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Green Corridors May Sustain Habitats for Earthworms in A Partially Converted Grassland

Barbara Simon [1], Krisztina Boziné Pullai [2], Dóra Selmeczi [1], András Sebők [1], Franciska Tóthné Bogdányi [3], Tsedekech G. Weldmichael [1], Mihály Zalai [4], Justine Phenson Nsima [5] and Ferenc Tóth [6,7,*]

[1] Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary; simon.barbara@uni-mate.hu (B.S.); nightingale27.99@gmail.com (D.S.); sebok.andras@uni-mate.hu (A.S.); tsedyweld@gmail.com (T.G.W.)
[2] Doctoral School of Plant Sciences, Hungarian University of Agriculture and Life Sciences, 2103 Gödöllő, Hungary; kriszti.pullai@gmail.com
[3] ImMuniPot Independent Research Group, 2100 Gödöllő, Hungary; t.bogdanyi.franciska@gmail.com
[4] Department of Integrated Plant Protection, Institute of Plant Protection, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary; zalai.mihaly@uni-mate.hu
[5] Doctoral School of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, 2103 Gödöllő, Hungary; phenson2016@gmail.com
[6] Department of Zoology and Ecology, Institute for Wildlife Management and Nature Protection, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary
[7] Research Institute of Organic Agriculture (ÖMKi), 1033 Budapest, Hungary
* Correspondence: ferenc.toth@biokutatas.hu

Abstract: Permanent grasslands provide a healthy and undisturbed environment. We investigated how mulching altered the soil physicochemical parameters, earthworm abundance, biomass, species composition and vegetation cover compared to grassland and cultivated alfalfa field. Microplots (2×2 m) were mulched with either weed control fabric (WF) alone or WF combined with straw (WF + S) on a grassland to grow tomato in Ősagárd (Nógrád county, Hungary) between 2018 and 2021. We had two other microhabitats: a conventionally cultivated alfalfa field (CA) and grassland (GR). We measured soil parameters (physical: soil moisture content (SMC), soil penetration resistance (SPR); chemical: pH, soil organic matter; and biological: earthworm abundance, biomass, species composition and vegetation). SMC was significantly higher on covered plots (WF; WF + S) compared to CA and GR. SPR values were the highest in CA and GR at 20 cm depth. The abundance and biomass of earthworms were the highest in GR and lowest in CA in all seasons. Plant abundance was highly influenced by season and habitat. Despite the higher compaction and lower SMC figures, grass vegetation still provided a more suitable environment for earthworms than mulched plots (WF, WF + S). Therefore, where there is agricultural production on grassland, we suggest leaving uncultivated and uncovered patches as biodiversity corridors.

Keywords: grassland conversion; agronomical alternative; biodiversity; soil quality; *Allolobophora chlorotica*; *Aporrectodea rosea*; *Aporrectodea caliginosa*

Citation: 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. https://doi.org/10.3390/agronomy12040793

Academic Editor: Karoly Penksza

Received: 10 February 2022
Accepted: 24 March 2022
Published: 25 March 2022

1. Introduction

Grasslands, comprising about 40% of the terrestrial surface [1–3], can be either of natural origin, formed by long-term climatic and soil conditions; semi-natural (or secondary), where centuries or thousands of years of human activities, including deforestation, mowing or grazing, have definitely put their mark on the landscape; or intensified, formed and maintained by modern agriculture [4,5].

From the ecological aspect, natural and semi-natural grasslands are resourceful, biologically diverse ecosystems featured by their high species richness [6,7], and grasslands have been recognized not only for supplying mankind directly or indirectly with various products (herbs, food, fiber, fodder or wool, cultural heritage values, to name a few), but for providing a wide spectrum of ecosystem services (ES), including habitat for permanent and migratory species and pollinators, pollination of crops, the natural management of pests and diseases of agriculture, flood and erosion control, carbon storage, climate and air quality regulation at local, regional and continental scale [8–12].

Ecosystem services provided by natural and semi-natural grasslands are threatened by various factors and human activities, including traffic, industrial pollution, but most importantly, agricultural production. With changes to land use, when grasslands are converted to arable fields, the physical and chemical conditions are altered, and thus, biological conditions are altered too: diversity figures of habitats, flora and fauna drop. As a consequence, the occurrence of pollinators and natural control agents of pests and pathogens decrease too. Sometimes, the mere addition of chemical fertilizers in the pursuit of higher crop yields lowers biodiversity [13].

On the other hand, agriculture is able to increase biodiversity on grasslands [14], and with careful management, degradation and loss of ecological values are avoidable. The prevention of pessimistic scenarios is possible through thoughtful planning and favoring long-term sustainable goals to temporary economic gains, both in practice and in policies and incentives too [15–17]. When integrated with agriculture as special production areas, grasslands may produce various products at acceptable amounts and at an acceptable quality while retaining their ecological benefits [11].

Agricultural management affects the physiochemical properties of the soil too. Prolonged application of chemical fertilizers, the use of heavy machines and tillage change not only plant associations, but the microbial communities of the soil as well, which in turn may alter the natural suppressivity of the soil [18,19].

With the intention to counteract and prevent the disadvantages of conventional agriculture and prevent or reverse soil degradation, alternative production systems have been introduced and are being used worldwide too. These may include the reduction or complete lack of tillage (no till) or the use of mulch and many other elements.

Mulching refers to the presence of any material, apart from the soil itself and living vegetation on the soil surface [20], and the deliberate action of spreading mulch materials, which may be organic (compost, straw, grass clippings, etc.) or inorganic (plastic foils, landscape and weed control fabrics, etc.), or a combination of both [21]. Mulching usually involves reduced tillage. Depending on the type of mulch material applied, the thickness of mulch, tillage system, site-specific soil properties and climate [22], mulching may improve crop yield and crop health, positively alter soil fertility, water dynamics and water retention of the soil, balance soil temperature fluctuations, prevent or reduce soil compaction and sealing, and enhance microbial richness [23], increase soil organic matter content and promote suppressivity against soil-borne pathogens [18].

Straw is one of the most widely used mulch materials with the benefits of being biodegradable and, therefore, environmentally acceptable [24]. Straw mulching was observed to improve the physical properties of soil, increase soil organic carbon content, and the general increase in the nutrient content was found to enhance the biological characteristics of the soil, including the diversity and metabolic activities of the soil microbiome [25–28]. Organic mulching can perform all the above benefits, yet it is not without any drawbacks. Mulch-covered soils warm up later in the spring in a four-season climate. Obtaining, transporting and spreading mulch materials is labor intensive and therefore expensive, which may restrict their use in crop production [21].

The diversity of land and the physical, chemical and biological parameters of the soil of the area are interrelated. In order to promote sustainability via management and gain as many benefits from human intervention as possible, soil parameters should be monitored with recognized and scientifically sound methods [16]. Some of the most often used indicators include texture, water storage capacity, soil penetrability to interpret physical conditions, total organic matter, electrical conductivity and pH for chemical status. Biological indicators may include the total mass of microorganisms, soil respiration and the abundance of selected soil-dwelling taxa [29].

Monitoring earthworm communities, their abundance and species composition, is also a frequently used tool to assess soil quality and biodiversity [30–32] due to the fact that earthworms contribute to many ESs, and on the other hand, as compiled by a recent review, earthworms are highly influenced by management intensity, cultivation practices and the use of chemicals [33].

Earthworms play a significant role in breaking down plant residues by ingesting and mixing them with the minerals in the soil [34]. However, their role is more complex. Directly or indirectly, earthworms influence soil organic matter content, transformation and dynamics, nutrient cycles, soil structure formation and soil fertility [35–39].

The objective of our study was to investigate how certain management practices, namely mulching with weed control fabric, alone or in combination with straw, and spatial separation of production and conservation areas, affect the soil physicochemical parameters, earthworm abundance, biomass, species composition and vegetation abundance on grassland to create a basis for any further studies on the balance between agricultural production and habitat protection.

2. Materials and Methods

2.1. Experimental Site and Mulch Materials

The experimental area is located in Őságárd (GPS coordinates: 47°85′42.25″ N, 19°18′88.31″ E, according to WGS84 standard) in Cserhát Mountain in the western part of Nógrád county, in north central Hungary. The area belongs to the Kosdi Hill region, at 270 m ASL. The average annual mean temperature is 9.5 °C, with 16.0–16.5 °C during the vegetation period. Annual precipitation is 580–600 mm, of which 340 mm falls during the vegetation period. The soil is a Haplic Luvisol according to WRB [40]. Its texture is loam, clay loam.

The experiment started on 8 June 2018 and was carried out on a 1-hectare field between 2018 and 2021. In previous years, the area was an arable land where triticale was grown in monoculture for several years until 2014 when, after a final disc tiller operation, the land was set aside. The leftover green fallow was gradually turning into grassland between 2015 and 2018.

One part of this 1 ha grassland was used for a tomato experiment (explained below), while the rest was prepared for alfalfa production. There were 40 tomato microplots on the experimental area, measuring 2 × 2 m, creating a mosaic of cultivated rectangles as "islands" bordered with undisturbed patches or corridors with a width of 0.7 m along the borders of the tomato plots within the grassland (Figures 1c,d,g and 2). Both the future tomato and alfalfa areas were covered in a 10 cm thick layer of mature goat manure (Figure 1a,b). The green corridors composed of the original grassland were not manured. Tomato microplots were not tilled, but on the future alfalfa field, goat manure was incorporated by a discing tiller (Figure 1f), and the seed bed was prepared.

On the microplots, goat manure on the green fallow was covered by mulch materials: weed control fabric (WF) or by combination of weed control fabric and straw, with straw as a second layer atop the fabric (WF + S). Weed control fabric is a woven polypropylene raffia, a 100 g/m^2 a porous material that lets precipitation drain through, thus allowing oxygen and nutrients to the roots.

Before transplanting tomato seedlings in each subsequent May, mulch materials of the previous year were lifted and rolled up to the side, and goat manure was spread again evenly in 5–10 cm thickness, carried by wheelbarrow, only onto the microplots. The old straw layer was removed and replaced by a new one. To minimize disturbance and compaction, no heavy vehicles have been used on the experimental site since 2018.

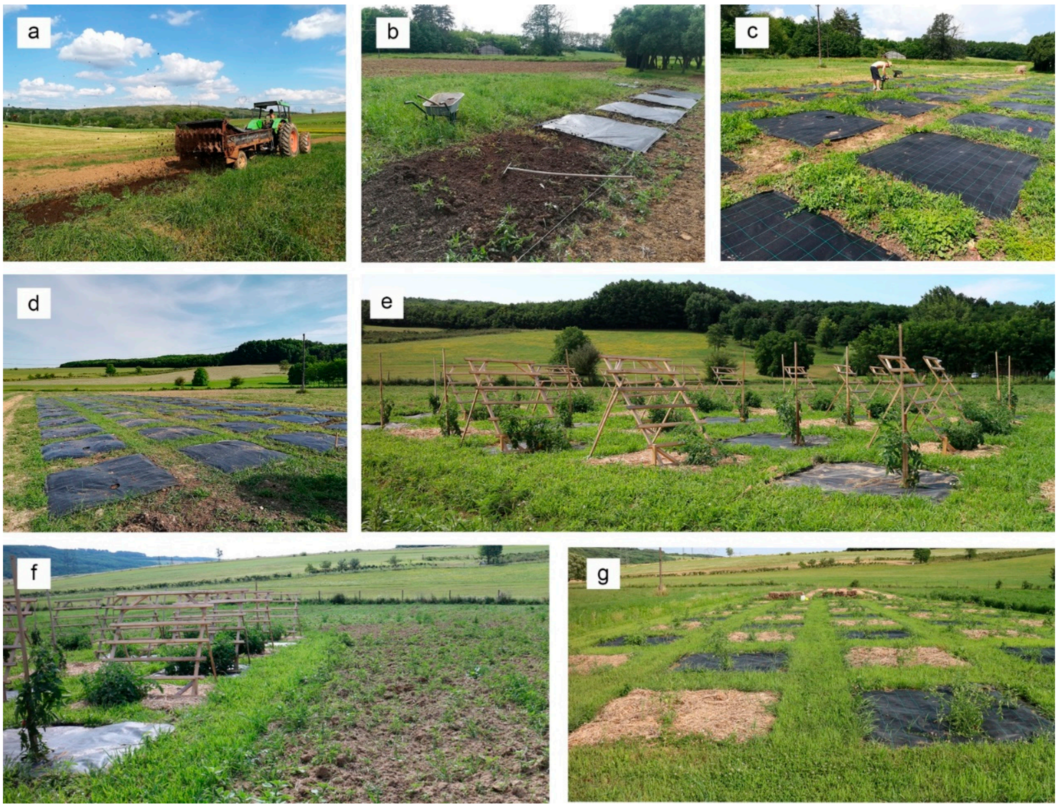

Figure 1. The experimental site at Ősagárd (**a**) Before setting up the microplots, manure was evenly spread on the green fallow in 2018; (**b**) Manure was raked into the frame of microplots to clear the path area in 2018; (**c**,**d**) Weed control fabric "islands" were laid on the manure rectangles in 2018; (**e**) The experimental site with the tomato plants with different pruning and mulching treatments in 2018; (**f**) The mulched microplots and grassy path on the left, tilled fallow before preparing seeding bed for alfalfa on the right in 2018; (**g**) Microplots after tomato planting but before setting up the stakes and trellises in 2019. On the upper right corner, alfalfa sown in the previous year is already visible with its 40–50 cm height.

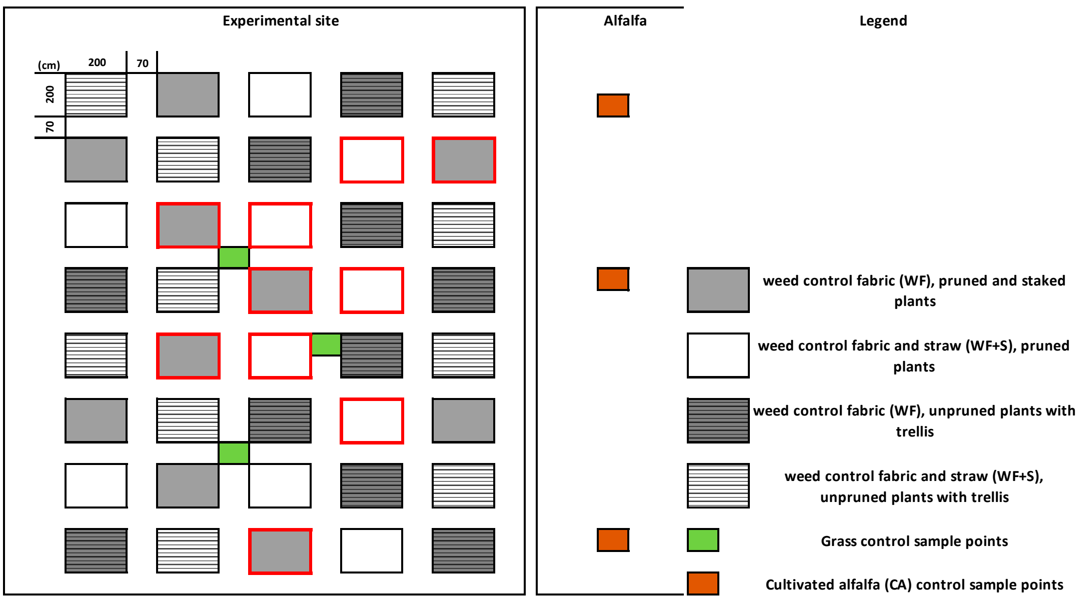

Figure 2. Experimental setup, the arrangement of microplots and sample points (Ősagárd, Hungary, 2018–2021). Microplots with red borders were sampled for soil parameters and for earthworms.

2.2. Tomato Production and the Control Areas

Parallel with the study presented here, another experiment investigating the effects of management practices on tomato was performed. Two indeterminate Hungarian tomato landraces were used as test plants: "Cegléd" (gene bank code: RCAT030275), with 160–180 g average fruit weight, and "Fadd" (RCAT030373), with 70–90 g average fruit weight. These accessions were obtained from the National Centre for Biodiversity and Gene Conservation, Tápiószele, Hungary. One plant was planted into each microplot. Tomatoes were planted on 8 June 2018, 7 June 2019 and 7 June 2020. Half of the plants were pruned and staked; the other half were unpruned and supported by ladder-like trellises (Figure 1e). We had five replications for each mulching and pruning treatments. To monitor soil and earthworm parameters, staked microplots were sampled.

The experimental area was rainfed.

The green paths between tomato microplots were mowed every three weeks with a mulching lawnmower.

The cultivated alfalfa field (CA) beside the experimental area was under conventional agricultural management without the use of chemical fertilizers and pesticides throughout the experiment. Alfalfa was sown in September 2018. The crop was cut 4–5 times per season with a tractor-mounted sickle bar; then, the hay was prepared with a windrower; and later, round bales were made and collected. Overall, the alfalfa field was tread by heavy machinery 25 times per season.

2.3. Examined Soil Parameters

For physical analyses, soil texture was obtained by measuring the amount of distilled water that 100 g soil can absorb until it reaches its upper limit of plasticity [41]. Soil texture was determined in autumn of 2018. To measure soil moisture content (SMC), four sampling categories were used: (1) weed control fabric with 5 sample points (within the microplot); (2) weed control fabric + straw with 5 sample points; (3) cultivated alfalfa with 3 sampling points; and (4) grassland with 3 sample points. The gravimetric method was used, where soil samples were dried in the oven at 105 °C for 24 h according to Buzás [41]. SMC was determined six times (between autumn 2018 and spring 2021) during the experiment. Soil penetration resistance (SPR) was measured twice (autumn 2018 and 2019) by an electronic penetrometer equipped by a datalogger (Eijkelkamp Penetrologger soil compaction tester) for immediate storage and data processing. SPR was measured in each cm, by 1 N accuracy, within 0–80 cm soil depth, with 2 cm/s penetration speed and 2 cm^2 cone, where soil conditions were favorable. The range of the measurements was between 0 and 150 lbf, with 2 lbf intervals, i.e., between 0 and 6.67 MPa. During the measurements, the penetrologger was pushed into the soil at a constant speed of 2 cm s^{-1}, with simultaneous SMC measurements at each point using a 4-pin Soil Moisture Sensor Theta Probe mounted on the penetrologger (read in vol.%). The obtained data were downloaded and processed on a personal computer. Due to an unforeseen technical problem with the equipment in 2019, we were able to sample only the soils of the WF and the WF + S treatments.

Soil sampling for chemical analyses was first carried out on 9 November 2018. Subsequent samples were taken simultaneously with earthworm samplings to determine soil moisture content (SMC), at a total of six samplings (Table 1). Sixteen sampling areas were selected on the experimental site: five from weed control fabric (WF); five from weed control fabric and straw combination (WF + S) treatments; three from the grassy area (GR); and three from the cultivated alfalfa (CA). Composite soil samples, consisting of minimum of 6–8 subsamples, were taken from the top 25 cm and mixed thoroughly in a bucket. Then, one kilogram of the sample was taken to the laboratory (n = 16), where samples were air dried, ground and sieved (<2 mm mesh size) for further analyses.

Table 1. Summary of the examined soil parameters, time of sampling and sampling frequency (Ősagárd, Hungary).

	Measured Parameters	Time of Measurements	Frequency
I.	Physical parameters		
	soil texture	autumn 2018	once
	soil moisture content	autumn 2018; spring and autumn 2019, 2020; spring 2021	6 times
	soil penetration resistance	autumn 2018 and 2019	twice
II.	Chemical parameters		
	soil pH(H_2O), pH(KCl)	autumn 2018; January 2022	twice
	$CaCO_3$ content	autumn 2018; January 2022	twice
	soil organic matter	autumn 2018; January 2022	twice
III.	Biological parameters		
	earthworm abundance, biomass, species composition	autumn 2018; spring and autumn 2019, 2020; spring 2021	6 times
	plant abundance (cover)	spring and autumn 2021	twice

Chemical parameters were examined in triplicate. To obtain pH(H_2O), pH(KCl) values, a digital pH meter (HACH-LANGE, HQ411D) was used with a 1:2,5 soil to liquid ratio (distilled water or KCl). $CaCO_3$ content was determined volumetrically by Scheibler method [42]. Soil organic matter (SOM) was measured with the wet oxidation method [43]. These three basic chemical parameters were recorded in 2018, prior to the experiment, and again in 2022, after termination, to detect any changes that may have occurred.

Biological parameters, namely earthworm abundance (ind m^{-2}), biomass (g m^{-2}), species composition, were measured six times (autumn, 2018; spring, autumn 2019 and 2020; and spring 2021). Earthworms were sampled in situ by excavating a 25 × 25 × 25 cm soil block onto a plastic sheet in all selected plots, followed by hand sorting according to the ISO Standards (ISO, 2006). Animals were killed in a 70% ethanol, fixed in a 4% formalin solution for two weeks, then stored in 70% ethanol. Species were determined according to Csuzdi and Zicsi [44], and Csuzdi [45], based on the external and internal characteristics of the individuals.

Plant vegetations of the three treatment or habitat types (WF, WF + S, GR) were surveyed twice in 2021. First, we surveyed spring vegetation (12 April 2021) before the growing season of tomato, while the second survey focused on the autumn vegetation (10 September 2021). All species as weeds in covered habitats (WF, WF + S) and both grassy and dicot species on grassland (GR) were determined to species level by analyzing the coverage of the selected 1 × 1 m plots with 8 replications. Weeds of the cultivated alfalfa (CA) were not recorded.

2.4. Statistical Analyses

Statistical methods were used to process and understand the following recorded data:

Physical parameters

Soil moisture content was analyzed by ANOVA and Tukey post hoc tests for each habitat separately by data in survey periods.

Chemical parameters

Soil organic matter and soil pH(H_2O), pH(KCl) were analyzed by ANOVA and Tukey post hoc tests for each habitat separately by data in 2018 and 2022.

Biological parameters

Both earthworm abundance (ind m^{-2}) and earthworm biomass (g ind^{-1}) were tested by multivariate ANOVA with factors of season and habitat and their interactions. In significant cases, variable groups were tested by Tukey post hoc test.

Plant vegetation

Total plant cover was tested by multivariate ANOVA with factors of season and habitats and their interactions. In significant cases, variable groups were tested by Tukey post hoc tests (in case of habitats) and by two-sample *t*-tests (in case of season).

3. Results

3.1. Physical Parameters of the Soil

Samples were found homogenous. Soil texture was loam and clay loam in all samples.

Soil moisture content (SMC) analysis revealed (Figure 3) that in all seasons, mulch treatments (WF; WF + S) resulted in higher SMC values. These two treatments resulted in significantly higher values than GR and CA in half of the sampling occasions (spring, autumn 2019 and autumn 2020). In spring 2021, WF treatment resulted in the highest SMC (28.8%), which was significantly higher than GR and CA treatments.

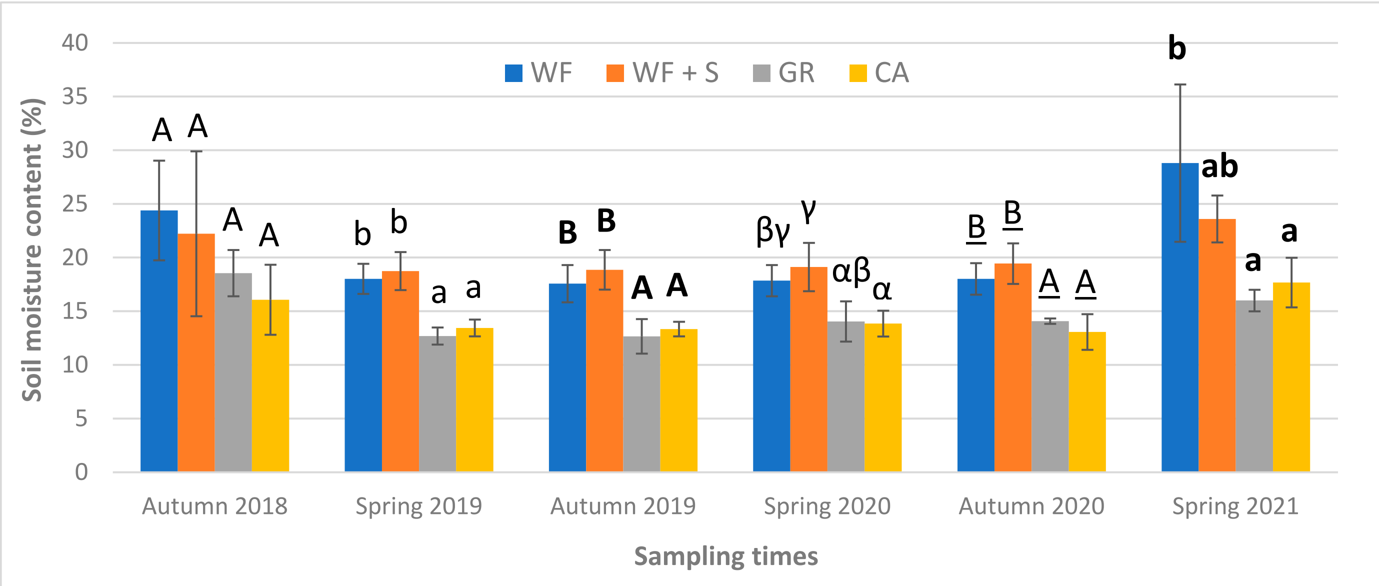

Figure 3. Soil moisture content between autumn of 2018 and spring of 2021. Same letters above bars mean no statistical difference. Results of each sampling times were analyzed separately from each other, so each set of results per sampling time was marked with a different type of letter. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; CA: cultivated alfalfa; Ősagárd, Hungary).

In 2018, there was a definite difference in soil penetration resistance (SPR) values between the grassland area (marked with 4) and all the other areas (Figure 4). SPR values were definitely higher on the grassland, especially around 20 cm depth, compared to the two mulch treatments (marked with 1 and 2). In some cases, average SPR values reached greater values than 5.0 MPa at 20 cm depth in the grassland (4), whereas, under mulched areas (1 and 2), average SPR values remained below 3.0 MPa. Cultivated alfalfa (marked with 3) had the highest SPR values around the 10 cm depth (4.5 MPa on average), but it decreased quite steeply below 3.0 MPa by depth.

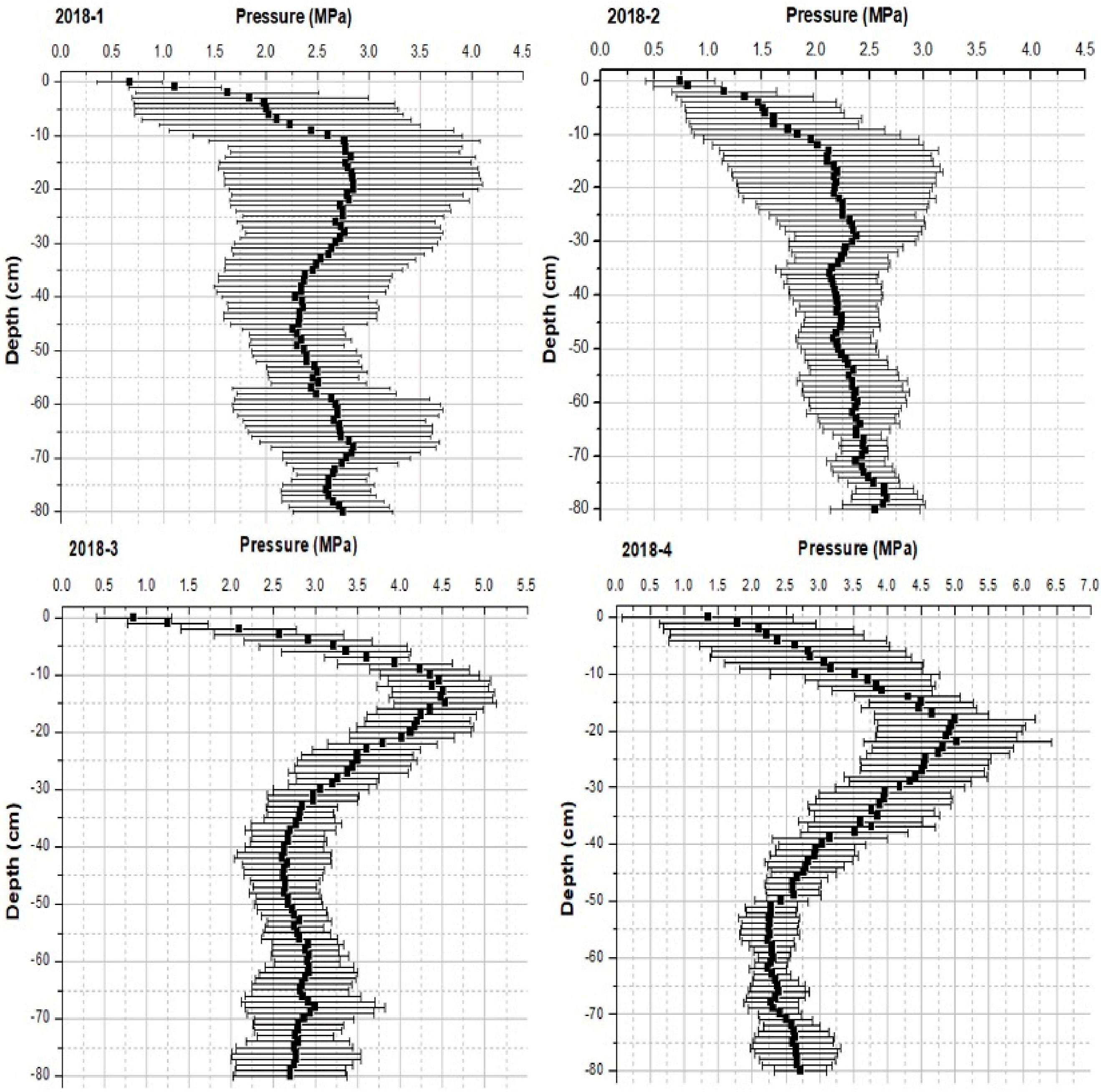

Figure 4. Soil penetration resistance values (average values with SD) in autumn 2018. Treatments were marked with numbers as follows: (1) weed control fabric; (2) weed control fabric + straw; (3) cultivated alfalfa; (4) grassland (Ősagárd, Hungary).

In 2019, we focused on the mulched areas (1 and 2) (Figure 5). Compared to previous years, even the highest SPR values were lower than 2 MPa, on average, throughout the 80 cm soil profile.

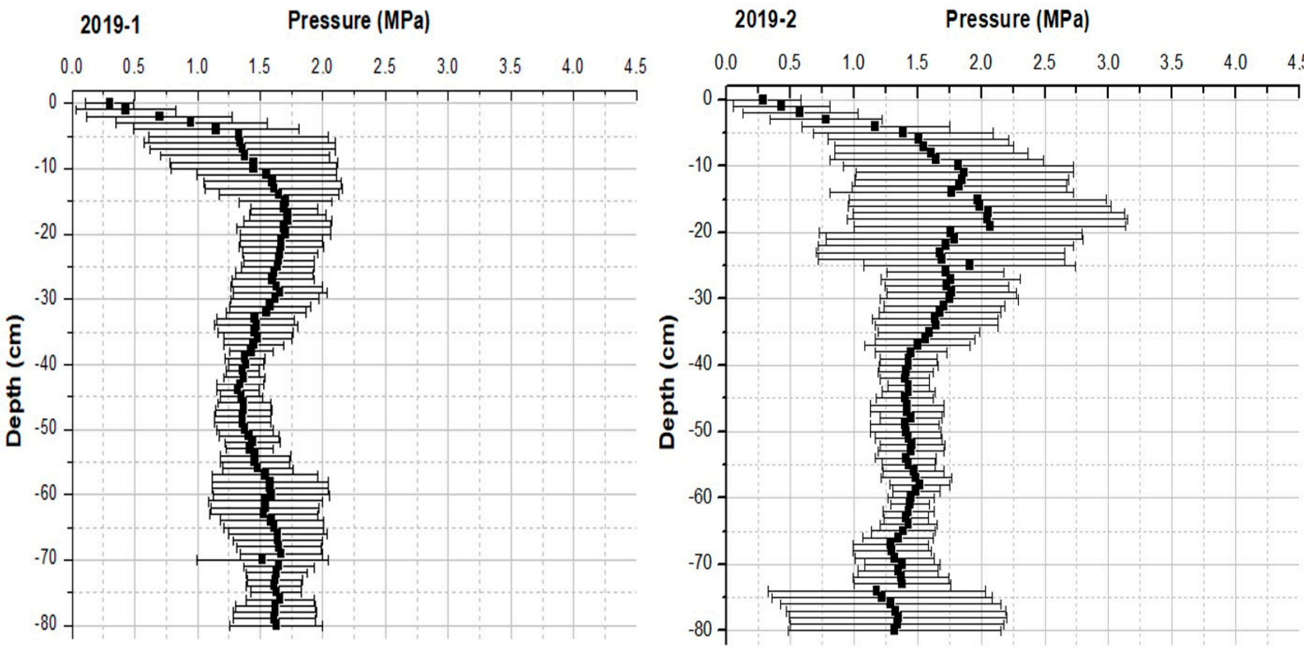

Figure 5. Soil penetration resistance values (average values with SD) in autumn 2019. Treatments were marked with numbers as follows: (1) weed control fabric; (2) weed control fabric + straw (Ősagárd, Hungary).

3.2. Chemical Parameters of the Soil

Initially, soil pH(H_2O) values were between 7.0 and 7.3, while pH(KCl) values were between 6.2 and 6.7 (Figure 6). Regarding average pH values, none of the future treatment areas were statistically different from any other before the experiment started (Figure 6A). Measurements in January 2022 revealed that pH(H_2O) values were between 7.0 and 7.6, while pH(KCl) values were between 6.4 and 7.0, on average. There was a slight pH increase with WF and WF + S treatments, while a little decrease was detected with GR and CA treatments. More specifically, as for pH(H_2O), WF and WF + S treatments were significantly higher than GR and CA treatments, while for pH(KCl), WF and WF + S were significantly higher than CA plots.

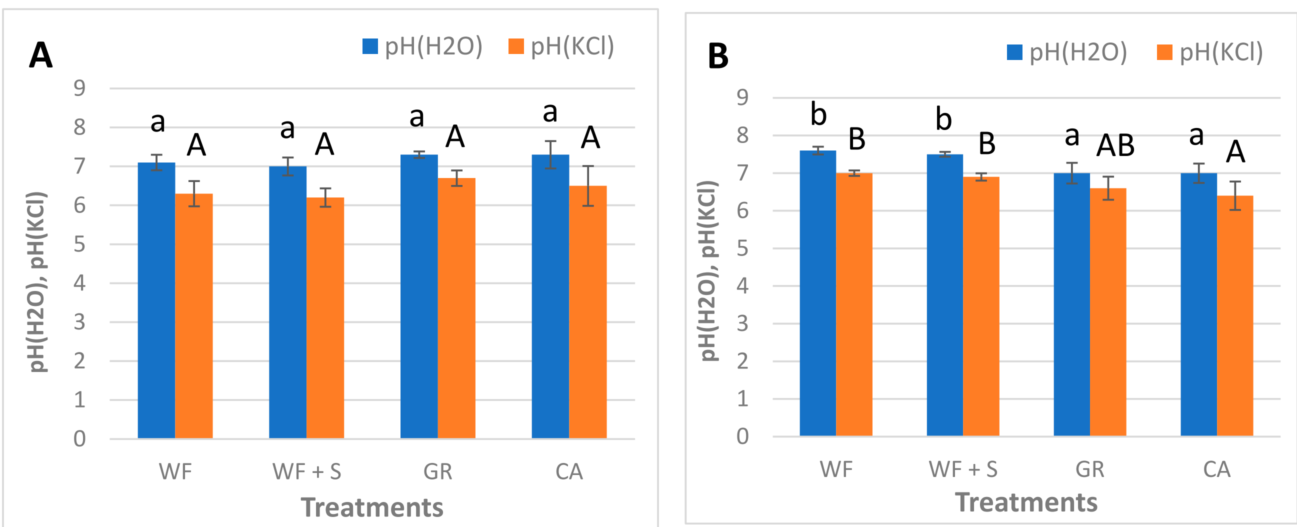

Figure 6. Soil pH values measured in pH(H_2O) and pH(KCl) in 2018 (**A**) and in 2022 (**B**). Same letters above bars mean no statistical difference. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; CA: cultivated alfalfa; Ősagárd, Hungary).

In all treatments, the $CaCO_3$ content of the soil was low, between 0.0 and 1.5% in 2018 and in 2022 as well (data not shown).

Initial soil organic matter (SOM) values were between 2.4 (CA) and 3.0% (WF) in 2018 (Figure 7A). By the end of the experiment, January 2022, SOM values increased in all treatments. SOM content was significantly higher with WF or WF + S when compared to GR and CA plots. In the case of WF, SOM content increased from 3.0 to 6.9, while with the combination (WF + S), the increment was larger: from 2.9 to 7.5%. The rise in SOM content was less pronounced with GR (4.3%) and CA (3.4%) treatments.

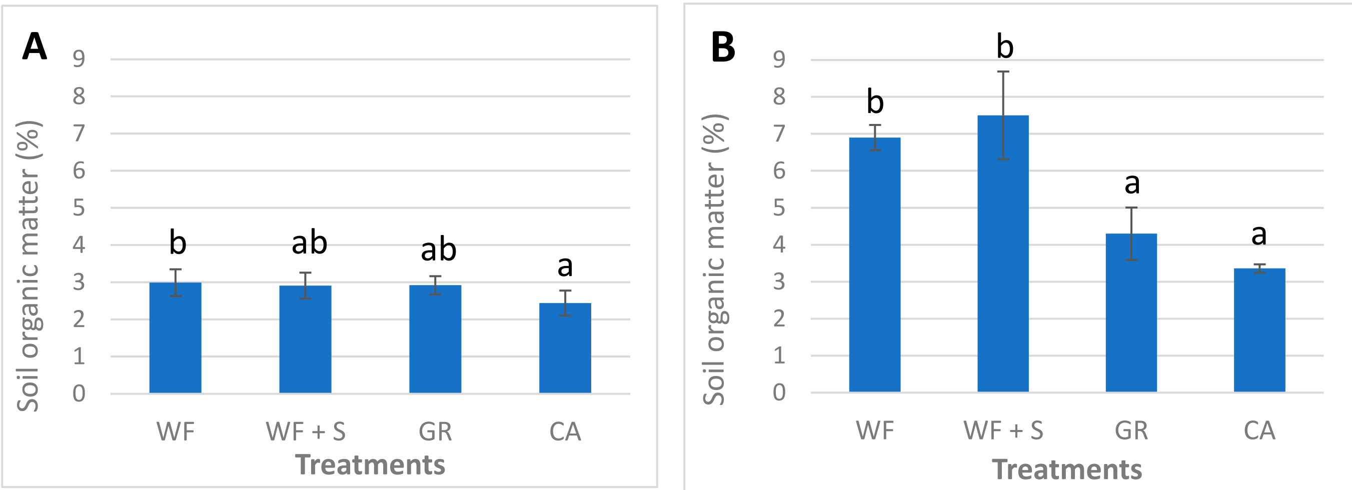

Figure 7. Soil organic matter values in 2018 (**A**) and in 2022 (**B**). Same letters above bars mean no statistical difference. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; CA: cultivated alfalfa; Ősagárd, Hungary).

3.3. Biological Parameters of the Soil

Out of the six sampling times for earthworm abundance, two (spring of 2020 and 2021) occasions did not show any significant difference among treatments (Figure 8). However, on the other four sampling times, earthworm abundance was always the highest on grassland, and on three times (spring and autumn 2019; autumn 2020), it was significantly greater than WF and CA sites. On two times (spring and autumn 2019), its values were significantly higher when compared to the other three treatments.

There were significant differences in earthworm biomass at all sampling times (Figure 9). It was the highest under the grass vegetation, except for spring 2021. In three sampling times (autumn 2018; spring 2019; autumn 2020), the values for GR were significantly greater than those of WF + S and CA.

The most abundant earthworm species was *Allolobophora chlorotica*, dominating the list of species regardless of sampling time or treatments. Its proportion was the highest under WF (68%), followed by GR (63%), and 57% in case of both WF + S and CA. The second most dominant species was *Aporrectodea rosea* (17% for WF; 15% for WF + S; 13% for GR; 21% for CA). The third was *Aporrectodea caliginosa* (5% for WF; 12% for WF + S; 10% for GR; 14% for CA). Other earthworm species were only present at a maximum of 6% (Figure 10).

The number of species (nine) was the same in WF and WF + S treatments, followed by GR with eight species, while the lowest number was obtained in CA plots (five species).

Regarding the different morphotypes, all three dominant earthworm species belonged to the endogeic group. Other species, present at a lower rate, such as *Octolasion cyaneum*, *Proctodrilus opisthoductus*, *Octolasion lacteum*, also belonged to the endogeic morphotype. There were also some epigeic (*Lumbricus rubellus*, *Eisenia fetida*) and anecic species (*Lumbricus terrestris*, *Aporrectodea longa*, *Dendrobeane depressa*) found in lower percentages.

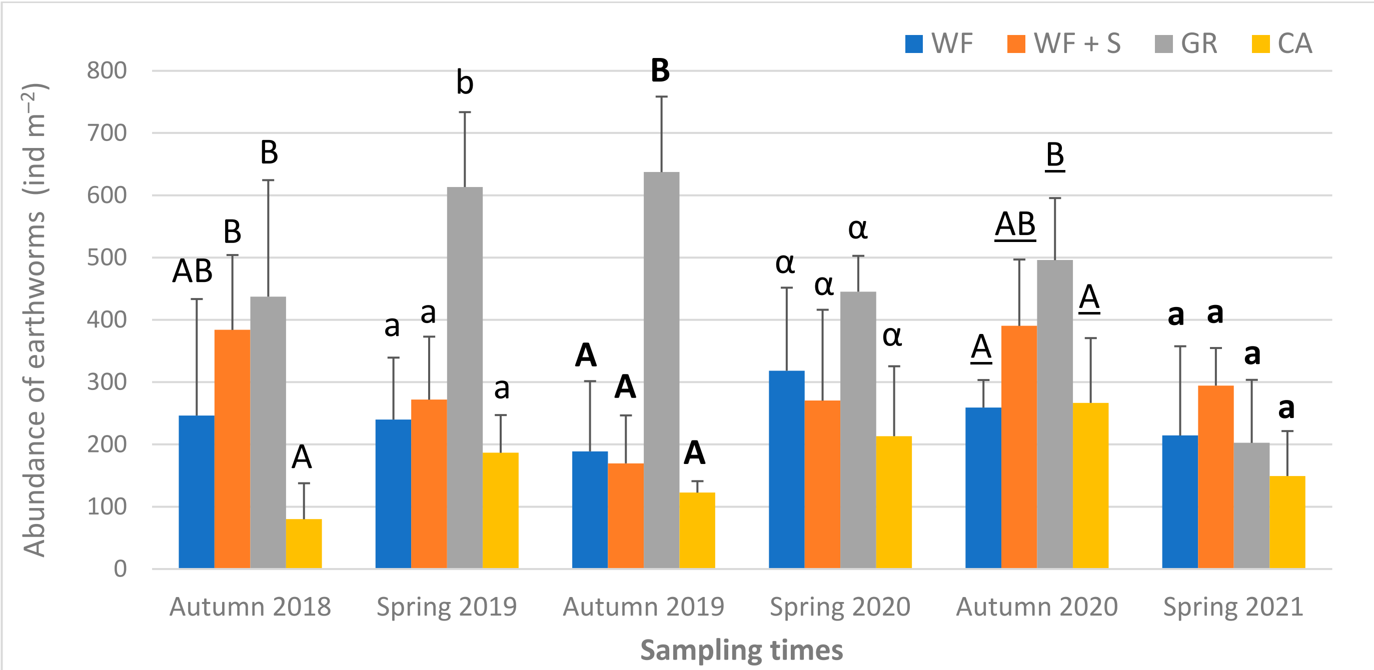

Figure 8. Abundance of earthworms between autumn of 2018 and spring of 2021. Same letters above bars mean no statistical difference. Results of each sampling times were analyzed separately from each other, so each set of results per sampling time was marked with a different type of letter. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; CA: cultivated alfalfa; Ősagárd, Hungary).

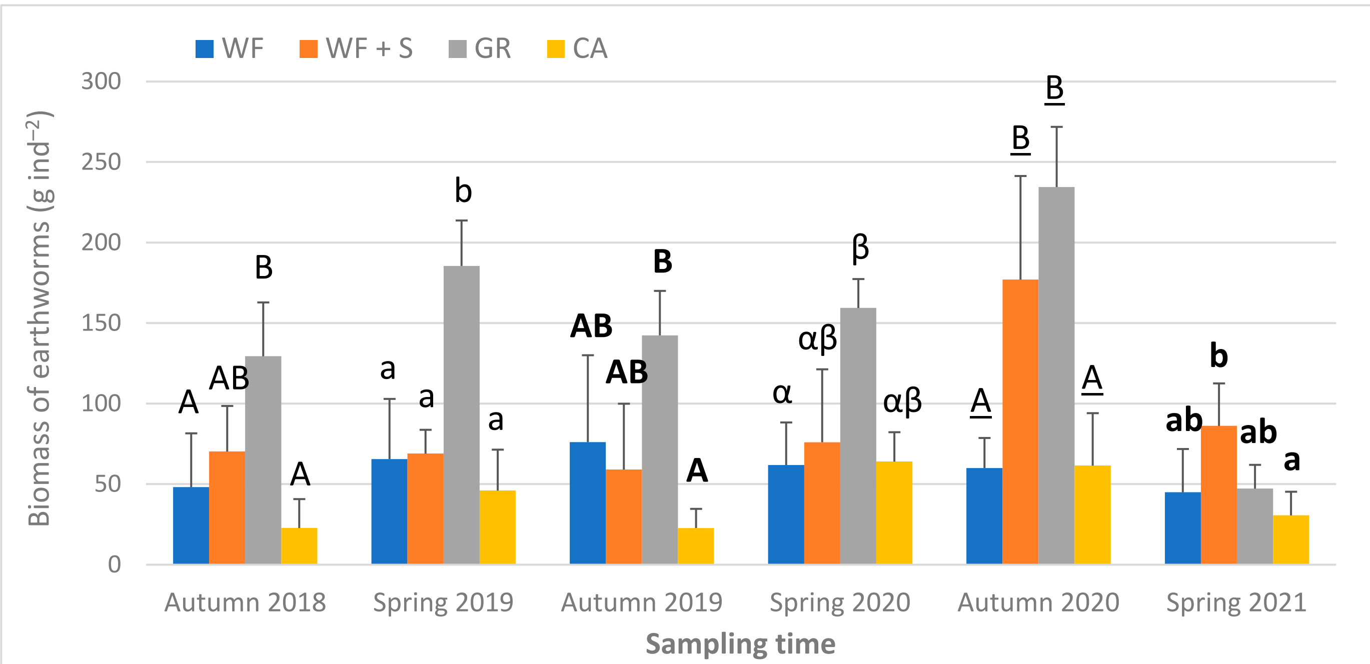

Figure 9. Earthworm biomass between autumn 2018 and spring 2021. Same letters above bars mean no statistical difference. Results of each sampling times were analyzed separately from each other, so each set of results per sampling time was marked with a different type of letter. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; CA: cultivated alfalfa; Ősagárd, Hungary).

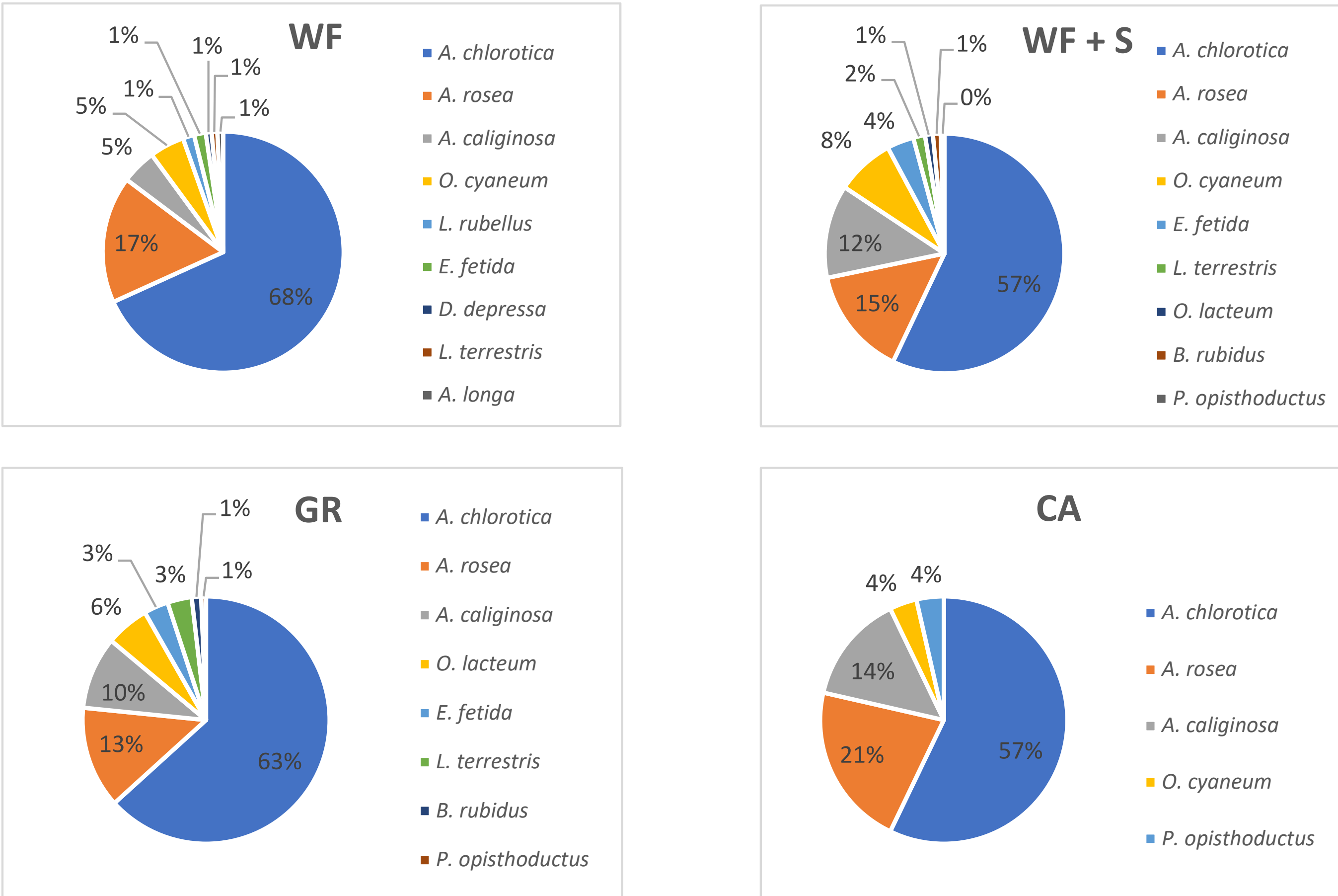

Figure 10. Species compostion of earthworms for the four treatments. (WF: weed control fabric; WF + S: weed control fabric + straw; GR: grass vegetation; CA: cultivated alfalfa; *A. chlorotica*—*Allolobophora chlorotica*, *A. rosea*—*Aporrectodea rosea*, *A. caliginosa*—*Aporrectodea caliginosa*, *O. cyaneum*—*Octolasion cyaneum*, *L. rubellus*—*Lumbricus rubellus*, *E. fetida*—*Eisenia fetida*, *D. depressa*—*Dendrobaena depressa*, *L. terrestris*—*Lumbricus terrestris*, *A. longa*—*Aporrectodea longa*, *O. lacteum*—*Octolasion lacteum*, *B. rubidus*—*Bimastos rubidus*, *P. opisthoductus*—*Proctodrilus opisthoductus*; Ősagárd, Hungary).

3.4. Vegetation

Between the beginning and the end of the examination period, only slight changes to plant composition were detected on any of the treated microplots. The highest differences were observed between grassland (GR) and weed control fabric (WF), and between grassland (GR) and weed control fabric + straw (WF + S) habitats.

Microplots on the grassland (GR) were dominated by the usual monocots and dicots of grassy habitats (*Elymus repens*, *Lolium perenne*) on both sampling occasions. The most important weeds of mulched habitats (WF or WF + S) were either species that dominated the grassland as well (e.g., *Elymus repens*, *Taraxacum officinale*, *Urtica dioica*, *Polygonum aviculare*), or species that are usually frequent on arable fields, including *Stellaria media*, *Capsella bursa-pastoris* and *Veronica hederifolia* in spring, and *Setaria glauca* and *Convolvulus arvensis* in autumn 2021 (Table 2).

According to MANOVA, total plant abundance was influenced by the variables of season and habitat (Table 3).

Apart from this, it was our general observation that plant abundance was higher in the autumn than in the spring, and the percentage of cover was lower on mulched surfaces (WF or WF + S) than on the grassland (Figure 11).

Table 2. Order of dominance and total cover of plant vegetation in the surveyed habitats (Őságárd, Hungary).

Habitat	Order of Dominance	Spring 2021	Autumn 2021
Weed control fabric	1	*Elymus repens*	*Urtica dioica*
	2	*Urtica dioica*	*Polygonum aviculare*
	3	*Taraxacum officinale*	*Elymus repens*
	4	*Veronica hederifolia*	*Setaria glauca*
	5	*Glechoma hederacea*	*Taraxacum officinale*
	Total cover	3.34%	15.03%
Weed control fabric + straw	1	*Elymus repens*	*Urtica dioica*
	2	*Stellaria media*	*Elymus repens*
	3	*Capsella bursa-pastoris*	*Convolvulus arvensis*
	4	*Taraxacum officinale*	*Setaria glauca*
	5	*Glechoma hederacea*	*Cichorium intybus*
	Total cover	6.73%	9.29%
Grass	1	*Elymus repens*	*Elymus repens*
	2	*Lolium perenne*	*Lolium perenne*
	3	*Urtica dioica*	*Taraxacum officinale*
	4	*Taraxacum officinale*	*Urtica dioica*
	5	*Lamium purpureum*	*Polygonum aviculare*
	Total cover	86.85%	100%

Table 3. Effect of habitat and season on vegetation (total cover; Őságárd, Hungary).

Variable	d.f.	MANOVA		Comparison		
		F	*p*-Value	Group	Avg. Value (%)	Sign. Class
Habitat	2	636.695	<0.001	WF	9.18	a
				WF + S	8.01	a
				GR	93.43	b
Season	1	16.596	<0.001	spring 2021	32.3063	a
				autumn 2021	41.4375	b

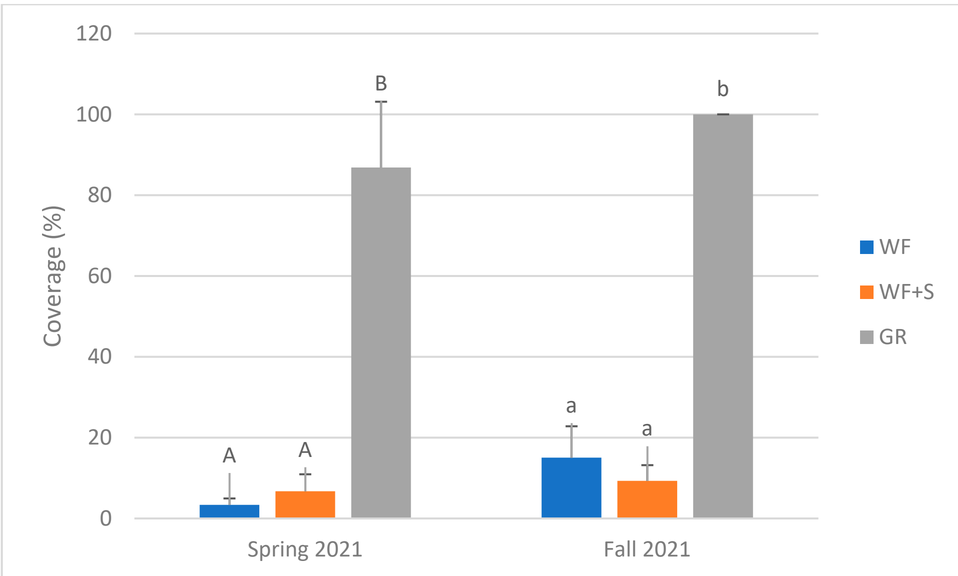

Figure 11. Effect of habitat and season on plant vegetation (total cover). Same letters above bars mean no statistical difference. (WF: weed control fabric; WF + S: weed control fabric and straw; GR: grass vegetation; Őságárd, Hungary).

4. Discussion

Habitats with high diversity are more sustainable and can provide more complex ecosystem services. The preservation of semi-natural grasslands contributes to the maintenance of biodiversity, and a loss of semi-natural habitats was linked to actual species loss [46].

4.1. Physical Parameters: Soil Moisture Content (SMC)

The two physical parameters we analyzed were soil moisture content (SMC) and soil compaction. SMC was initially measured near the end of the first growing season, and the results were similar in all areas (or habitats), regardless of the presence of mulch layers. Soon, however, a definite trend evolved, and it remained throughout the whole experiment: SMC was significantly higher on the mulched plots (WF and WF + S) on all further sampling occasions. The general ability of mulch to maintain SMC has long been documented [47–49], but fewer studies have investigated the difference between the effects of organic and a combination of organic and inorganic mulches. In our experiment, we expected that the extra addition of straw would help retain more moisture within the soil, but instead, we could not detect significant differences between WF and WF + S treatments, unlike a recent study where inorganic mulching using white pebbles sustained more moisture within the soil than organic mulches, especially during the warmer seasons [50]. The moisture content of the soil increased in the vegetable plots protected with plastic mulch too [51], but this effect was found inconclusive in an experimental setting similar to ours, where mulched patches followed unmulched patches in a regular pattern because SMC seemed to reflect soil heterogeneity, as opposed to the presence of mulch [52].

4.2. Physical Parameters: Soil Compaction

In our experiment, the ability of inorganic mulch and the combination of inorganic and organic mulch to decrease soil compaction was recorded as early as near the end of the first growing season. Our finding agrees with that of a recent study [53], where a previously compacted soil was ameliorated with mulching; and with that of a four-year study too [54]; and, to a certain degree, with the results found in onion in a protected environment [55] too. However, interestingly, this latter study focused on the thickness of plastic as well, and while for all the thinner plastics the penetrometer-based compaction figures were similar and appropriately low, once the thickness of the plastic exceeded 35 μm, soil compaction of the mulched area was almost as high as that of the uncovered soil surface. While the μm figure for the foil used in our experiment is lacking, the efficiency of our WF was obvious: SPR values even in deepest layers of the soil were below 2 MPa, which is the level where compaction starts to hinder root development, as recalled [54]. We also have to note that during adjustment of the plants or sampling, we avoided stepping on the mulch layers and used the corridors instead. The highest compaction penetrometer figures belonged to the cultivated alfalfa field, as we expected, given the significant tread pressure generated by the repeated use of heavy machinery. SPR values reveal the presence of a definite plough pan within the 10–20 cm depth of the soil, which is not due to the original discing before sowing but rather to the recurrent use of machinery.

4.3. Chemical Parameters: pH

The use of mulch elicited significant differences between the pH of WF and WF + S treatments and GR and CA; and between WF and WF + S and CA measured either in (H_2O) or in (KCl), respectively. Our results do not concur with papers investigating the effect of plastic mulch materials on soil properties, because in these studies, changes to pH values were not significant, while other physicochemical parameters, including saturated hydraulic conductivity, field capacity, residual nitrate and nitrite, were significantly altered [54,56]. It seems that the use of plastic materials as mulch has its consequences, which will have to be accounted for.

4.4. Chemical Parameters: Ca

None of the treatments seem to have caused any changes to the $CaCO_3$ content of the soil, and the reason behind this may be similar to the one suggested in an earlier experiment, namely that the soil buffering capacity compensated the impact of mulches on the $CaCO_3$ content [57].

4.5. Chemical Parameters: Soil Organic Matter (SOM)

While in a two-year study rotating vegetables and cereals, soil organic carbon content saw a major decline on plots covered with plastic mulch [51], and another two-year study of tomato production also recorded losing organic material [58], and yet another, ten-year study of tree plantations observed a reduced organic matter content [59], our experimental area definitely encountered the opposite: SOM increased regardless of cover type. The highest rise was found with the combination of inorganic and organic mulch material. By the addition of straw on top of the inorganic mulch layer (WF) as a second mulch layer, we assume we scaled down the innate ability of plastic mulch to increase soil temperature and curb mineralization, a phenomenon described in a paper presenting the results of a long-term mulching experiment [60]. In other words, straw helped retain more of the organic matter when compared to plots covered only with plastic mulch.

The reason behind the elevated value for grassy patches (GR) can be attributed to the mulching lawnmower that left organic material on the land. Sometimes, not removing the organic material produced by a certain area may help save this valuable material. CA had the lowest SOM content, as expected, because intensive tillage and disturbance have an adverse effect on SOM [61]. Additionally, mulched areas kept receiving goat manure evenly every year and were not disturbed by treading.

4.6. Biological Parameters: Earthworm Abundance, Biomass, Species Composition

When we sampled mulched microplots in our experiment, staked and pruned tomato plants were selected because the abundant vegetation of unpruned plants grown on trellises casts a large shadow on the mulch and would have modified the effect of mulching itself. Considering that straw mulch had a positive effect on earthworm populations [22,26,62], we anticipated higher values for earthworm abundance and biomass on mulched plots (WF and WF + S). Yet, this only happened in spring 2021, and even then, the difference was not significant. In fact, none of the figures for abundance and biomass of any treatment were statistically different from one another. This sampling time stood out of the six sampling occasions because, on all the other five sampling times, earthworm abundance and biomass values were the highest with the grassland treatment (GR), although the difference was not significant in spring 2020. Similarly, when a freshly established tree plantation was monitored for ten years, the presence of plastic mulch was found to reduce both earthworm abundance and biomass by 46.8% and 61.2%, respectively, when compared to uncovered areas [59]. The explanation may lie in the type of mulch material, i.e., plastic. As an earlier review points out, freshly fallen organic materials, being in the state of senescence, are one of the most important and preferred food sources for earthworms [63]. Additionally, because plastic acts as a physical barrier between soil and this organic input, earthworms might have to migrate to other areas where this type of food is more available.

4.7. Earthworm Species Composition

The earthworm species composition of plastic mulch and grasslands was, in a way, similar, while the combination of plastic and straw and the alfalfa field also had species composition patterns similar to each other. WF and GR were dominated by the most abundant species, *Allolobophora chlorotica* (68 and 63%, respectively), and all the other species were present in small percentages. WF + S and CA, on the other hand, had a lower figure (57%) for *A. chlorotica*, meaning higher occurrence figures for subsequent species (15 and 21% for the second most abundant species, *Aporrectodea rosea*, and 12 and 14% for the third species, *Aporrectodea caliginosa*). When investigating the role of spatial distribution of soil characteristics in forming earthworm diversity and species distribution, our two most dominant species, *A. chlorotica* was found to be attracted by high organic material, and *A. rosea* favored sampling sites with higher moisture content [64]. It seems that, although the four habitat types of our experimental field had significantly different figures for both SOM and SMC, these soil conditions were still suitable for the two earthworm species to be present in relatively high numbers. The third species on our dominance list, *A. caliginosa*, on the other hand, has been documented to have one of the highest ecological tolerances among earthworms [65]. Its presence, therefore, is general in any soil where earthworms are present and may not be correlated to any of our management variations.

Earthworm diversity was similar throughout the whole experimental area. The number of species was slightly lower on the cultivated alfalfa field, but the difference was not significant. Most species belonged to the endogeic group. Although our species diversity results were not statistically analyzed, we may point to a recent observation where earthworm species richness of grasslands was negatively correlated to the presence of grazing animals, with more animals resulting in lower earthworm diversity [66]. There was no trampling by animals per se on our experimental area, but it was regularly supplied with goat manure, which, beside trampling pressure, is also a highly influential element of grazing. We may speculate that the high amount of animal excrement might have contributed to lower diversity results.

4.8. Plant Abundance

Our experiment had a weed-control-fabric-only treatment (WF) and a combination of WF with straw, but not a straw only treatment, because straw mulch has a lower ability to suppress weeds, especially perennial ones, including *Cirsium arvense* and *Elymus repens* [67–69], which were found dominant in the grassland before the experiment.

In contrast to earlier studies [70,71], mulch type had no influence on the species composition of weeds nor on their diversity, but only on the order of dominance of the five most frequent species. The persistence of *Taraxacum officinale* and *Setaria glauca* on mulched plots was unexpected because the application of mulch reduced these species in one of our earlier studies [72]. The reason may be, again, the type of mulching material, suggesting that organic mulch made of leaf litter may be a better candidate if our aim is to combat these specific weed species.

In our experiment, habitat and season had the highest influence on total plant cover. Plant biomass was not recorded, but plant abundance (cover) was significantly higher on the grassland than on mulched habitats (WF, WF + S). Yet, weed control efficiency was definitely below those figures obtained by plastic mulch in a study examining the potential of various mulch materials against weeds [73]. *Elymus repens*, a common perennial of grasslands, for example, and *Convolvulus arvensis*, a perennial weed of agricultural areas, were able to pierce through the plastic, even when covered with straw. Straw, as a second mulch layer (WF + S), was probably responsible for keeping soil temperature cold in the spring, resulting in stunted tomato growth when compared to WF-only plots, which was quite an unwanted consequence from the perspective of the farmer. However, the same mechanism prevented the crop from being overheated and spoilt during the hot spell of summer too. We speculate that straw must have similar effects on weeds, and this may explain why total cover was low in the spring and higher in the autumn.

5. Conclusions

The objective of our study was to investigate the effect of mulch applications on physical, chemical and biological parameters, which in turn affect agricultural production, so as to be able to find suggestions for converting a grassland to a double-purpose land, where ecological and economic aspects are both achieved. We observed the practical consequences of working with two different mulch types too.

The addition of straw as a second layer was multi-purpose. It prevented the topsoil from overheating during summer under the plastic material; it increased the lifetime of the fabric; and finally, a visible straw layer was aesthetically more pleasing than a plastic cover. Transportation, distribution, removal and replacement of straw is extremely labor intensive. If the straw of the previous year remains, it starts decomposing, and its uneven surface fills up with plant residues and soil, which creates an excellent propagation area for weeds. Weeds are the reason why the plastic cover needs removal too. Certain weed species practically stitched the fabric to the ground, creating holes and wearing out the material. It is best to remove the plastic at the end of the growing season and reapply it only at the beginning of the new season.

Weed control fabric, alone or in combination with straw, is beneficial for the plants, but to meet the long-term ecological goals, its application should be minimized. Creating a sowing or plantation pattern similar to ours that is alternating fabric-covered strips or islands with undisturbed green strips or corridors may help achieve the ecological benefits while generating acceptable yields in the same area.

The presence of green corridors made mowing slightly difficult, but with a carefully selected machinery or with a hand scythe, it was feasible. For maximum ecosystem benefits, it is advised not to mow all the corridors at once and leave certain areas for pollinators.

Grassland conversion does not necessarily mean losing the advantages of a biologically and structurally diverse ecosystem. Our study sets an example of the combination of creating and maintaining the conditions for agricultural production while saving biodiversity and ecosystem services.

Author Contributions: Conceptualization, F.T.; methodology, B.S. and K.B.P.; software, M.Z.; validation, F.T.; formal analysis, M.Z.; investigation, M.Z., B.S., K.B.P., A.S., D.S. and T.G.W.; resources, A.S., K.B.P. and B.S.; data curation, M.Z., B.S., D.S., T.G.W. and F.T.; writing—original draft preparation, F.T.B., K.B.P., B.S. and T.G.W.; writing—review and editing, F.T.B. and F.T.; visualization, K.B.P., M.Z., F.T. and B.S.; supervision, F.T., B.S. and K.B.P.; project administration, K.B.P.; funding acquisition, D.S. and J.P.N. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the New National Excellence Program (ÚNKP-19-1-I/5.) of the Ministry of Human Capacities, Hungary. We would like to thank the financial support received from Doctoral School of Environmental Sciences and Plant Sciences.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to express our special thanks to Csaba Csuzdi for helping in the identification of earthworm species.

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

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