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Examination of earthworm abundance; biomass and correlations of soil organic matter in an irrigated (with river and catfish effluent water) and mulched agroforestry system

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Abstract: The aim of our study was to evaluate a complex agroforestry system with the intercropping of aerobic rice and the utilization of reclaimed water for sustainability and climate change adaptation. The foreseeable positive outcomes of the intercropping system could be higher yields for the arable crops, additional woody products and indirectly favourable microclimate, water conservation, increased biodiversity and wind damage reduction. 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 a three-year irrigation period, we investigated the woody line (WL), the buffer zone (BZ) and the crop line (CL) habitats. In our small-scale (0.3 ha) experiment, aerobic rice production took place between poplar and willow rows. The rice cultivar and woody lines were irrigated with different doses of river water and effluent water from an intensive catfish farm. The effect of irrigation and organic mulching on earthworm abundance, biomass and species composition was also investigated. In conclusion, this study demonstrated the beneficial effects of straw mulching on reducing soil salinity and improving soil health indicators. Based on our results, significantly greater earthworm abundance (274 ind 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%). These findings emphasize the potential advantages of reused water irrigation, mulching, and agroforestry systems in promoting soil health and effective weed control. 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.

Keywords: irrigation, aerobic rice, organic mulching, earthworm, agroforestry system

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Introduction

The world population is projected to increase to 9 billion by 2050 (Shiferaw et al., 2011). Such growth increases the global need for the production of more food, fiber and fuel. However, future climate extremes are pro-

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jected to threaten the goal of meeting the ever-increasing population's food, fibre and fuel demands. Therefore, growers must adapt to future environmental changes by practicing, climate-smart agriculture (Zizinga et al., 2022).

Agroforestry practices globally distribute numerous ecological benefits (for instance, climate change mitigation and climate adaptation), and land preservation (e.g., erosion control, enhanced soil fertility). Additionally, methods of combating modern agricultural practices complications, such as loss of moisture quality due to overuse of synthetic nutrient supplements (e.g., N and P) and pesticides. However, the incorporation of trees in agriculture may cause competition for available water with planted crops. In southern Australia, studies revealed a positive correlation between crop yield reduction and moisture competition alley systems (Hall et al., 2002; Unkovich et al., 2003). Kowalchuk and Jong (1995) discovered that competition for moisture is the main factor impacting intercropped grain quantity of spring wheat and shelterbelts in Western Saskatchewan, particularly in dry periods.

Fish effluent water rich in organic matter resulting from excretion and fish feed can be used as a supplement to curb water competition between crops and plants in agroforestry systems (AFS). Additionally, the soil and plants' physical, chemical, and biological properties will benefit from its high nutrient status (Kolozsvári et al., 2021).

Furthermore, organic mulch improves the physical, chemical and biological properties of the soil. The two common materials utilized as ground cover mulch that may decrease soil moisture loss are stubble and plastic. The two further may improve water use efficiency while regulating the soil temperature to aid crop development (Cook et al., 2006; Vincent-Caboud et al., 2019; Yu et al., 2018). Similar to Paulis (2007), an increase in soil organic carbon (SOC) in the top 200 mm was observed owing to the addition of tree stubble residue (Youkhana & Idol, 2009) predominantly in more stable fractions.

Earthworms are biological soil tillers and they are subjected to changes in the physical and chemical properties of the soil (Bakti et al., 2017). Several authors mentioned that the impact of tree plantations on earthworm abundance can be achieved by changing the chemical and/or physical soil properties (moisture regime, pH, SOM levels, biomass additions) (Bakti et al., 2022; Kun et al., 2023; Tian et al., 2000; Gonzalez & Zou, 1999). Earthworm abundance prefers minimal disturbance and more conventional agroforestry management methods (Römbke et al., 2009). Studies by Vaupel et al. (2023) observed higher earthworm density and biomass in agroforestry system tree rows systems compared to monoculture cropland.

AFS effectively improves organic matter addition, consequently improving physical properties, including soil structure, and pores (Kumar et al., 2020). Moreover, AFS as a universal system, can decrease nitrate leaching (Kay et al., 2018), and enhance biodiversity, while sustaining agri-productivity (Pardon et al., 2018; Swieter et al., 2019) and food safety of wheat and barley (Beule et al., 2019). In this context, incorporating the production of food, fibre and fuel in AFS play a significant role in carbon sequestration. For example, Rizvi et al. (2011) observed 50t/ha carbon was sequestered under 7 years of rotation in poplar AFS. Moreover, due to the direct relationship involving soil organic carbon (SOC) and soil organic matter (SOM), an increase in SOC storage by AFS will increase SOM (Gyuricza et al., 2018).

Managing high-saline agricultural irrigation water is particularly important during droughts, when plants are already growing in stressful environments. Integrated soil and water management can help minimize adverse effects. In a water conservation

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context, high-saline water can be used in drought-affected areas where freshwater is limited, especially with systems such as drip irrigation, where salt accumulation can be minimized (Hussain et al., 2020). Cavalcante et al. (2022) 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. Some waters with high salt content may contain trace elements such as magnesium, potassium or sodium, which can improve the nutrient supply of the soil in small amounts. The salt content may also improve the stress response capacity of some plants (induced stress mechanisms). 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 (Liu et al., 2019; Sun et al., 2019). The benefits only occur when the salinity level is precisely controlled and adapted to the needs of salt-tolerant crops and applied under controlled conditions. The leaching of salts and the maintenance of soil structure are of paramount importance for the long-term sustainability of this type of irrigation. Although high-saline irrigation water is not an ideal solution, under the right conditions and with careful management, it can provide certain benefits for crop production.

Our study aimed to evaluate a complex agroforestry system with the intercropping of aerobic rice and the utilization of reclaimed water for sustainability and climate change adaptation. 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. The diversity of the project, which results from the complexity of the research's goals covering each slice of the biosphere, hydrosphere, lithosphere and atmosphere, requires that the topic has dealt with consortium level (the Hungarian University of Agriculture and Life Sciences and the University of Sopron).

Materials and Methods

2.1. Site Description and Climatic Condition

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 (Fig 1).

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. 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, the second (12.1 °C) and third year (11.6 °C) were cooler.

At the experimental plantation, two types of trees were planted in 2013, one is the candidate variety willow (*Salix alba* L."82" Naperti clone) of the University of Sopron Forest Research Institute, Department of Plantation Forestry and *Populus* × *euramericana* cv. *Kopecky* poplar. This clone is an artificial hybrid created by Ferenc Kopecky at the Sárvár Experimental Station of the University of Sopron Forestry Science Institute

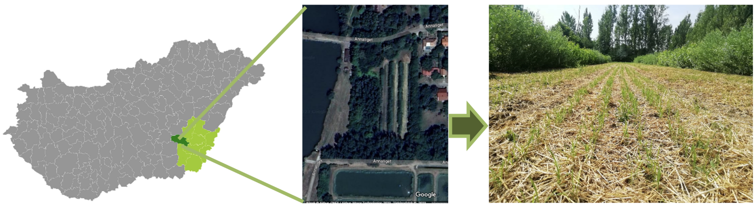

Figure 1: Localization map of the experimental site Szarvas, Hungary.

(B. Tóth, 2006). The geographical origin of the willow clone included in the experiment is Eastern Hungary. The use of the breed cultivation is for energy purposes, the variety was included in the national variety protection list in 2013 under the variety name "Naperti".

The area of the experimental site is 0.3 ha, there are 18 plots of the same size in the area: 136.5 m^2, one plot is 13 m long and 10.5 m wide. There are 8 rows of trees in each plot. The row spacing is 2.5 m and the stem spacing is 0.5 m. All sites are irrigated (a non-irrigated plot was not found in this experiment) from two types of irrigation water sources. 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-meter width) (Fig 1). The soil type belongs to Vertisols (IUSS Working Group WRB, 2022) with clay texture, 8.3 pH, 5.4% total calcium carbonate, and 2.4% total organic carbon.

2.1. Site Description and Climatic Condition

For irrigation, two types of water were used in the experiment. 1) The "Körös River" (natural surface water, K) originated from the the Bikazug Oxbow Lake of the Körös River, which is suggested for irrigation due to its appropriate quality for irrigation purposes (Kun et al., 2017). 2) The "Effluent water" (E) originating from an intensive African catfish farm. The fish farm used water from deep-groundwater wells to fill their fish farming pools, and then to treat the used water the farm established a constructed wetland (Kolozsvári et al., 2021). The combined constructed wetland system consists of two stabilization ponds and two wetlands (F. Tóth et al., 2016). The water from the first stabilization pond was used to irrigate this 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. This wastewater contains large amounts of debris such as fish faeces, and organic materials (F. Tóth et al., 2020). According to the irrigation water classification of USDA (Gregory, 1982; Richards, 1954), the wastewater belongs to the C3-S2 group with high salinity and medium sodium hazard.

2.3. Treatments and mulching

The experimental site (80 × 10 m) was divided into two parts, on one we used mulch (mulched plots) (400 m^2), and on the other (400 m^2) there was no ground cover (unmulched plots). Both sites were irrigated with wastewater using micro-sprinkler irrigation. In each experimental year (2019, 2020, and 2021) the amount of irrigation water was 150 mm $year^{-1}$. Irrigation was done five times each year with 30 mm. The results of the salt content and other values were published earlier (Kun et al., 2023), here we only focus on the effect of mulching on earthworms and soil health.

Winter wheat straw (0.25 kg m^{-2}) was applied for mulching (71% soil cover). The mass of the ground cover material was cal-

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culated based on the equation defined in Stefanovits' research (Stefanovits, Filep, & Füleky, 2010).

An energy plantation was installed in the area in 2013, it was transformed and we established the agroforestry system in 2019. Irrigation has been done with agricultural water from fish farming and natural "Körös River" with single and double doses since 2013. In the case of the double-dose treatment, salt accumulation began to appear in the soil due to the negative effect of high-salt irrigation water from fish farming. In order to prevent this and to improve the soil, we used liming and straw mulch covering in the experimental area. The mulch was applied every other year with an amount of 2.5 t/ha, because the straw breaks down slowly.

2.4. Sampling and analyses

Composite soil samples were taken from 0-15 and 15-30 cm depths. Regarding the applied treatments, soil samples were taken from mulched (straw) and unmulched areas in four repetitions. The soil carbon content was determined by CNS analyser (Elementor, Vario MAX Cube), and the soil organic matter was calculated by multiplying the result by 1.74 (Zhang et al., 2022).

Disturbed bulk 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 and 30-60 cm, however, we did not differentiate between soil depths during the statistical analysis.

The specific electrical conductivity (EC) of the soil 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 by 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).

$$ESP(exchangeablesodiumpercantage, \%) = \frac{Na}{(Na+K+Ca+Mg)} \times 100 \quad (1)$$

where, Na^+, K and Mg_2^+, concentrations are expressed in milliequivalents per 100 g of soil (Gregory, 1982; Richards, 1954).

Concerning the earthworm sampling, the sampled habitats 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; c) *woody line* (WL): area under the tree line, where no soil disturbance or agricultural cropping occurred. The samples were collected in four repetitions, by hand-sorting method (ISO 23611-1:2018, 2006). 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 the mulched areas three times in 2022, in spring (April 29), in summer (August 17) and in autumn (October 14). Data collection included all non-crop plants with four replications of all habitats. For each panel, for each distance measured from the edge and for each time, 4 pieces (Zalai et al., 2012), on a 1×1 meter square, were assessed by direct coverage percentage estimation of the coverage of the present weeds by species (Németh & Sárfalvi, 1998). Thus, 4 sample plots were selected per transect, in the tree rows, in the immediate vicinity of the tree rows (buffer zone) and in the cultivated areas. So, the sample plots were selected at the "0" meter (in the undisturbed strip), at the 1 meter directly at the edge of the undisturbed strip at a distance of 0-100 cm from it), at the 2nd meter (at a distance of 100-200 cm from the cultivation edge) and at the 4th meter (at a distance of 300-400 cm from the cultivation edge). The results obtained were averaged per field and per distance from the edge, so the averaged results are presented.

2.5. Statistical analyses

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

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

Results

3.1. Earthworm abundance and biomass

Based on MANOVA, (Fig. 2/B; Tab. 1), significantly greater earthworm abundance taken from WL (264 pc m^{-2}) was found as compared to CL (84 pc m^{-2}) under mulched treatments. The unmulched treatments showed a similar tendency, WL (284 pc m^{-2}) was significantly greater than CL (60 pc m^{-2}).

As for earthworm biomass (Fig. 2/A; Tab. 1), significantly greater values were found in WL (55.4 g m^{-2}) and BZ (55.1 g m^{-2}) as compared to CL (24.6 g m^{-2}) habitat in mulched treatments. Whereas, in unmulched treatments, significantly greater biomass values were obtained in WL (52.6 g m^{-2}) as compared to BZ (26.2 g m^{-2}) and CL (14.1 g m^{-2}) habitats.

3.2. Soil Organic Matter Content and Total Weed Coverage

Regarding the soil organic matter (SOM) content, the effect of mulching was statistically significant (Fig. 2/C; Tab. 1). Significantly greater SOM content was detected under the mulched treatment in WL (4.7%) as compared to CL (4.5%) habitat. Concerning the unmulched treatments, the following decreasing order was obtained: 4.0 (WL), 3.9 (BZ), and 3.8% (CL), with significant differences only between WL and CL.

As for the total weed coverage (Fig. 2/D; Tab. 1), the mulched plots were examined

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Table 1: 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 agroforestry 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	MANOVA		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

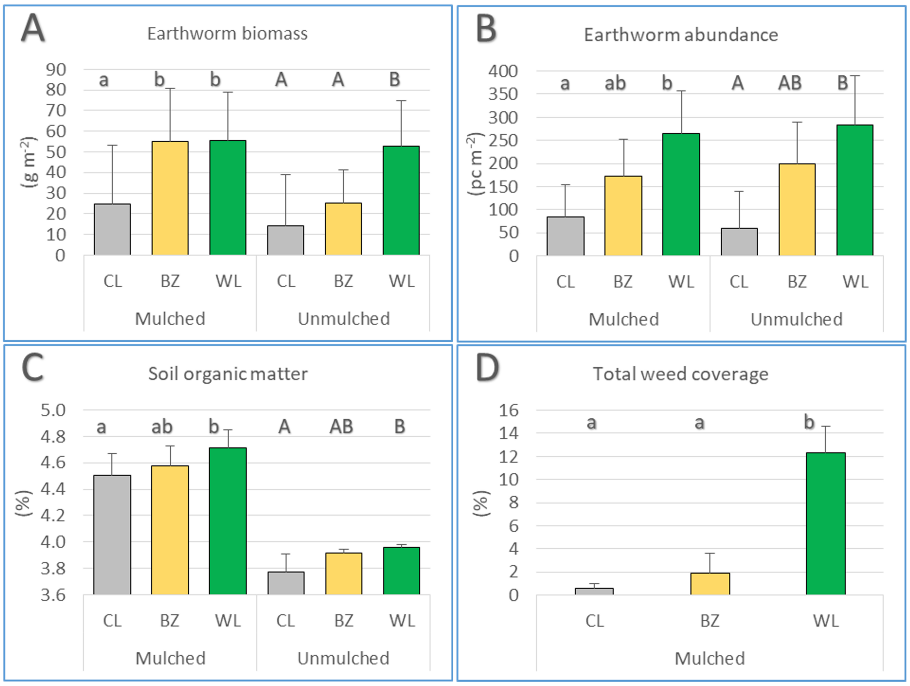

Figure 2: Effect of mulching and habitat on earthworm abundance (pc m^{-2}) (B), earthworm biomass (g m^{-2}) (A), soil organic matter (%) (C) and total weed coverage (%) (D) in an agroforestry experiment with different habitats: crop line (CL), buffer zone (BZ) and woody line (WL). (Szarvas, Hungary, 2022).

only. 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. Based on the results obtained, we found that there was a significant difference in vegetation depending on the different cultivation. The largest part of the cover of the WL was made up of Geophyta species, such as *Rubus caesius, Convolvulus arvensis, Elymus repens* and *Calystegia sepium*. We experienced a smaller degree of weeding in the CL between the WL, and both Geophyta and Therophyta species appeared in these areas. The weeds most typical of the CL were the following: *Convolvulus arvensis, Taraxacum officinale, Elymus repens, Cirsium arvense, Veronica spp., Calystegia sepium, Setaria glauca, Digitaria sanguinalis* and *Ballota nigra*.

Applying mulch is a sustainable, economical and environmentally friendly way to support crop production, while offering numerous benefits in maintaining soil and plant health (El-Beltagi et al., 2022). Mulch reduces evaporation from the soil surface, thus preserving soil moisture for a longer period of time, protecting the soil from the direct effects of large amounts of precipitation, preventing soil compaction and surface crusting. Soil cover protects the soil from erosion caused by wind and water, slows down water runoff, thus reducing soil erosion. The mulch layer covering the soil suppresses the germination and growth of weeds, as it blocks their access to light (Clare et al., 2015). Organic mulches (e.g. straw, compost, tree bark) form humus when they decompose, which improves the structure and fertility of the soil. They promote the activity of beneficial microorganisms, fungi and earthworms living in the soil. These organisms help the nutrient cycle and health of the soil (Akter & Oue, 2018).

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Discussion

Several authors stated that organic mulching materials increase water retention capacity, enhance soil health and fertility, and protect the soils against environmental extremes (e.g. erosion) (Chen et al., 2014; Prosdocimi et al., 2016) and also provide habitat, carbon input and food source for soil organisms (Jodaugienė et al., 2010). However, in our study, mulching treatment did not result in any significant growth of earthworm abundance. Despite other studies (Radics et al., 2022; Simon et al., 2022; Tian et al., 1997), they found greater earthworm abundance due to mulching materials compared to unmulched areas.

Therefore, we pooled the earthworm abundance values of the mulched and unmulched treatments together. As a result, we obtained significantly greater earthworm abundance in WL (274 pc m^{-2}) and BZ (186 pc m^{-2}) as compared to CL (72 pc m^{-2}) (Figure 4/B). This might be due to low soil disturbance in BZ and WL habitats and high natural input of raw organic matter (plant leaves, roots, etc.) Our result was in line with Norgrove et al. (2011), who stated that greater earthworm abundance was found under undisturbed timber plantation in tropical agrisilvicultural systems compared to cropped plots.

As for earthworm biomass (Fig. 2/A; Tab. 1), almost similar values were gained for BZ (54.9 g m^{-2}) and WL (55.4 g m^{-2}) in mulched treatments. It means that these individuals could gain greater biomass, even with lower abundance (BZ: 172 pc m^{-2}) values, suggesting that mulching provided a great/better weight increase as a food source. Since mulching did not show any significant differences, we pooled these values together, and found that earthworm biomass in WL differed significantly from CL (Tab. 1).

Regarding the soil organic matter (SOM) content, the mulched treatments provided significantly higher values (Tab. 1), suggesting the positive effect of organic mulching on soils. The WL habitat probably provided greater raw organic residue and, thus, resulted in significantly greater SOM content compared to the CL habitat. The intensive disturbance in CL resulted in lower SOM content.

The difference in weed composition was highly collated to the intensity of tillage and 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 on WL (12.3%) than both not-covered habitats (CL and BZ).

Conclusion

In conclusion, this study highlights the positive impact of straw mulching in reducing soil salinity and enhancing soil health indicators. It was found that the woody line (WL) and buffer zone (BZ) habitats exhibited higher earthworm abundance compared to crop line (CL) habitats. The use of mulching also contributed to increased earthworm biomass and higher soil organic matter content. Weed coverage, influenced by both tillage intensity and tree cover, showed higher weed density in the woody line habitat. These results underscore the advantages of reused water irrigation, mulching, and agroforestry systems in promoting soil health and controlling weeds. This research provides valuable insights into sustainable soil management practices and supports the integration of agroforestry systems with reused water irrigation. Further investigation into the long-term effects and scalability of these practices is essential. Agroforestry systems have the potential to improve soil biodiversity and microbial activity, which are key drivers of nutrient cycling and soil health. Studying the effects of these practices on soil biology will enhance our understanding of how agroforestry can contribute to soil quality improvement.

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References

Akter, M., & Oue, H. (2018). Effect of Saline Irrigation on Accumulation of Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} Ions in Rice Plants. Agriculture **8**(10), 164. doi: 10.3390/agriculture8100164

Bakti, B., Bozán, C., Keserű, Z., Jancsó, M., Kolozsvári, I., Gyuricza, C., & Kun, Á. (2022). Interactions between trees, crops and pedosphere: experiences in irrigated bioenergy-agroforestry system in Hungary. In D. Spano et al. (Eds.), Euraf2022 book of abstracts (p. 115). Nuoro, Italy.

Bakti, B., Simon, B., & Gyuricza, C. (2017). Növénytáplálási kísérletek talajtani vizsgálata kedvezőtlen termőhelyen létesített fás szárú energetikai ültetvényben. In J. Kátai & Z. Sándor (Eds.), Okszerű talajhasználat – Talajvédelem (p. 327-337). Debrecen.

Beule, L., Lehtsaar, E., Rathgeb, A., & Karlovsky, P. (2019). Crop Diseases and Mycotoxin Accumulation in Temperate Agroforestry Systems. Sustainability **11**(10), 2925. doi: 10.3390/su11102925

Cavalcante, E. S., Lacerda, C. F., Mesquita, R. O., de Melo, A. S., da Silva Ferreira, J. F., dos Santos Teixeira, A., … Gheyi, H. R. (2022). Supplemental Irrigation with Brackish Water Improves Carbon Assimilation and Water Use Efficiency in Maize under Tropical Dryland Conditions. Agriculture **12**(4), 544. doi: 10.3390/agriculture12040544

Chen, Y., Wen, X., Sun, Y., Zhang, J., Wu, W., & Liao, Y. (2014). Mulching practices altered soil bacterial community structure and improved orchard productivity and apple quality after five growing seasons. Scientia Horticulturae **172**(), 248-257. doi: 10.1016/j.scienta.2014.04.010

Clare, A., Shackley, S., Joseph, S., Hammond, J., Pan, G., & Bloom, A. (2015). Competing uses for China's straw: the economic and carbon abatement potential of biochar. GCB Bioenergy **7**(6), 1272-1282. doi: 10.1111/gcbb.12220

Cook, H. F., Valdes, G. S., & Lee, H. C. (2006). Mulch effects on rainfall interception, soil physical characteristics and temperature under *Zea mays* L. Soil and Tillage Research **91**(1), 227-235. doi: 10.1016/j.still.2005.12.007

El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A. R., … Ghazzawy, H. S. (2022). Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. Agronomy **12**(8), 1881. doi: 10.3390/agronomy12081881

Gonzalez, G., & Zou, X. (1999). Plant and litter influences on earthworm abundance and community structure in a tropical wet forest. Biotropica **31**(3), 486-493. doi: 10.1111/j.1744-7429.1999.tb00391.x

Gregory, J. M. (1982). Soil Cover Prediction with Various Amounts and Types of Crop Residue. Transactions of the ASAE **25**(5), 1333-1337. doi: 10.13031/2013.33723

Gyuricza, C., Bakti, B., Benke, A., Kovács, G. P., Balla, I., & Borovics, A. (2018). Energetikai ültetvények szerepe az agrárerdészeti rendszerekben. In C. Gyuricza, A. Borovics, G. Radó, & N. Somogyi (Eds.), Agrárerdészet (p. 171-218). Gödöllő, Hungary.

Hall, D. J. M., Sudmeyer, R. A., McLernon, C. K., & Short, R. J. (2002). Characterisation of a windbreak system on the south coast of Western Australia. 3. Soil water and hydrology. Australian Journal of Experimental Agriculture **42**(6), 729. doi: 10.1071/ea02009

Hussain, M. I., Farooq, M., Muscolo, A., & Rehman, A. (2020). Crop diversification and saline water irrigation as potential strategies to save freshwater resources and reclamation of marginal soils – a review. Environmental Science and Pollution Research **27**(23), 28695-28729. doi: 10.1007/s11356-020-09111-6

IUSS Working Group WRB. (2022). World Reference Base for Soil Resources. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Vienna, Austria: International Union of Soil Sciences (IUSS).

Jodaugienė, D., Pupalienė, R., Sinkevičienė, A., Marcinkevičienė, A., Žebrauskaitė, K., Baltaduonytė, M., & Čepulienė, R. (2010). The influence of organic mulches on soil biological properties. Zemdirbyste-Agriculture **97**(2), 33-40.

Kay, S., Crous-Duran, J., Ferreiro-Domínguez, N., García de Jalón, S., Graves, A., Moreno, G., … Herzog, F. (2018). Spatial similarities between European agroforestry systems and ecosystem services at the landscape scale. Agroforestry Systems **92**(4), 1075-1089. doi: 10.1007/s10457-017-0132-3

Kolozsvári, I., Kun, Á., Jancsó, M., Bakti, B., Bozán, C., & Gyuricza, C. (2021). Utilization of Fish Farm Effluent for Irrigation Short Rotation Willow (*Salix alba* L.) under Lysimeter Conditions. Forests **12**(4), 457. doi: 10.3390/f12040457

Kowalchuk, T. E., & Jong, E. d. (1995). Shelterbelts and their effect on crop yield. Canadian Journal of Soil Science **75**(4), 543-550. doi: 10.4141/cjss95-077

Kumar, R., Ghosh, M., Kumar, S., & Prasad, M. (2020). Single Cell Metabolomics: A Future Tool to Unmask Cellular Heterogeneity and Virus-Host Interaction in Context of Emerging Viral Diseases. Frontiers in Microbiology **11**(), 1152. doi: 10.3389/fmicb.2020.01152

Kun, Á., Bozán, C., Oncsik, M. B., & Barta, K. (2017). Evaluating of wastewater irrigation in lysimeter experiment through energy willow yields and soil sodicity. Carpathian Journal of Earth and Environmental Sciences **13**(1), 77-84. doi: 10.26471/cjees/2018/013/008

Kun, Á., Simon, B., Zalai, M., Kolozsvári, I., Bozán, C., Jancsó, M., … Bakti, B. (2023). Effect of Mulching on Soil Quality in an Agroforestry System Irrigated with Reused Water. Agronomy **13**(6), 1622. doi: 10.3390/agronomy13061622

Liu, B., Wang, S., Kong, X., Liu, X., & Sun, H. (2019). Modeling and assessing feasibility of long-term brackish water irrigation in vertically homogeneous and heterogeneous cultivated lowland in the North China Plain. Agricultural Water Management **211**(), 98-110. doi: 10.1016/j.agwat.2018.09.030

Németh, I., & Sárfalvi, B. (1998). Gyomfelvételezési módszerek értékelése összehasonlító vizsgálatok alapján. Növényvédelem **34**(1), 15-22.

Norgrove, L., Csuzdi, C., & Hauser, S. (2011). Effects of cropping and tree density on earthworm community composition and densities in central Cameroon. Applied Soil Ecology **49**(), 268-271. doi: 10.1016/j.apsoil.2011.05.008

Pardon, P., Reubens, B., Mertens, J., Verheyen, K., De Frenne, P., De Smet, G., … Reheul, D. (2018). Effects of temperate agroforestry on yield and quality of different arable intercrops. Agricultural Systems **166**(), 135-151. doi: 10.1016/j.agsy.2018.08.008

Paulis, J. (2007). Measurable soil organic carbon fractions for modelling soil carbon sequestration (Unpublished doctoral dissertation). University of Guelph, Guelph, Canada.

Prosdocimi, M., Tarolli, P., & Cerdà, A. (2016). Mulching practices for reducing soil water erosion: A review. Earth-Science Reviews **161**(), 191-203. doi: 10.1016/j.earscirev.2016.08.006

Radics, Z., Dekemati, I., Gyuricza, C., Simon, B., Ibrahim, H., Vinogradov, S., & Birkás, M. (2022). Effects of Irrigation and Organic Mulching on the Abundance and Biomass of Earthworms. Polish Journal of Environmental Studies **31**(3), 2811-2821. doi: 10.15244/pjoes/143258

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils. Soil Science **78**(2), . doi: 10.1097/00010694-195408000-00012

Rizvi, R. H., Dhyani, S. K., Yadav, R. S., & Singh, R. (2011). Biomass production and carbon stock of poplar agroforestry systems in Yamunanagar and Saharanpur districts of northwestern India. Current Science **100**(5), 736-742.

Römbke, J., Schmidt, P., & Höfer, H. (2009). The earthworm fauna of regenerating forests and anthropogenic habitats in the coastal region of Paraná. Pesquisa Agropecuaria Brasileira **44**(8), 1040-1049. doi: 10.1590/S0100-204X2009000800037

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Security **3**(3), 307-327. doi: 10.1007/s12571-011-0140-5

Simon, B.,Boziné Pullai, K., Selmeczi, D., Sebők, A., Tóthné Bogdányi, F., Weldmichael, T. G., … Tóth, F. (2022). Green Corridors May Sustain Habitats for Earthworms in A Partially Converted Grassland. Agronomy **12**(4), 793. doi: 10.3390/agronomy12040793

Stefanovits, P., Filep, G., & Füleky, G. (2010). Talajtan. Budapest: Mezőgazda Kiadó.

Sun, G., Zhu, Y., Ye, M., Yang, J., Qu, Z., Mao, W., & Wu, J. (2019). Development and application of long-term root zone salt balance model for predicting soil salinity in arid shallow water table area. Agricultural Water Management **213**(), 486-498. doi: 10.1016/j.agwat.2018.10.043

Swieter, A., Langhof, M., Lamerre, J., & Greef, J. M. (2019). Long-term yields of oilseed rape and winter wheat in a short rotation alley cropping agroforestry system. Agroforestry Systems **93**(5), 1853-1864. doi: 10.1007/s10457-018-0288-5

Tian, G., Kang, B., & Brussaard, L. (1997). Effect of mulch quality on earthworm activity and nutrient supply in the humid tropics. Soil Biology and Biochemistry **29**(3), 369-373. doi: 10.1016/S0038-0717(96)00099-5

Tian, G., Olimah, J., Adeoye, G., & Kang, B. (2000). Regeneration of Earthworm Populations in a Degraded Soil by Natural and Planted Fallows under Humid Tropical Conditions. Soil Science Society of America Journal **64**(1), 222-228. doi: 10.2136/sssaj2000.641222x

Tóth, B. (2006). Nemesnyár-fajták ismertetője–Irányelvek a nemesnyár-fajták kiválasztásához. Budapest: Agroinform Kiadó.

Tóth, F., Kerepeczki, É., Berzi, N., & Gál, D. (2016). Létesített vizes élőhelyek hasznosítása az intenzív haltermelés elfolyóvizének kezelésében. Kutatói utánpótlást elősegítő program I. szakmai konferenciája. Gödöllő: NAIK.

Tóth, F., Zsuga, K., Kerepeczki, É., Berzi-Nagy, L., Körmöczi, L., & Lövei, G. L. (2020). Seasonal Differences in Taxonomic Diversity of Rotifer Communities in a Hungarian Lowland Oxbow Lake Exposed to Aquaculture Effluent. Water **12**(5), 1300. doi: 10.3390/w12051300

Unkovich, M., Blott, K., Knight, A., Mock, I., Rab, A., & Portelli, M. (2003). Water use, competition, and crop production in low rainfall, alley farming systems of south-eastern Australia. Australian Journal of Agricultural Research **54**(8), 751. doi: 10.1071/ar03049

Vaupel, A., Bednar, Z., Herwig, N., Hommel, B., Moran-Rodas, V. E., & Beule, L. (2023). Tree-distance and tree-species effects on soil biota in a temperate agroforestry system. Plant and Soil **487**(1), 355-372. doi: 10.1007/s11104-023-05932-9

Vincent-Caboud, L., Casagrande, M., David, C., Ryan, M. R., Silva, E. M., & Peigne, J. (2019). Using mulch from cover crops to facilitate organic no-till soybean and maize production. A review. Agronomy for Sustainable Development **39**(5), 45. doi: 10.1007/s13593-019-0590-2

Youkhana, A., & Idol, T. (2009). Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. Soil Biology and Biochemistry **41**(12), 2527-2534. doi: 10.1016/j.soilbio.2009.09.011

Yu, Y.-Y., Turner, N. C., Gong, Y.-H., Li, F.-M., Fang, C., Ge, L.-J., & Ye, J.-S. (2018). Benefits and limitations to straw- and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. European Journal of Agronomy **99**(), 138-147. doi: 10.1016/j.eja.2018.07.005

Zhang, Z., Zhang, Z., Feng, G., Lu, P., Huang, M., & Zhao, X. (2022). Biochar Amendment Combined with Straw Mulching Increases Winter Wheat Yield by Optimizing Soil Water-Salt Condition under Saline Irrigation. Agriculture **12**(10), 1681. doi: 10.3390/agriculture12101681

Zizinga, A., Mwanjalolo, J.-G. M., Tietjen, B., Bedadi, B., Pathak, H., Gabiri, G., & Beesigamukama, D. (2022). Climate change and maize productivity in Uganda: Simulating the impacts and alleviation with climate smart agriculture practices. Agricultural Systems **199**(), 103407. doi: 10.1016/j.agsy.2022.103407