JEE Journal of Ecological Engineering

Volume 21, Issue 6, August 2020, pages 248–256
https://doi.org/10.12911/22998993/123471

Received: 2020.04.20
Revised: 2020.05.30
Accepted: 2020.06.15
Available online: 2020.07.01

Fire Effects on Soils – A Pilot Scale Study on the Soils Affected by Wildfires in the Czech Republic

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ABSTRACT

Fires have always been a natural component influencing ecosystems and driving their evolution; however, in recent years they have become too frequent and ecosystems are not able to cope with them anymore. Fires destroy the natural vegetation, which prevents the soil erosion, and affect the soil properties which delay the natural recovery of the fire affected area. This experiment was conducted to assess the phytotoxicity of fire affected soil and to investigate whether different soil amendments can help to decrease the negative effect of fire on soil properties. The study utilised the Phytotoxkit^{TM} test. The tested burnt soil was supplemented with 3% w/w of the following individual soil amendments: bentonite, biochar, compost and diatomite. Then, the phytotoxicity tests were carried out with garden cress (*Lepidium sativum* L.) and white mustard (*Sinapis alba* L.). The pH and electrical conductivity of soil were measured and it was revealed that the individual soil amendments affected the values of pH and electrical conductivity diversely. The highest root growth stimulation for *Sinapis alba* L. was observed when diatomite was added, whereas the most favourable amendment for the stimulating root growth of *Lepidium Sativum L.* were compost, diatomite and biochar, respectively. This study recommended repeated testing for the amendments that show a capability to stimulate the root growth and conducting tests on a wider group of plant species.

Keywords: wildfire, soil amendments, effects on soil properties, preliminary testing, phytotoxicity, *Sinapis Alba* L., *Lepidium Sativum* L.

INTRODUCTION

The frequency of wildfires has been increasing during the last decade which has caused the environmental and economic losses (Mahmoud and Chulawat, 2018). The effects of wildfires on the environment have become a worldwide problem (Faboya et al., 2020). Wildfires affect ecosystems, landscapes and the future occurrence of fires significantly. The impact is highly space specific and depends on various factors such as time incidence (an interval between fire occurrence and duration of the event), spatial distribution and fire behaviour (including type of vegetation and type of fire) (Moody et al., 2013). Wildfires are a source of the carbon (C) emissions, which creates concerns about the global cycles and climate change, and a significant natural source of polycyclic aromatic hydrocarbons (PAHs) (Kim et al., 2003). During a wildfire of the above-ground and under-ground plant biomass, the humus layer and soil organic matter are burnt and the greenhouse gases (GHG) e.g. carbon dioxide (CO_2), methane (CH_4) a dinitrogen monoxide (N_2O) are being released (Shorohova et al., 2009; Ribeiro-Kumara et al., 2019).

The production and consumption of GHGs in soil can be altered in the areas affected by wildfires due to the physical, chemical and biological changes of soil properties caused during the fire succession (Certini, 2005; Hart et al., 2005). The heat generated by a wildfire affects the soil system, which subsequently has an impact on the soil hydrological processes (Wittenberg et al., 2019).

Deterioration of the soil properties depends on the increasing duration and temperature of burning (Stoof et al., 2014). The changes in the soil properties and loss of soil cover together with the precipitation amount play an important part in reaction to fire (Moody et al., 2013) and altogether influence the infiltration rate, runoff dynamics and erosion. The effects of wildfire on the change of the soil system, as far as the soil properties, functions and related ecosystem services are concerned, require more attention from the scientific area (Certini, 2005). The effects of wildfire on the soil properties can be direct and indirect. The direct effects are associated with the heat and they are usually short-term. The indirect effects are related to the ash-bed effects, rate of vegetation regeneration, weather trend, topography and management of fire protection (Pereira et al., 2018).

The issue of fires and the related effects on soil, human health and ecosystems is currently very up to date. In general, it can be stated that fires have always had an impact on the environment. However, in the Czech Republic (CR) there is a lack of data on the post-fire contaminants. A major limitation of using the classical chemical analysis of soils affected by fires is caused by a fact that the compounds present in trace amounts remain undetected and their potential biological effects remain underestimated. Therefore, the control of the impact of soils affected by fires within this research was based on the selected biological methods. The main aim of this study was to conduct: (i) a comprehensive field investigation on a selected area affected by a wildfire, (ii) physicochemical analysis of the selected soil properties (iii) phytotoxicity tests of the soil supplemented with different amendments.

MATERIAL AND METHODS

Study area

The study area is located on a periphery of Brno, Pod Hády, Maloměřice (49.2130883N, 16.6644528E), Southern Moravia (Figure 1). It is a deciduous wood where a local wildfire occurred on 11th June 2019. The area borders with a nearby brownfield with former light industry history and was identified via the Geographical Positioning System (Garmin GPS 72H).

On the basis of an incident report from the fire brigades, the fire might have been initiated by the burning of dry undergrowth in the immediate neighbourhood of the service road. The ignition was probably triggered by a cigarette thrown out from a window of a passing car late in the evening. The area is relatively remote; therefore, the fire spread without observation to the surrounding lower shrubs and at the time of reporting the incident, tree trunks and their lower branches were burning as well on an area of about 5×10 m, with flames reaching up to a height of about 6 m.

Sampling and laboratory tests

The samples of burnt soil were collected 6 months after the occurrence of the described forest fire from the topsoil (0–20 cm) from 10 different places. Altogether, 15 kg of burnt soil was taken and transported to the laboratory in 3 polyethylene (PE) vessels. The experiment was conducted under the laboratory conditions at Mendel University in Brno, Department of Applied and Landscape Ecology (Figure 2). The soil was left to air-dry at room temperature for

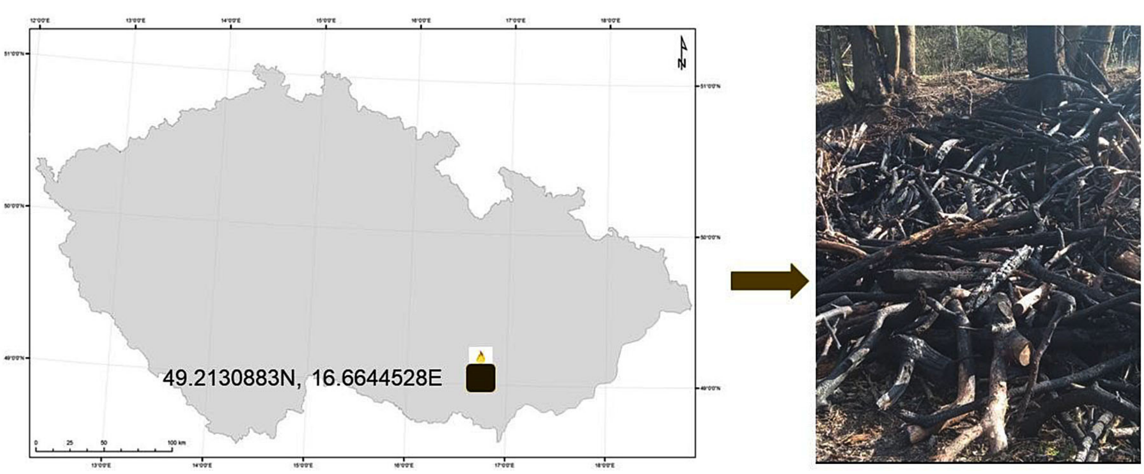

Figure 1. Study area after the fire

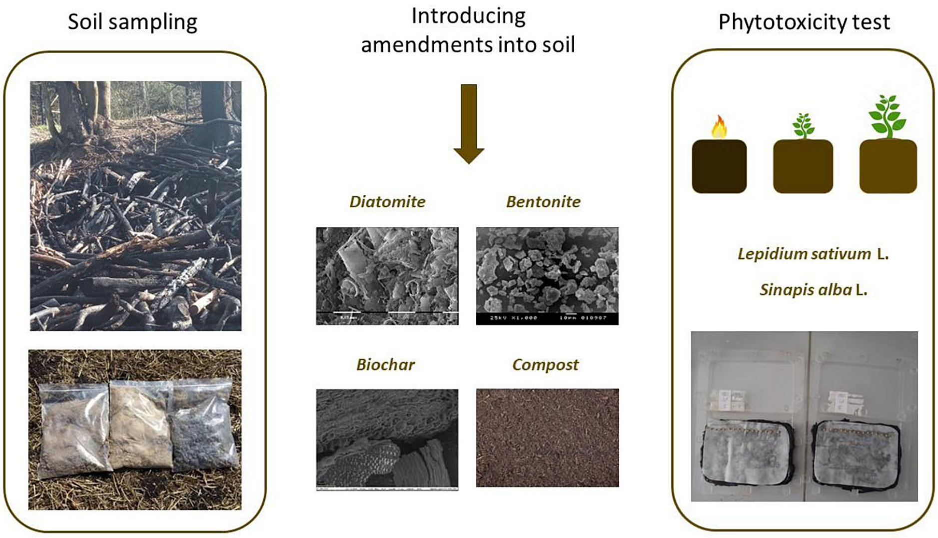

Figure 2. Test trial under the laboratory conditions

72 hours, coarse material (stones, imperfectly burnt pieces of wood) were removed manually and the soil was sieved through a 6-mm and subsequently a 2-mm mesh. A composite sample was prepared by mixing four subsamples and then it was stored for the physicochemical analysis and Phytotoxkit™ test (MicroBioTests Inc. 2004).

Investigated soil properties

The composite sample was characterised by the physicochemical properties, specifically pH and electrical conductivity, which both, in certain values or mutual combination, signal what characteristics the environment will acquire and how the plants will be able to take up the nutrients and prosper. The pH meter with a combined glass and calomel electrode was adjusted to the outdoor temperature. Then, the electrode was calibrated using two muffling buffers with known pH. Afterwards, 10 g of soil sieved through a 2-mm mesh was weighed to a 50 ml beaker and 25 ml distilled water was added. The content was stirred and let to extract for 20 hours. ISO/DIS 10390 (1992) allows an extraction time range of 2 hours to a maximum of 24 hours. The pH was measured and rounded to two decimal places. This procedure was done for the burnt, unburnt soil and all the soil samples supplemented with individual amendments (bentonite, biochar, compost, diatomite).

Electrical conductivity (EC) of soil was measured in an aqueous solution, which is prepared from 10 g of soil sieved through a 2-mm mesh mixed with 50 ml of distilled water (1:5 soil:water ratio) and allowed to extract for 20 hours. The aqueous solution was prepared for the burnt, unburnt soil and all the soil samples supplemented with individual amendments (diatomite, bentonite, biochar, compost).

Seed germination test

Phytotoxkit™ test is a widely available screening bioassay designed for fast assessment of contaminants in soil with the use of terrestrial plant growth (Van der Vliet, 2012). The principle of phytotoxicity test consists in measuring the decrease or the absence of seed germination and of the root growth of higher plants after incubation in darkness at 25°C and exposure to contaminated soil for at least 72 hours. In this research, each sample was supplemented with a different amendment. After this period, the samples were compared to the controls in a reference soil and inhibition or stimulation of the seed germination and the root growth was calculated (from the Standard Operational Procedure provided with the kit) (MicroBioTests Inc. 2004).

The test samples were taken for two plant species: garden cress (*Lepidium sativum* L.) and white mustard (*Sinapis alba* L.). The test soil was supplemented with following amendments in 3% w/w dilution: bentonite, compost, diatomite and biochar. The addition of 3% w/w of amendments was chosen based on the studies carried out by Radziemska et al. (2017) in the field of aided phytostabilisation.

Phytotoxicity test procedure

Phytotoxkit comprises a plastic test plate made of two compartments. The lower one was filled with test soil, saturated till the water holding capacity of the soil was reached and spread evenly with a spatula within the compartment. Then, a filter paper was laid on the water saturated soil and 10 seeds of a test plant of the same species were placed in one row on the top of the filter paper keeping same distances between each other and the plastic plate was closed carefully. This procedure is carried out in 3 replicates for all combinations of each plant species (*Lepidium sativum* L., *Sinapis alba* L.) with individual soil amendments (biochar, diatomite, compost, biochar). Additionally, 3 replicates for each test plant species were prepared using the control OECD soil (15% kaoline, 75% air-dried sand, 5% sphagnum peat). The OECD soil was purchased from the microbiotest (MicroBioTests Inc. 2004). The OECD artificial soil is a widely used substrate in the soil toxicity tests. It has been recommended as a medium for ecotoxicological tests and it is a reference soil in the testing of complex solid samples (Jaśko and Oleszczuk, 2013). All the plastic test plates were placed vertically in an incubator where they were held in dark at temperature 25°C for 72 hours.

After this period, the germinated seeds and length of roots were measured for all the seeds in all the test plates. The data were noted down to Phytotoxkit Result sheets and a percentage inhibition of seed germination (SG) and root growth inhibition (RI) for each plant and each soil amendment were calculated using the following formulas (1, 2). For assessing phytotoxicity of burnt soil and individual samples enriched with above mentioned amendments:

$$\mathrm{SG/RI} = (\mathrm{A} - \mathrm{B})/\mathrm{A} \times 100 \qquad (1)$$

where: A – stands for a mean seed germination or root length in the control OECD soil
B – stands for a mean seed germination or root length in the test soil (SOP)

For assessing effectiveness of individual amendment added to burnt soil:

$$\mathrm{SG/RI} = (\mathrm{A}_{\mathrm{burnt}} - \mathrm{B})/\mathrm{A}_{\mathrm{burnt}} \times 100 \qquad (2)$$

where: A_{burnt} – stands for a mean seed germination or root length in the burnt soil
B – stands for a mean seed germination or root length in the test soil (SOP)

RESULTS AND DISCUSSION

Soil pH value

The soil pH is a key determinant for a soil being able to form aggregates. Owing to aggregates by cations are available for plants uptake, in particular calcium ions, which interconnect organic colloids and soil particles (Bronick et al., 2005). The level of soil pH plays an irreplaceable role in the ability of plants to absorb the nutrients necessary for their growth. The optimum value of the soil pH for an easy uptake of nutrients is situated between 6.0 and 7.0 (Brady, 1990).

As such, the pH value is a useful tool in the choosing suitable plant species for different soils, as it can predict various chemical activities that will likely occur in a particular soil. The pH value can also be an indicator for a pH adjustment, which will ensure keeping the nutrient availability optimal for the given plant (Mylavarapu et al., 2020). Garden cress (*Lepidium sativum* L.*)* prefers a relatively narrow pH range between 6.0 (mildly acidic) and 7.0 (neutral) while white mustard (*Sinapis alba* L.) can prosper in a wider pH range (Table 1).

Soil electrical conductivity

The correlation of the EC of soils with their properties affecting the crop productivity is a widely known premise. The measurement of EC gives us a picture about a number of soil properties such as its texture, drainage conditions, cation exchange capacity and others. The EC of soils is a basic measure determining the salinity of soils and thus their ability to transmit electricity in an aqueous solution. The excess salts in soils have a major harmful physical and chemical impact on the plant nutrient availability (Mylavarapu et al., 2020).

EC determines the ability of the environment to conduct the electrical current. The EC of a solution increases proportionally with the presence of ions (salt). In the absence of salts, the EC value is low, and the solution does not conduct electricity well. The EC value indicates the presence or

Table 1. Preferred pH range of selected plant species

Plant species	Low pH	High pH
Sinapis alba L.	4.5	8.2
Lepidium sativum L.	6	7

Table 2. Electrical conductivity and soil type

Soil type	Specific conductivity (mS.cm^{-1})	Plants reaction
Unsalted	to 0,7	Normal status
Medium saline	0,7 – 1,4	More sensitive plants (potatoes, cabbage, peas) react
Salted	1,4 – 2,8	Cereals and beets also react unfavourably
Heavily saline	over 2,8	Nor halophytes not last

absence of salt; however, it does not provide the information about the source of the salts, meaning that if a value of EC of a particular sample is high, it cannot be deduced whether this condition has been caused by any external factors e.g. saltwater irrigation or recent soil fertilisation (Mylavarapu et al., 2020). Additional chemical analyses are required to determine the salt source.

Physicochemical properties of soil

The values of the measured physicochemical properties, pH and EC, are presented in Table 3. The pH values show that the wildfire caused a slight increase of pH in the burnt soil compared to the pH of the unburnt soil, which matches with Certini´s (2005) findings about pH being increased during wildfire due to soil heating and denaturation of organic acids. It needs to be emphasised that significant increases occur only at temperatures higher than 450°C (Certini, 2005). The slight difference between the pH of the burnt and unburnt soil might have been caused by the fact that the soil samples were not collected immediately after the wildfire. The soil properties tend to return to the state before the fire with time. The addition of bentonite, biochar and compost resulted in increasing pH on which *Lepidium sativum* L. and *Sinapis alba* L. reacted differently, as will be described later in this section.

The EC measured in an aqueous solution of burnt soil was the highest and the addition of diatomite, bentonite and biochar, respectively, was beneficial for decreasing its values. Only the soil amended with compost manifested an increase in electrical conductivity of the sample. EC of the sample made of unburnt soil is the lowest.

The mean values of six replicates indicated

Results of the phytotoxicity test

The test of phytotoxicity integrates the relationship between the plant and the substrate. The seed germination capacity, which is compared with the reference OECD soil, is essential in the phytotoxicity test. On the basis of the germination capacity, one can decide whether the tested compost inhibits or stimulates seed germination (Voběrková et al., 2020). Figure 3 shows the effect of burnt soil phytotoxicity using various amendments on the growth inhibition/stimulation of the *Lepidium sativum* L. sample, as compared to the OECD soil sample. Compost appears to be the most successful amendment, because the percentage of the RI is the lowest, 37.77 %.

Figure 4 shows the effect of burnt soil phytotoxicity using various amendments on the root growth inhibition/stimulation of the *Lepidium sativum* L. sample, as compared to burnt soil sample. The soil supplemented with 3% w/w of compost shows very positive influence on the root growth stimulation. Compost proved to be a stimulating element also in a laboratory experiment carried out by Paradelo et al. (2012) where the mulch made of a mixture of municipal waste compost, composted pine bark and other components was used to allow seeds to germinate in the burnt soil. The addition of compost in order to restore soil microbial activity and consequently re-establish physical soil properties in burnt soil was researched in a field experiment by Guerrero et al. (2000) where the addition of compost was found favourable as well.

Figure 5 shows the effect of burnt soil phytotoxicity on the root growth inhibition/

Table 3. Physicochemical properties, pH and electrical conductivity

Parameter	Value					
	3 % w/w bentonite	3 % w/w diatomite	3 % w/w biochar	3 % w/w compost	Burnt soil	Unburnt soil
pH [-]	8.05	7.66	7.87	7.81	7.67	7.64
Electrical conductivity [mS.m^{-1}]	0.410	0.401	0.436	0.460	0.449	0.366

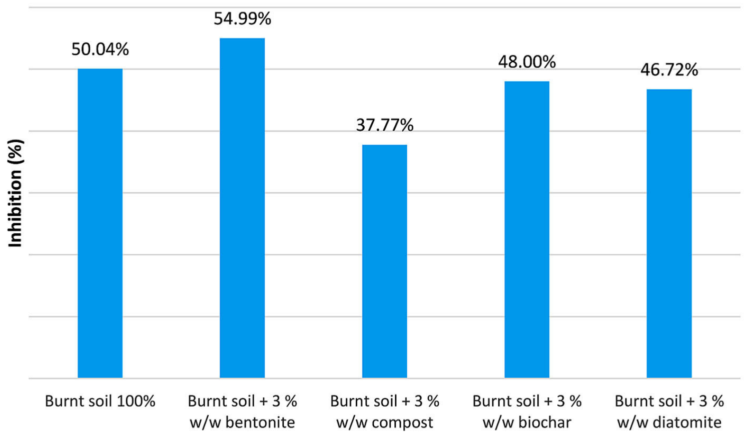

Figure 3. Root growth inhibition/stimulation of the *Lepidium sativum* L. compared to OECD

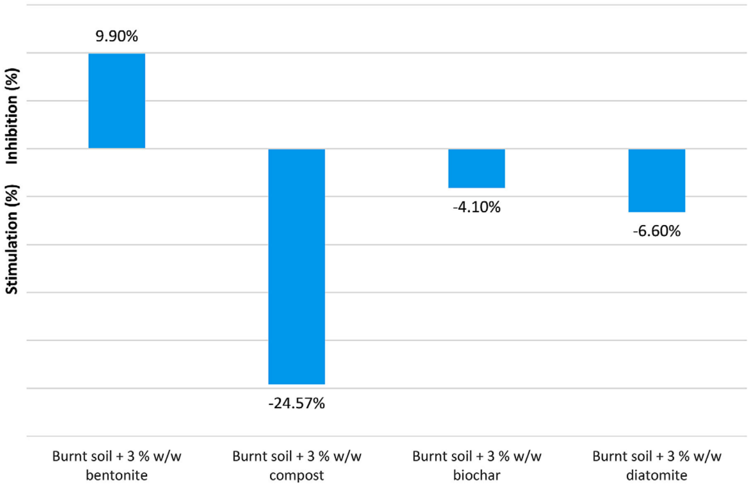

Figure 4. Root growth inhibition/stimulation of the *Lepidium sativum* L. compared to burnt soil

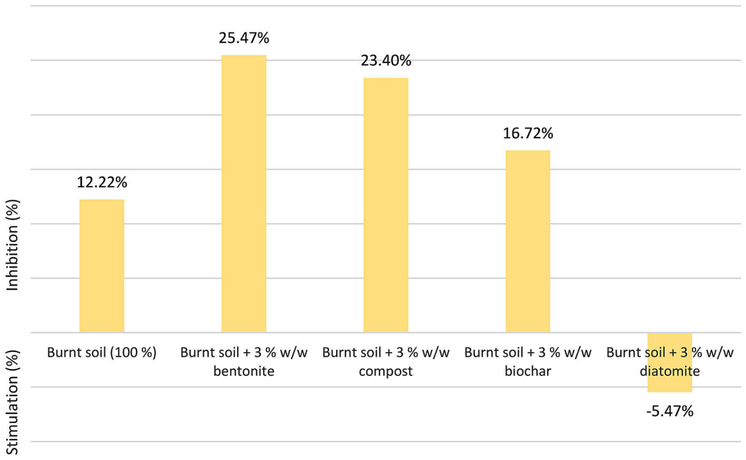

Figure 5. Root growth inhibition/stimulation of the *Sinapis alba* L. compared to OECD

stimulation of *Sinapis alba* L. sample, as compared to the OECD soil sample when using the earlier mentioned amendments. The burnt soil enriched with 3% w/w diatomite created better conditions for growth than the OECD soil and the root growth was stimulated 5.47%. Conversely, biochar, compost and bentonite displayed an opposite effect and inhibited the root growth even more than the non-enriched burnt soil. The lack of effect of compost on root growth can be explained by the application of this organic amendment in a low dose, although observing normal recommendations, and carrying out the assay over a short period of time (Turrión et al., 2010). Generally, the soil respiration in the soils treated by compost is increased (Pedra et al., 2007; Tejada et al., 2009).

Figure 6 shows the effect of burnt soil toxicity using various amendments on the root growth inhibition/stimulation of the *Sinapis alba* L. sample compared to the burnt soil sample. Diatomite is the only stimulating element. The addition of diatomite lowered the soil EC most when compared to the rest of the amendments. This might have a positive effect on the root growth of *Sinapis alba* L.

This trend was also observed in the research conducted by Radziemska et al. (2018) where the application of 10% diatomite showed the highest ability to decrease the value of EC. The susceptibility of the tested plant species, *Lepidium sativum* L. and *Sinapis alba* L. corresponds with the findings of the same research where *Lepidium sativum* L. was found to be more sensitive to soil contamination than *Sinapis alba* L..

Despite the fact that biochar does not stimulate the root growth of *Sinapis alba* L. and even demonstrates worse results than the unamended burnt soil, it should be taken into account that, as opposed to raw materials (e.g. compost) which are an immediate source of nutrients for plants and soil microorganisms, biochar plays a role of a catalyst that improves and speeds up the uptake of nutrients and water by plants (Lehman et al., 2006) and can be more beneficial from a long-term perspective.

Assumptions and conditions for further research

Assessing the impact of fires on the properties and quality of affected soils is a complex issue where, in addition to the applied methods and procedures, a detailed chemical analysis of the ashes produced by a mix of a certain soil type and plant community remains crucial. Therefore, the basic research focused on the properties of the ashes produced during a wildfire is an area that undoubtedly deserves more attention than is currently being given by the professional public.

CONCLUSION

The phytotoxicity test, measurement of the seed germination and root growth inhibition was performed for following plant species: *Lepidium sativum* L. and *Sinapis alba* L. under different growing conditions, namely control soil, burnt soil and burnt soil supplemented with four different amendments. These preliminary tests provided relevant information. The plant response to the experimental tests shows their varying degree of phytotoxic sensitivity depending on the level of soil contamination and amendment used. The ability of seeds to germinate and roots to grow under different testing conditions showed significant differences as far as their inhibition/stimulation was concerned.

The carried out tests were preliminary and their results indicate that a number of other aspects, such as detailed chemical analysis of ashes, survey of composition and proportions of elements in the burnt soil and amended burnt soil, and many others, will need to be taken into

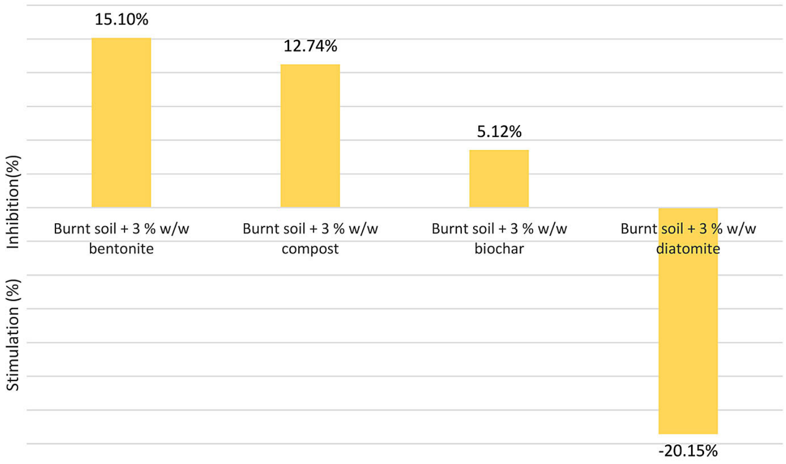

Figure 6. Root growth inhibition/stimulation of the *Sinapis alba* L. compared to burnt soil

account in order to evaluate the subject matter objectively, which inevitably leads to continuing the research to complement and expand the range of analytical methods and tools.

It is recommended to repeat testing for amendments that stimulated seed germination and root growth at an early stage, namely, diatomite, compost and biochar and to investigate the reaction of seeds to increasing the amount of stimulating amendments. It is also important to carry out testing for a wider group of plant species.

The practical effect of repeating tests with the already tested plant species and increasing their number is to achieve a reasonably large statistical sample for the application of mathematical methods of its evaluation, and thus also to increase the accuracy and informative ability of the test results.

Acknowledgement

This work was supported by the Internal Agency Faculty of AgriSciences (MENDELU No. AF-IGA2020-IP007)

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