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Aided Phytoremediation in Fire-Affected Forest Soil

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Abstract: Wildfires are occurring with an increasing frequency, and substances they generate can negatively affect the environment. A pot experiment with *Lolium perrene* was performed on burnt soil supplemented with organic (biochar, compost) and inorganic (NPK fertilizer) supplements and combinations of soil amendments in order to assess the possibility of aided phytomanagement of fire-affected areas. Soil amendments affect more aboveground biomass growth than underground biomass growth. Organic amendment, biochar, and compost promoted aboveground biomass growth; however, they did not increase the bioconcentration of metal elements in the roots. Unamended burnt soil achieved the highest bioconcentration of metal elements in underground biomass, while it produced significantly less aboveground biomass than burnt soil amended with biochar and with compost. Based on the ash composition from this study, aided phytostabilization appears to be a suitable phytomanagement method, as the priority is to rapidly recover vegetation in order to prevent soil erosion. This study therefore recommends selecting a suitable phytoremediation method based on the composition of ash.

Keywords: burnt soil; soil amendments; biochar; compost; NPK fertilizer; aided phytoremedation; phytostabilization; wildfires

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1. Introduction

Wildfires have become an increasingly common phenomenon due to changing climatic conditions [1,2] and earlier policies of fire suppression which have led to fuel accumulation and created a potential risk of large-scale fires [3,4]. The abandonment of agricultural areas and pastoral activities or plots with solar power plants contributes to fire occurrence as well [4,5]. The increased frequency of wildfires has substantial environmental and socio-economic impacts [6]. Fires have a lasting impact on the environment from the moment of their occurrence and over their whole duration, and their impact can be evident even several decades afterwards [7].

During combustion, harmful substances such as heavy metals (HM), potentially toxic metal elements, polycyclic aromatic hydrocarbons (PAH), gases, and carbon emissions are released. These substances affect the fire-affected area itself, nearby ecosystems, water supplies [8], adjacent agricultural systems, and humans due to the resulting air pollution and possible entry of potentially toxic elements into the food chain [9]. The biodiversity and wildlife habitat are altered and destroyed during a wildfire [7]. The fire-affected area is especially vulnerable, as the soil cover is partially or completely combusted and does not protect the soil against water and wind erosion. Water and wind erosion are responsible for spreading potentially toxic substances released during combustion to both the surrounding and very distant ecosystems, exposing them to contamination.

It is not always necessary to intervene in the fire-affected area, as a species-rich and stable ecosystem can be created through natural recovery and succession [10,11]. On the other hand, in certain cases, depending on many factors (as mentioned later in this paper), it is advisable to initiate a post-fire treatment as soon as possible. Among those factors are, for example, the size of the fire-affected area, if and how many human lives, properties, and water supplies are endangered, and the extent of expected erosion in the fire-affected area is [12].

A possible method of post-fire management is phytoremediation. It is an eco-friendly, low-cost, plant-based method the principle of which consists in re-vegetating contaminated soils using plants capable of sequestering trace elemental pollutants in various ways [13], thereby preventing their spread through the environment. The advantage of phytoremediation is that it uses organisms in a natural manner and maintains the ecological balance of the environment, making it less damaging than conventional alternatives [14]. Plants can extract pollutants by translocating them from soil to the aboveground harvestable biomass (phytoextraction), reduce their bioavailability in soil (phytostabilization) or convert them into less toxic form, and release them via transpiration through their foliage system (phytovolatilization) [15]. Simultaneously with revegetation, the soil surface is consolidated and runoff and soil erosion are mitigated. Other types of phytoremediation include phytodegradation and rhizodegradation; however, these apply to organic pollution. Rhizodegradation uses microorganisms in the rhizosphere to decompose organic pollutants [16], while, during phytodegradation, plants degrade organic pollutants with the help of enzymes instead of rhizospheric microorganisms [17,18].

The efficiency of phytoremediation can be enhanced by the addition of soil amendments; therefore, it often combined with their application, which is called "aided phytoremediation". Thanks to the addition of soil amendments, the physico-chemical properties of soil are improved, the contaminant bioavailability is lowered, and a better environment for the reintroduction of vegetation cover is facilitated [19], which results in a reduced soil recuperation period. Soil amendments can be materials of organic (e.g., compost, biochar) or inorganic (e.g., bentonite, diatomite) origin. Based on previous studies carried out by Barroso et al. [20,21], the following organic soil amendments have been chosen here: biochar, compost, a combination of the two, and a combination of biochar and NPK fertilizer with *Lolium perenne* L., (a grass species that is commonly used for phytoremediation owing to its global geographical distribution in both cold to humid regions). Grass species are used in phytoremediation thanks to properties such as rapid growth, tolerance to contaminants, and the capability to regrow shoots after cutting [22,23].

The efficiency of phytoremediation, particularly of phytoaccumulation/phytoextraction, can be indicated by the Bioconcentration Factor (BCF) and Translocation Factor (TF) [24]. Both are indicators of plants' ability to accumulate or translocate heavy metals and other metal elements from the soil. In the case of BCF, the number indicates a ratio of concentration of HM in plant tissue against the concentration of HM in the surrounding environment [25,26], while TF demonstrates the efficiency of translocating HM from the underground biomass (UGB) to the aboveground biomass (AGB) [27].

Wildfires are a process in which radical changes occur throughout a whole ecosystem, including the availability of selected metal elements for vegetation. Therefore, our hypothesis is that the addition of soil amendments to the soil after a fire does not change the availability of selected metal elements for uptake by plants. To confirm or refute this hypothesis, the following sub-objectives were set: (i) to determine the effect of applying soil amendments to burnt soil (BS) on the growth of model plant biomass; (ii) to determine the effect of applying soil amendments to the BS on the proportion of selected metal elements in soil and biomass; and (iii) to determine the effect of applying soil amendments to the BS on the mobility of selected metal elements between the burnt soil and the biomass of the model plants.

2. Materials and Methods

2.1. Study Area and Sample Collection

The study area is located on the border of Treboň and Pelhřimov bioregions [28]. Oak–coniferous biota predominates in these bioregions; the main coniferous species are Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The investigated area is characterized by acidic cambisol typical for this region [28]. The study area was hit by bark beetle infestation, due to which the affected trees were logged and removed from the forest. The remaining slashed wood was fired at five sites, each with an approximate size of 5 × 5 m (Figure 1).

Figure 1. (**a**) Pile burning of slashed woods; (**b**) smoldering fires; (**c**) aftermath of the pile burning.

These fire sites were tracked by a GPS Garmin etrex 10 device (Figure 2, Table A1). A composite of samples, i.e., six subsamples, each weighing around 1 kg, was taken from each fire site. The soil was mined from a depth of 15 cm under the surface, and the collection included the layer of the ash. The burnt soil samples were transported in plastic vessels to Mendel University, Department of Applied and Landscape Ecology on the day of collection, where they were passed through a 5 mm sieve to remove stones and larger unburnt biomass residues. The sieved soil was spread in a 4 cm layer and air-dried at 20 °C ± 2 °C for two weeks in a dust-free enclosed room. The air-drying soil was mixed once every day. After two weeks, a mixed sample was created by thorough homogenization. The homogenized burnt soil was then divided into six equal parts and placed into six performed plastic vessels (12 L).

2.2. Soil Amendmends and Sample Preparation

Based on previous studies on soil amendments, compost, biochar, their combinations, fertilizer NPK, and the combination of fertilizer NPK with biochar were selected. The properties of the soil amendments are listed in Table 1. The amount of added soil amendments is displayed in Table 2. The amount of biochar was adjusted due to its very low specific weight. The amount of fertilizer NPK was calculated according to the manufacturer's recommendations for fertilizing grasslands. The compost was dosed according to the recommendations resulting from previously performed experiments.

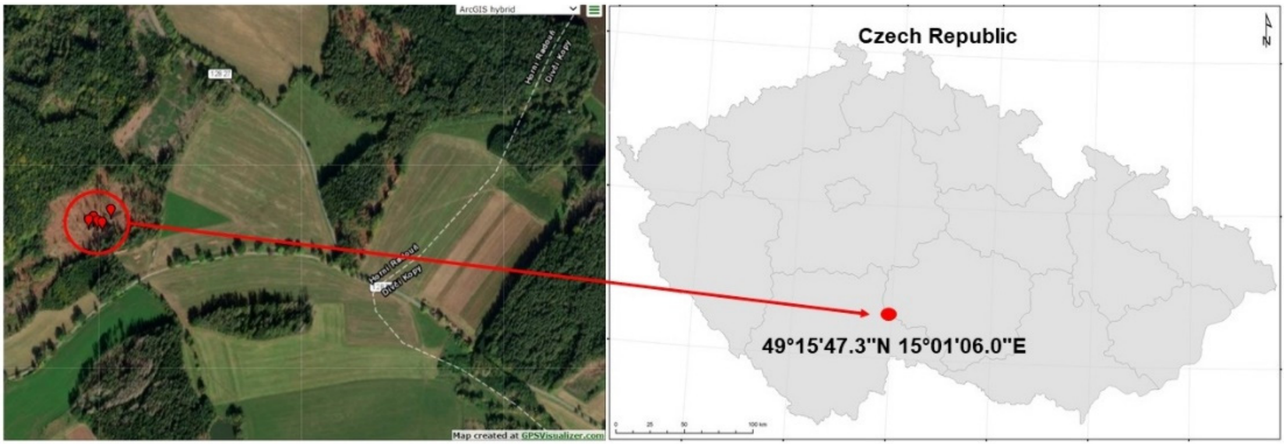

Figure 2. GPS localization of collection points.

Table 1. Characterization of soil amendments.

Soil Amendment	Characterization
Compost	Organic fertilizer made by composting biodegradable organic substances and plant nutrients. Thanks to its application, active hummus, microorganisms, and elemental nutrients are incorporated into the soil. Obtained from a municipal composting plant [29]. The parameters of compost comply with those set by law for soil conditioners [30].
Biochar	Carbonaceous material made by pyrolysis of chemically untreated wood. Functional properties: water retention, pollutant sorption, carbon sequestration, effective nutrient usage. Content of risk trace elements complies with regulations set for soil conditioners (technical sheet, Prauhel, [31]. Bought from [31]).
NPK Fertilizer	During the burning of litter and organic matter, nutrients can be released and become more available for plants (in the case of low-intensity fires) or combusted and volatilized (in the case of high-intensity fires) [32]; therefore, the macronutrients nitrogen (N), phosphorus (P), and potassium (K) needed for proper growth and development of plants can be supplemented in soil through NPK Fertilizer. Brand: Forestina s.r.o., Střelské Hoštice; composition: 11% N + 7% P_2O_5 + 7% K_2O; recommended dosage for grass: 50–90 g·m^{-2}
Biochar + Compost	Suggested combination of biochar with other soil conditioners to prevent leaching of nutrients provided by NPK Fertilizer [33] or, on the other hand, preventing adsorption of nutrients by biochar in poor soils, which makes them unavailable for uptake by plants. Synergic effects can be expected with a combination of soil amendments [34].
Biochar + NPK Fertilizer	

Six different samples of amended burnt soil were prepared before starting the pot experiment; their composition is shown in Table 2. After preparation, they were left in a dark room at a temperature of 20 ± 2 °C and 60 ± 5% relative humidity for one week to provide time for property stabilization. The last sample of BS was not enriched by any soil amendment, and was subjected to the same procedure. During this period, the soil mixtures were watered twice, each time until reaching the water-holding capacity of the soil.

2.3. Pot Experiment

The mixture from each variant was divided into five terracotta pots with the dimensions 152 mm height, 140 mm width, and 140 mm depth; 1 g of *Lolium perenne* seeds (501 ± 3 seeds) were sown in each pot. The number of seeds in 1 g of *Lolium perenne* was determined by manual calculation of 1 g of the seeds in five replicates. In total, 6 × 5 pots were prepared (five variants with amended BS and one variant with unamended BS). The pot experiment was chosen for its simplicity and capacity to provide an answer for a set hypothesis. The pot experiment was carried out under controlled conditions (an air-conditioned laboratory at 20 ± 2 °C, natural daylight) and was used to investigate the effect of added soil amendments on the biomass yield for both AGB and UGB.

Table 2. Weight of soil amendments in individual variants and pot experiment arrangement.

Variants BS + Type of Amendment	BS [g]	Compost [g]	Biochar [g]	NPK [g]	Total Weight of Soil Mixture [g]
BS + 3% *w*/*w* Comp. + 1.2% *w*/*w* Biochar	5105	160	65	0	5330
BS + 0.18% *w*/*w* NPK + 1.2% *w*/*w* Biochar	5255	0	65	10	5330
BS + 1.2% *w*/*w* Biochar	5265	0	65	0	5330
BS + 3% *w*/*w* Comp.	5170	160	0	0	5330
BS + 0.18% *w*/*w* NPK	5320	0	0	10	5330
BS	5330	0	0	0	5330

All pots were labelled, indicating the variant and number of replicates, and located randomly within the laboratory. Their position was changed every third day to ensure that equal conditions were provided to all the pots. The pot experiment lasted 45 days. After this time, the AGB was harvested, dried, packed individually, and labelled accordingly (Figure 3). UGB was removed thoroughly from the soil, cleaned by distilled water, and dried. AGB and UGB were weighed.

Figure 3. (**a**) Burnt soil with soil amendments before mixing; (**b**) terracotta pots; (**c**) *Lolium perenne* biomass growth; (**d**) dried and packed AGB, UGB, and soil after pot experiment.

2.4. Chemical Analysis

2.4.1. Selected Analyzed Metals

The following trace elements in AGB, UGB, and soil were analyzed in an accredited laboratory (ALS CZECH REPUBLIC, s.r.o.) using atomic emission spectrometry with inductively coupled plasma and stoichiometric calculations of compound concentrations from measured values [35]:

- Essential metal elements (Fe, Cu, Zn, Ni) important for healthy plant growth and biological activities; when these elements occur in excess, they become toxic [13,36].
- Non-essential metal elements (Cr, Pb) that are highly toxic even in trace amounts; they provide no known benefit to plants [13,37].

2.4.2. Biomass Analysis

Chemical analyses were performed on composite samples of AGB and UGB due to the limited material availability (sums of AGB and UGB ranging between 6.435 g and 10.899 g and 0.265 g and 0.863 g, respectively). Composite sampling increases the availability of material for measurements wherein analyses would otherwise be excluded due to the insufficient weight of material [38]. Representative composite samples of AGB, UGB, and soil were prepared by careful physical mixing and pooling of five subsamples of individual variants. The weights of individual component samples were equal. It was assumed that a composite sample value represented the mean of the sample unit measurements [38].

Although compositing reduces the variance of the mean, the variation and extremes are not erased, and composite samples deliver more information about the mean of the analyzed characteristic than individual samples [39].

2.4.3. Soil Analysis

All chemical analyses were performed on samples in an accredited laboratory after the termination of the pot experiment [35].

pH_{KCl} was determined electrochemically in suspension in water, KCl, $CaCl_2$, $BaCl_2$ (ČSN ISO 10390).

Dry matter (D.M.) at 105 °C was determined by gravimetry and calculation of moisture from measured values (ČSN ISO 11465).

Total carbon (TC) was determined by the combustion method with IR detection and calculation of total inorganic carbon (TIC) and carbonates from measured values (ČSN ISO 10694).

Total nitrogen (TN) was determined by modified Kjeldahl method by spectrometry (ČSN ISO 11261).

2.5. Calculation of BCF and TF

BCF and TF were calculated from the concentrations of selected metal elements analyzed by an accredited laboratory using the following Equations (1) and (2):

$$\text{BCF} = \text{concentration AGB}/\text{concentration BS}, \quad (1)$$

$$\text{TF} = \text{concentration AGB}/\text{concentration UGB}. \quad (2)$$

2.6. Data Analysis

The acquired data values were processed by descriptive statistics; exploratory data analysis was performed using Statistica 12 (Dell Software, Round Rock, TX, USA) in order to guarantee that the basic assumptions for ANOVA testing were met. The normality of distribution of individual populations was confirmed by the Shapiro–Wilk test, and the homogeneity of variances was proven by Levene's test. The independence of individual observations was determined by the design of the experiment. Input analysis was complemented with one- and two-way analysis of variance (ANOVA). Post hoc LSD Fischer Test and F-test were carried out for the identification of significant differences. All statistical analyses were performed with the level of significance $p < 0.05$

3. Results

3.1. Aboveground Biomass (AGB)

The mean weight of AGB in individual variants is shown in Table 3. Descriptive statistics of AGB and UGB weight of D.M. is shown in Table A2. The highest yields of AGB were seen in the variant supplemented with biochar (2.180 g) and in the variant enriched with compost (2.086 g). The combination of compost and biochar did not promote the expected increase in the growth of AGB, and the yield stayed under 2 g (1.973 g). No significant difference was found among these three variants; however, the variants amended only with biochar and only with compost were significantly different ($\alpha = 0.05$) from the unamended burnt soil, where the amount of AGB reached 1.559 g. The variants where fertilizer NPK and combinations of fertilizer NPK and biochar were used showed the lowest mean yield of AGB (1.417 g and 1.287 g, respectively). A significant difference among the variants with the highest and lowest yields of AGB was found.

Table 3. Mean weight of AGB in individual variants.

Variant	Weight [g]	Fischer test		
BS + 0.18% *w*/*w* NPK + 1.20% *w*/*w* Biochar	1.287 ± 0.150	b		
BS + 0.18% *w*/*w* NPK	1.418 ± 0.150	b		
BS	1.559 ± 0.281	b		d
BS + 3.00% *w*/*w* Comp. + 1.20% *w*/*w* Biochar	1.973 ± 0.280		c	d
BS + 3.00% *w*/*w* Comp.	2.086 ± 0.242		c	
BS + 1.20% *w*/*w* Biochar	2.180 ± 0.197		c	

AGB—aboveground biomass, BS—burnt soil; mean values of AGB (n = 5) ± SE are presented; different small letters indicate significant differences between individual variants.

3.2. Underground Biomass (UGB)

The mean weight of underground biomass in individual variants is shown in Table 4. Descriptive statistics of AGB and UGB weight of D.M. is shown in Table A2. The amount of UGB in individual variants varied; nevertheless, a statistical difference was not proven among individual variants. For better visibility, the interaction of the type of biomass with individual variants is denoted in Figure 4.

Table 4. Mean weight of UGB in individual variants.

Variant	Weight [g]	Fischer Test
BS	0.053 ± 0.003	a
BS + 0.18% *w*/*w* NPK + 1.20% *w*/*w* Biochar	0.069 ± 0.009	a
BS + 0.18% *w*/*w* NPK	0.099 ± 0.028	a
BS + 1.20% *w*/*w* Biochar	0.128 ± 0.018	a
BS + 3.00% *w*/*w* Comp.	0.165 ± 0.018	a
BS + 3.00% *w*/*w* Comp. + 1.20% *w*/*w* Biochar	0.173 ± 0.023	a

UGB—underground biomass; BS—burnt soil; mean values of UGB (n = 5) ± SE are presented; different small letters indicate significant differences between individual variants.

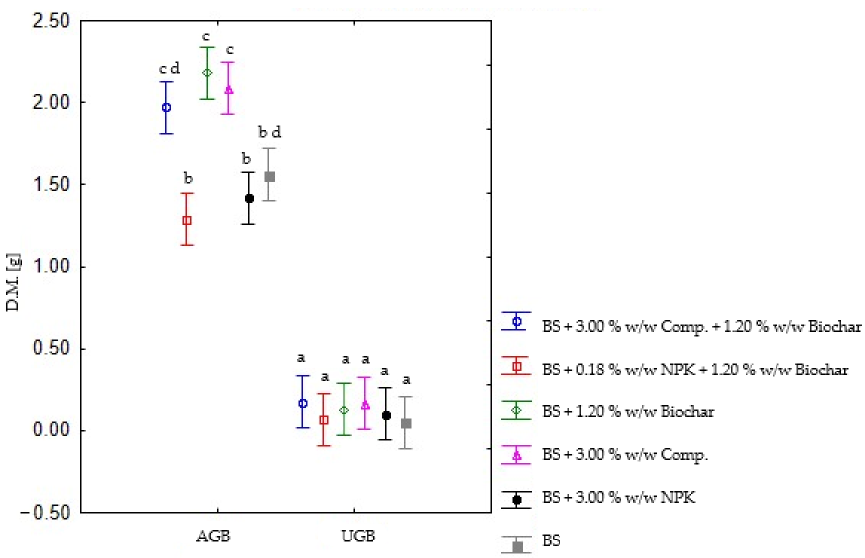

Figure 4. Graphical illustration of the effect of individual factors (soil amendments and type of biomass) on the D.M. biomass yield. Vertical columns present mean values of AGB and UGB ± SE (n = 5). Different small letters indicate significant differences between individual variants.

3.3. Selected Metal Elements in AGB, UGB, and Soil

Table 5 indicates concentrations of selected metal elements (or microelements) in soil, AGB, and UGB. None of the essential metal element concentrations measured in soil exceeded the preventive limit values in the Decree of the Ministry of Environment (Table A1) [30]. Concentrations of Pb and Cr in soil were relatively similar in all the variants. Although the values captured in UGB were not negligible, the concentrations in AGB were under detectable limits.

3.4. Translocation and Bioconcentration Factors

The highest BCF values for the majority of the analyzed elements, namely, Fe, Zn, Ni, Pb, and Cr, were recorded in the variant with unamended BS (Table 6). The only element in which BCF stood out was Cu. The BCF for Cu was highest in the variant with BS + 0.18% *w*/*w* NPK + 1.20% *w*/*w* biochar.

TF, which indicates plants' ability to translocate elements absorbed by the roots to the plant tissues, was the highest in two variants. These were BS + 3.00% *w*/*w* Comp. for Fe and Zn, and BS + 0.18% *w*/*w* NPK for Ni and Cu (Table 6). It was not possible to calculate the TF for Pb and Cr, as their concentrations in AGB were under the limit of detection (Table 6). Variants BS + 3.00% *w*/*w* Comp. + 1.20% *w*/*w* biochar and BS + 0.18% *w*/*w* NPK + 1.20% *w*/*w* biochar were the only ones that limited the translocation of Ni to plant tissue.

The distribution of monitored metal elements in soil and biomass of *Lolium perenne* is illustrated in Figure 5. Small proportions of Fe, Pb, Ni, and Cr in AGB indicate that *Lolium perenne* biomass is not suitable for phytoaccumulation of these metal elements. A higher proportion of these elements was concentrated in UGB, and was more pronounced for variants without amendment (BS) and for variant BS + 0.18% *w*/*w* NPK. These amendments can further support *Lolium perenne* phytostabilization ability.

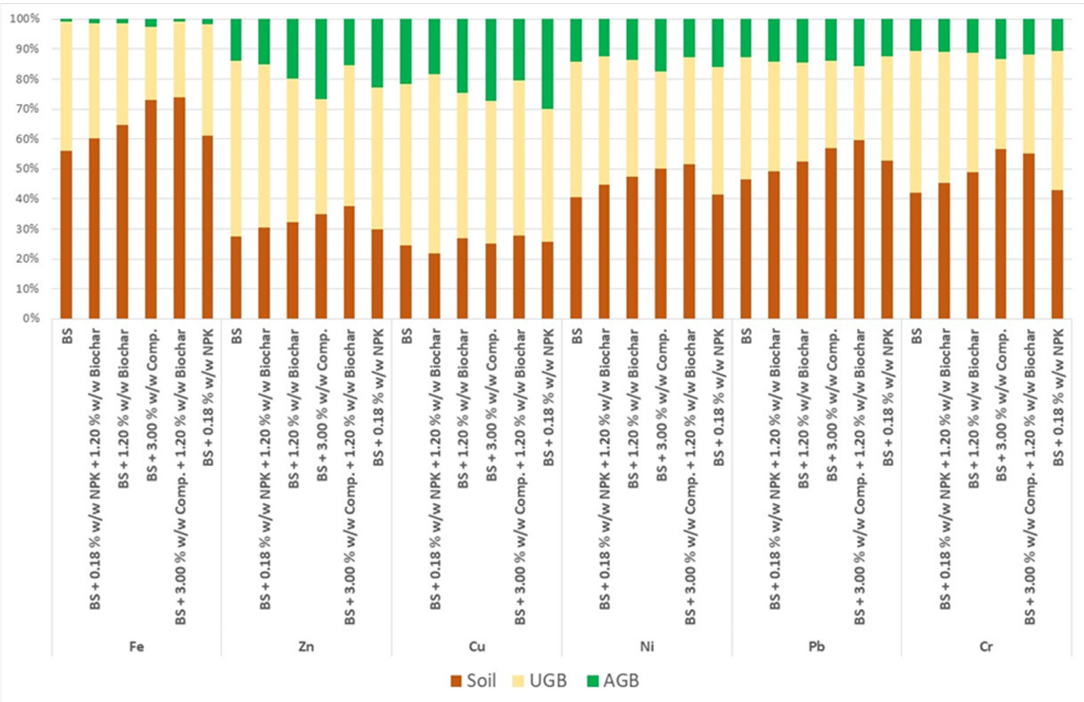

Figure 5. Proportions of monitored metal elements in soil and biomass of *Lolium perenne*.

Although *Lolium perenne* is used mainly for its ability to phytostabilize [40], it is possible to augment the translocation of Zn and Cu to AGB by application of compost or NPK, and thus support its phytoaccumulation ability.

Table 5. Mean concentration of Fe and Zn in soil, AGB, and UGB biomass.

	Fe [mg.kg^{-1}]			**Zn [mg.kg^{-1}]**			**Cu [mg.kg^{-1}]**			**Pb [mg.kg^{-1}]**			**Cr [mg.kg^{-1}]**			**Ni [mg.kg^{-1}]**			**Pb [mg.kg^{-1}]**			**Cr [mg.kg^{-1}]**		
	Soil	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**	**Soil**	**AGB**	**UGB**
BS + 3.00 % *w*/*w* Comp. + 1.20 % *w*/*w* Biochar	18,600.00	237.00	6350.00	81.20	33.40	102.00	9.80	7.14	18.20	19.00	<5.00	7.90	13.90	<3.00	8.35	8.20	<2.00	5.68	19.00	<5.00	7.90	13.90	<3.00	8.35
BS + 0.18 % *w*/*w* NPK + 1.20 % *w*/*w* Biochar	17,300.00	401.00	11,100.00	69.00	34.00	124.00	8.00	6.72	22.00	17.40	<5.00	12.90	12.30	<3.00	11.90	7.30	<2.00	6.98	17.40	<5.00	12.90	12.30	<3.00	11.90
BS + 1.20 % *w*/*w* Biochar	17,900.00	401.00	9360.00	75.10	46.60	112.00	9.20	8.41	16.50	18.20	<5.00	11.40	13.20	<3.00	10.80	7.90	2.28	6.47	18.20	<5.00	11.40	13.20	<3.00	10.80
BS + 3.00 % *w*/*w* Comp.	16,900.00	569.00	5640.00	80.00	61.50	88.50	9.80	10.70	18.80	20.50	<5.00	10.60	12.70	<3.00	6.76	7.60	2.67	4.92	20.50	<5.00	10.60	12.70	<3.00	6.76
BS + 3.00 % *w*/*w* NPK	16,300.00	422.00	9950.00	71.20	54.90	113.00	8.70	10.20	15.00	21.00	<5.00	13.90	12.30	<3.00	13.30	7.30	2.82	7.47	21.00	<5.00	13.90	12.30	<3.00	13.30
BS	15,900.00	233.00	12,300.00	68.80	34.40	146.00	8.20	7.26	18.00	18.40	<5.00	16.20	11.90	<3.00	13.40	7.00	2.44	7.84	18.40	<5.00	16.20	11.90	<3.00	13.40

Table 6. Mean BCF and TF of Fe, Zn, Cu, Ni, Pb, and Cr; the highest values are marked in bold.

	Fe		Zn		Cu		Ni		Pb		Cr	
	BCF	**TF**	**BCF**	**TF**	**BCF**	**TF**	**BCF**	**TF**	**BCF**	**TF**	**BCF**	**TF**
BS + 3.00 % *w*/*w* Comp. + 1.20 % *w*/*w* Biochar	0.341	0.013	1.256	0.411	1.857	0.729	0.693	NA	0.416	NA	0.601	NA
BS + 0.18 % *w*/*w* NPK + 1.20 % *w*/*w* Biochar	0.642	0.023	1.797	0.493	**2.750**	0.840	0.956	NA	0.741	NA	0.967	NA
BS + 1.20 % *w*/*w* Biochar	0.523	0.022	1.491	0.621	1.793	0.914	0.819	0.289	0.626	NA	0.818	NA
BS + 3.00 % *w*/*w* Comp.	0.334	**0.034**	1.106	0.769	1.918	1.092	0.647	0.351	0.517	NA	0.532	NA
BS + 3.00 % *w*/*w* NPK	0.610	0.026	1.587	**0.771**	1.724	**1.172**	1.023	**0.386**	0.662	NA	1.081	NA
BS	**0.774**	0.015	**2.122**	0.500	2.195	0.885	**1.120**	0.349	**0.880**	NA	**1.126**	NA

4. Discussion

The application of soil amendments to burnt soil modifies the soil properties (pH, distribution of substances) and changes the conditions for vegetation recovery [20,21]. Limiting factors of phytoremediation include bad root growth and development in contaminated soil. The addition of soil amendments can precondition the soil and thereby reduce possible limitations posed by potentially toxic metal elements, resulting in successful establishment of vegetation cover [41,42]. The effect of soil amendments on biomass growth differed between aboveground and underground biomass. Soil amendments showed a more pronounced effect on AGB growth than on UGB, where a statistical difference in growth was not observed. The fact that UGB growth is more sensitive to the effects induced by fire than AGB growth has previously been described in a 2005 study by Snyman et al. [43] where changes in AGB and UGB growth were monitored. The most successful amendments for promoting AGB growth were biochar and compost. Yields of *Lolium perenne* AGB in these variants were significantly higher than the AGB yield obtained from the unamended BS. This can be attributed to their capacity to boost microbial activity in the soil, which contributes to increased available nutrient content for uptake by plants. Nutrient cycling is influenced by microorganism activity [44]. Low AGB yield in the unamended BS might be explained by a reduction in the microbial population in the BS by the effect of fire. The most dramatic change is perceptible in the first year after the fire [45]. With time, the microbial population tends to recover; however, the negative effects can persist for years [46].

Although there are few studies dedicated to the long-term effects of biochar application on soil biota and microbial communities [47], many researchers [48,49] have performed experiments confirming that its application to soil evokes a change in the structure of the soil microbial community and increases enzyme activity, which both support biomass production. Nutrient availability during biochar application was researched in a study by Vahedi et al. (2022) [50]; the authors recommended combining biochar application and inoculation with growth-promoting bacteria. Another study in which nutrient-poor soils conditioned by biochar were examined was Alburquerque et al. 2015 [51], who used a pot-grown experiment. Biochar alone did not mitigate the nutrient deficiency, and its potential benefits were mainly seen in its combination with other fertilizers. These findings were not confirmed by this study, as the AGB yield in a variant enriched with biochar was one of the highest, showing that *Lollium perenne* L. prospered well. This might have been caused by a low dosage of biochar.

The stimulating effect of compost on the microbial effect is well known, and emerges from the nature of its formation. Compost contributes to nutrient cycling in the soil and supports soil life [52,53], which results in better biomass development. The availability of metal elements in compost-amended soils was studied by Kubná et al. 2015 [54], and it was concluded that increasing the dose of compost enhances immobility, and thus the bioavailability of HM is decreased. This does not apply to all trace elements, e.g., Zn, which is able to form chelates with the organic compounds that are introduced to the soil thanks to compost application.

The effects of the application of organic (poultry manure) and inorganic (NPK fertilizer) soil amendments on burnt soil were studied by Villar et al. 2004 [42], resulting in similar findings, in that changes in biomass production induced by the organic amendments were more evident than those evoked by NPK fertilizer, and the effect was more evident on AGB.

Lolium perenne is a commonly used grass species for phytostabilization and aids phytostabilization, especially for Cd, Zn, Pb, and Cu [40]; therefore, it can be expected that metal elements will be primarily concentrated in UGB. *Lolium perenne*, along with other phytostabilizers, develops an abundant root system, produces rich AGB, and does not translocate metal elements to shoots, which is a required condition in phytostabilization that prevents contaminants from entering the food chain [13]. Phytostabilization offers more positives for the fire-affected area, namely, faster recovery of vegetation, which protects the soil from erosion and increases its infiltration capacity [55].

Although several of the soil amendments positively affected AGB growth, their BCF capacity was not increased. Therefore, it is essential to assess the main priority for the fire-affected area, whether it is rapid recovery of vegetation or the immobilization of contaminants. Our chemical analysis of the generated ash showed that the ash did not surpass the preventive limits (Table A3) in the Decree on Protection of Agricultural Land, thus, the priority should be erosion protection of the soil, which implies the promotion of AGB growth through the application of compost and biochar. The best capacity concentration of metal elements in roots (meaning highest BCF) was in a variant with unamended BS. The only exception was Cu, an element in which the uptake by plants is regulated well even in soils with different Cu concentrations [56,57].

The ability of *Lolium perenne* to translocate was higher in variants BS + 3.00% *w*/*w* Comp. for Fe and Zn and in variant BS + 0.18% *w*/*w* NPK for Ni and Cu. Cr usually accumulates in roots, and the concentration of Cr depends on the content of dissolved substances in soil. An undetectable concentration of Cr in AGB confirms that absorbed Cr is hardly translocated to the AGB [58,59].

5. Conclusions

The application of soil amendments to burnt soil can affect the growth of aboveground biomass. After the application of biochar and compost, aboveground biomass growth increased. The growth of underground biomass of *Lolium perenne* was not affected by the application of soil amendments. The occurrence of selected metal elements in the soil after performing the pot experiment did not exceed the preventive limits set by law, which allows for the possibility of employing phytostabilization instead of phytoaccumulation in this particular study. The monitored metal elements had the lowest concentrations in aboveground biomass of *Lolium perenne*.

The highest bioconcentration factor values for most of the analyzed elements (Fe, Zn, Ni, Pb, and Cr) were recorded in the variant with untreated burnt soil. Soil amendments limit the bioconcentration capacity of *Lolium perenne*. An exception was seen with Cu in certain soil amendments. These elements can be biologically blocked in *Lolium perenne* roots by applying the mentioned soil amendments. The ability of *Lolium perenne* to translocate was supported by burnt soil + 3.00% *w*/*w* Comp. for Fe and Zn and by BS + 0.18% *w*/*w* NPK for Ni and Cu. The addition of certain soil amendments (biochar and compost) to the soil promoted the formation of *Lolium perenne* biomass, which can be used for rapid revegetation of burnt areas, thereby reducing soil erosion. The experiment did not manage to demonstrate the ability of *Lolium perenne* to phytoaccumulate selected metal elements. However, certain soil amendments support the translocation of certain metal elements, and thus their temporary biological blocking in root biomass.

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Appendix A

Table A1. GPS locations of individual burn points.

Collection Points	Latitude	Longitude	Altitude [m]
1BS	49°15′47.1″ N	15°01′04.9″ E	500.3
2BS	49°15′47.3″ N	15°01′05.4″ E	548.8
3BS	49°15′47.0″ N	15°01′05.7″ E	550.2
4BS	49°15′46.9″ N	15°01′06.2″ E	572.1
5BS	49°15′47.7″ N	15°01′07.1″ E	586.6

Table A2. Descriptive statistics of AGB and UGB weight of D.M.

Variant	Biomass	Mean [g]	Median [g]	Sum [g]	SD	SE
BS + 3% *w*/*w* Comp. + 1.2% *w*/*w* Bioch.	AGB	1.973	1.906	9.865	0.625	0.280
BS + 0.18% *w*/*w* NPK + 1.2% *w*/*w* Bioch.	AGB	1.287	1.282	6.435	0.335	0.150
BS + 1.2% *w*/*w* Bioch.	AGB	2.180	2.248	10.899	0.440	0.197
BS + 3% *w*/*w* Comp.	AGB	2.086	2.459	10.429	0.540	0.242
BS + 0.18% *w*/*w* NPK	AGB	1.418	1.465	7.088	0.336	0.150
BS	AGB	1.559	1.318	7.795	0.628	0.281
BS + 3% *w*/*w* Comp. + 1.2% *w*/*w* Bioch.	UGB	0.173	0.154	0.863	0.052	0.023
BS + 0.18% *w*/*w* NPK + 1.2% *w*/*w* Bioch.	UGB	0.069	0.058	0.345	0.019	0.009
BS + 1.2% *w*/*w* Bioch.	UGB	0.128	0.106	0.640	0.040	0.018
BS + 3% *w*/*w* Comp.	UGB	0.165	0.148	0.824	0.040	0.018
BS + 0.18% *w*/*w* NPK	UGB	0.099	0.087	0.496	0.062	0.028
BS	UGB	0.053	0.053	0.265	0.007	0.003

Table A3. Metal element concentrations in the Decree on Protection of Agricultural Lands with metal element concentration in ash and original burnt soil. *common soils; sandy–loam, loam, clay–loam, and clay soils occupy the majority of agricultural land. Soils with normal variability of elements, normal soil development in various geomorphological conditions, including soil on carbonate rocks.

Metal Element	Preventive Limit Value mg·kg^{-1} D.M. in Common Soils* [30]	Values Obtained from Ash Analysis	Values Obtained from Original BS without Treatment
Zn	120.00	331.00	77.20
Cu	60.00	35.80	10.30
Ni	50.00	11.00	8.40
Pb	60.00	22.50	25.00
Cr	90.00	7.72	13.8

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