Special Publications*; Lal, R., Sanchez, P.A., Eds.; Soil Science Society of America and American Society of Agronomy: Madison, WI, USA, 2015; pp. 157–185, ISBN 978-0-89118-924-4.

17. González, G.; Zou, X.; Borges, S. Earthworm Abundance and Species Composition in Abandoned Tropical Croplands: Comparison of Tree Plantation and Secondary Forests. *Pedobiologia* **1996**, *40*, 385–391.
18. Melnichuk, R.D.S.; Tecimen, H.B.; Görres, J.H. Do the Invasive Earthworms Amynthas Agrestis (Oligochaeta: Megascolecidae) and Lumbricus Rubellus (Oligochaeta: Lumbricidae) Stimulate Oxalate-Based Browser Defenses in Jack-in-the-Pulpit (Arisaema Triphyllum) by Their Presence or Their Soil Biogeochemical Activity? *Soil Syst.* **2022**, *6*, 11. [CrossRef]
19. Bisht, R.; Pandey, H.; Bharti, D.; Kaushal, B.R. Population Dynamics of Earthworms (Oligochaeta) in Cultivated Soils of Central Himalayan Tarai Region. *Trop. Ecol.* **2003**, *44*, 229–234.
20. Charbonnier, F.; Roupsard, O.; Le Maire, G.; Guillemot, J.; Casanoves, F.; Lacointe, A.; Vaast, P.; Allinne, C.; Audebert, L.; Cambou, A.; et al. Increased Light-Use Efficiency Sustains Net Primary Productivity of Shaded Coffee Plants in Agroforestry System: NPP and LUE in a Coffee Agroforestry System. *Plant Cell Environ.* **2017**, *40*, 1592–1608. [CrossRef]
21. Rao, M.R.; Nair, P.K.R.; Ong, C.K. Biophysical Interactions in Tropical Agroforestry Systems. *Agrofor. Syst.* **1997**, *38*, 3–50. [CrossRef]
22. Mainardis, M.; Boscutti, F.; Rubio Cebolla, M.D.M.; Pergher, G. Comparison between Flaming, Mowing and Tillage Weed Control in the Vineyard: Effects on Plant Community, Diversity and Abundance. *PLoS ONE* **2020**, *15*, e0238396. [CrossRef] [PubMed]
23. Boinot, S.; Fried, G.; Storkey, J.; Metcalfe, H.; Barkaoui, K.; Lauri, P.-É.; Mézière, D. Alley Cropping Agroforestry Systems: Reservoirs for Weeds or Refugia for Plant Diversity? *Agric. Ecosyst. Environ.* **2019**, *284*, 106584. [CrossRef]
24. Schumacher, M.; Ohnmacht, S.; Rosenstein, R.; Gerhards, R. How Management Factors Influence Weed Communities of Cereals, Their Diversity and Endangered Weed Species in Central Europe. *Agriculture* **2018**, *8*, 172. [CrossRef]
25. Petrikovszki, R.; Zalai, M.; Tóthné Bogdányi, F.; Tóth, F. The Effect of Organic Mulching and Irrigation on the Weed Species Composition and the Soil Weed Seed Bank of Tomato. *Plants* **2020**, *9*, 66. [CrossRef] [PubMed]
26. IUSS Working Group WRB World Reference Base for Soil Resources. *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*, 4th ed.; International Union of Soil Sciences (IUSS): Vienna, Austria, 2022; ISBN 979-8-9862451-1-9.
27. Berzi-Nagy, L.; Mozsár, A.; Tóth, F.; Gál, D.; Nagy, Z.; Nagy, S.A.; Kerepeczki, É.; Antal, L.; Sándor, Z.J. Effects of Different Fish Diets on the Water Quality in Semi-Intensive Common Carp (*Cyprinus Carpio*) Farming. *Water* **2021**, *13*, 1215. [CrossRef]
28. Tóth, F.; Zsuga, K.; Kerepeczki, É.; Berzi-Nagy, L.; Körmöczi, L.; Lövei, G.L. Seasonal Differences in Taxonomic Diversity of Rotifer Communities in a Hungarian Lowland Oxbow Lake Exposed to Aquaculture Effluent. *Water* **2020**, *12*, 1300. [CrossRef]
29. Richards, L.A. Diagnosis and Improvement of Saline and Alkali Soils. In *Agricultural Handbook*; United Sates Department of Agriculture: Washington, DC, USA, 1954.
30. James, M. Gregory Soil Cover Prediction with Various Amounts and Types of Crop Residue. *Trans. ASAE* **1982**, *25*, 1333–1337. [CrossRef]
31. Stefanovits, P.; Filep, G.; Füleky, G. *Talajtan*; Mezőgazda Kiadó: Budapest, Magyarország, 2010; ISBN 978-963-286-563-8.
32. Zhang, Z.; Zhang, Z.; Feng, G.; Lu, P.; Huang, M.; Zhao, X. Biochar Amendment Combined with Straw Mulching Increases Winter Wheat Yield by Optimizing Soil Water-Salt Condition under Saline Irrigation. *Agriculture* **2022**, *12*, 1681. [CrossRef]
33. Samui, I.; Skalicky, M.; Sarkar, S.; Brahmachari, K.; Sau, S.; Ray, K.; Hossain, A.; Ghosh, A.; Nanda, M.K.; Bell, R.W.; et al. Yield Response, Nutritional Quality and Water Productivity of Tomato (*Solanum Lycopersicum* L.) Are Influenced by Drip Irrigation and Straw Mulch in the Coastal Saline Ecosystem of Ganges Delta, India. *Sustainability* **2020**, *12*, 6779. [CrossRef]
34. Huang, M.; Zhang, Z.; Zhai, Y.; Lu, P.; Zhu, C. Effect of Straw Biochar on Soil Properties and Wheat Production under Saline Water Irrigation. *Agronomy* **2019**, *9*, 457. [CrossRef]
35. Li, R.; Hou, X.; Jia, Z.; Han, Q.; Ren, X.; Yang, B. Effects on Soil Temperature, Moisture, and Maize Yield of Cultivation with Ridge and Furrow Mulching in the Rainfed Area of the Loess Plateau, China. *Agric. Water Manag.* **2013**, *116*, 101–109. [CrossRef]
36. Chen, Y.; Wen, X.; Sun, Y.; Zhang, J.; Wu, W.; Liao, Y. Mulching Practices Altered Soil Bacterial Community Structure and Improved Orchard Productivity and Apple Quality after Five Growing Seasons. *Sci. Hortic.* **2014**, *172*, 248–257. [CrossRef]
37. Prosdocimi, M.; Tarolli, P.; Cerdà, A. Mulching Practices for Reducing Soil Water Erosion: A Review. *Earth-Sci. Rev.* **2016**, *161*, 191–203. [CrossRef]
38. Jodaugienė, D.; Pupalienė, R.; Sinkevicienė, A.; Marcinkevicienė, A.; Zebrauskaitė, K.; Baltaduonytė, M.; Cepulienė, R. The Influence of Organic Mulches on Soil Biological Properties. *Zemdirb. -Agric.* **2010**, *97*, 33–40.
39. Kahlon, M.S.; Lal, R.; Ann-Varughese, M. Twenty Two Years of Tillage and Mulching Impacts on Soil Physical Characteristics and Carbon Sequestration in Central Ohio. *Soil Tillage Res.* **2013**, *126*, 151–158. [CrossRef]
40. Tian, G.; Kang, B.T.; Brussaard, L. Effect of Mulch Quality on Earthworm Activity and Nutrient Supply in the Humid Tropics. *Soil Biol. Biochem.* **1997**, *29*, 369–373. [CrossRef]
41. Simon, B.; Boziné Pullai, K.; Selmeczi, D.; Sebők, A.; Tóthné Bogdányi, F.; Weldmichael, T.G.; Zalai, M.; Nsima, J.P.; Tóth, F. Green Corridors May Sustain Habitats for Earthworms in A Partially Converted Grassland. *Agronomy* **2022**, *12*, 793. [CrossRef]
42. Radics, Z.; Dekemati, I.; Gyuricza, C.; Simon, B.; Ibrahim, H.; Vinogradov, S.; Birkás, M. Effects of Irrigation and Organic Mulchingon the Abundance and Biomass of Earthworms. *Pol. J. Environ. Stud.* **2022**, *31*, 2811–2821. [CrossRef]
43. Norgrove, L.; Csuzdi, C.; Hauser, S. Effects of Cropping and Tree Density on Earthworm Community Composition and Densities in Central Cameroon. *Appl. Soil Ecol.* **2011**, *49*, 268–271. [CrossRef]