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The Biochar Impact on Miscanthus and Sunflower Growth in Marginal Lands

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Abstract. The results of the experiment with biochar as a soil amendment are presented. Two energy crops (*Miscanthus* × *giganteus* and *Helianthus annuus*) were grown in the vegetation containers with two types of marginal lands. Low humus black soil Low humus black was taken in flood plain of Kilchen river. Red-brown clay was taken from the quarry board 15 yeas ago to create reclaimed mine land in site near "Blagodatna" coal mining tailing. It was defined that the biochar addition intensifies growth processes from 7–30% (*Helianthus*) to 20–88 % (*Miscanthus*). For Miscanthus, the effect was more pronounced on black soil, and for Helianthus on red-brown clay. Due to the biochar application, the plant capacity to take up heavy metals by above-ground organs decreased. As a result, the heavy metal content in leaves and stems has reduced by an average of 10–25%. However, because of the gain in biomass productivity, the uptake level of some heavy metals has increased. Especially, this was characteristic of the *Miscanthus* leaf biomass. So, the uptake of heavy metals by leaves increased from 28.1% (Pb) to 62.9% (Fe) on the black soil, and from 20.3% (Cu) to 46.6% (Zn) on the red-brown clay. The addition of biochar had a slight effect on thermolysis passing of *Miscanthus* and *Helianthus* biomass. So, in *Miscanthus*, duration of the process has grown shorter. The rate of thermal degradation in the leaf biomass was greater, which is especially noticeable in the region of hemicelluloses destruction. In the stem biomass a pronounced increase in the thermolysis rate was noted in the region of volatile components evaporation (on the black soil) and during the cellulose decomposition. Besides, under the impact of biochar, biomass combustion was more complete (by 5.1% on the red-brown clay and by 30% on the black soil). In leaf biomass of *Helianthus*, the onset of thermolysis has shifted toward higher temperatures. In addition, the magnitude of the thermal effect was greater at almost all stages of decomposition. In stem biomass, thermal effects also increased, but only slightly. Under the influence of biochar, the first stage of decomposition was faster. In biomass taken from red-brown clay, the rate of hemicellulose degradation also increased. In biomass taken from black soil, biochar application contributed to more intensive decomposition of lignin. After combustion, the share of residual mass in stem of plants grown on black soil with the biochar addition increased by 30%. The opposite effect was observed on red-brown clay: the share of residual mass decreased by 49%. Besides, the thermal stability of stem biomass grown on the substrates using biochar lessened by 8–16%.

Keywords: *Miscanthus*; *Helianthus*; post-mining soils; biochar; heavy metals; biomass thermal features.

Introduction

Soil degradation processes, as a result of anthropogenic activity, exceeding the natural soil formation rates, are urgent problems of our time. Among the major soil degradation processes are accelerated erosion, depletion of the soil organic carbon pool, loss of soil fertility and elemental imbalance, acidification and salinization (Jie, Jing-zhang, Man-zhi, & Zi-tong, 2002; Lal, 2015). In industrially developed regions, degradation occurs especially quickly, since during the cycles of mining and production a large amount of land is formed, unsuitable for farming. The disadvantage of such soils is not only loss of fertility, but also pollution by heavy metals and other industrial wastes. A direct implication of the imbalance between agricultural soil loss and erosion is that, given time, continued soil loss will become a critical problem for global agricultural production (Pimentel, 2006; Montgomery, 2007; Gomiero, 2016).

Soil degradation trends can be reversed by conversion to a restorative land use and adoption of recommended management practices. Improving soil quality can reduce risks of physical, chemical, biological and ecological soil degradation. Techniques of restoring soil quality include conservation agriculture, integrated nutrient management, and continuous vegetative cover such as residue mulch and cover cropping, and controlled grazing at appropriate stocking rates. The strategy is to produce "more from less" by reducing losses and increasing soil, water, and nutrient use efficiency (Labreuche, Lellahi, Malaval, & Germon, 2011; Lal, 2015). Sustainable intensification, producing more from less by reducing losses and increasing the use efficiency, is attainable through improvement of soil quality including chemical quality or soil fertility. Use of organic amendments, by recycling organic by-products is a useful strategy to enhance soil fertility and improve structural stability or aggregates (Abbott & Murphy, 2007; Laird, 2007; Lal, 2015). Use of biochar and biochar-compost mixtures from different alternative organic sources can be proposed as an option for improving soil fertility, restoring degraded land, and mitigating the emissions of greenhouse gasses associated with agriculture. Biochar application could be a feasible alternative to remediate the degraded soils and improve their productivity potential in the long-term (Verheijen, Jeffery, Bastos, van der Velde, & Diafas 2009; Scislowska, Wlodarczyk, Kobylecki, & Bis, 2015; Agegnehu, Srivastava, & Bird, 2017).

In the conventional sense, the term biochar means biomass that has undergone pyrolysis in an oxygen-free environment. Owing to its immanent properties, the biochar is regarded as soil amendment for sustained carbon sequestration and concurrent improvement of soil functions. In the presence of biochar in the soil mixture, its contribution to the physical nature of the system may be significant, influencing depth, texture, structure, porosity and consistency through changing the bulk surface area, pore-size distribution, particle-size distribution, density and packing. Biochar's effect on soil physical properties may then have a direct impact upon plant growth because the penetration depth and availability of air and water within the root zone is determined largely by the physical make-up of soil horizons (Downie, Crosky, & Munroe, 2012; Hardie, Clothier, Bound, Oliver, & Close, 2014; Chia, Downie, & Munroe, 2015). Each biochar made with a particular feedstock and process combination presents a unique mixture of phases and microenvironments that gives rise to a unique set of chemical properties. The molecular structure of biochars shows a high degree of chemical and microbial stability. A feature of most biochars is their highly porous structure and large surface area, which can provide a shelter for beneficial soil microorganisms and affects the binding of important nutritional cations and anions. This binding can increase the availability of macronutrients such as N and P. Moreover, the biochar application can lead to alkalinization of soil pH, increased conductivity and capacity of cation exchange (Chan, Zwieten, Meszaros, Downie, & Joseph, 2007; Atkinson, Fitzerald, & Hipps, 2010; Kameyama, Miyamoto, Shiono, & Shinogi, 2012). The application of biochar to marginal soils can contribute to a good physical, chemical and biological environment of the soil, and these positive changes influence growth and yield (Ippolito et al., 2011; Pandian, Subramaniayan, Gnasekaran, & Chitraputhirapillai, 2016). Application of biochar for remediation of contaminated soils can provide a new solution to the soil pollution problem. Due to a large surface area, biochar has a high ability to adsorb heavy metals and organic pollutants. It can potentially be used to reduce the bioavailability and leachability of heavy metals and organic pollutants in soils through adsorption and other physicochemical reactions. Biochar is typically an alkaline material which can increase soil pH and contribute to stabilization of heavy metals (Zhang et al., 2013; Paz-Ferreiro, Lu, Fu, Mendez, & Gasco, 2014).

Despite the great interest in the use of biochar in agriculture and for remediation, its current use is still limited. In terms of market development, if biochar can be used as a soil amendment to improve soil quality and to increase crop production, this will increase its appeal. In this regard, an obvious positive attribute of biochar is its value, supplied indirectly by improving soil quality, with consequent improvement in the efficiency of fertilizer use (Castaldi et al., 2011; Chan & Xu, 2009). A lack of long-term, well-designed field studies on the efficacy of biochar and biochar- mixtures on different soil types and agro-climatic zones are limiting current understanding of biochar's potential to enhance crop production and mitigate climate change.

Main goal of this study was to estimate biochar impact on plant growth parameters and heavy metals uptake in pot experiments with meadow black soil and hytomeliorated red-brown clay.

Material and methods

Pot trial was carried out. Two energy crops (*Miscanthus × giganteus* and *Helianthus annuus*) were grown in the vegetation containers with two types of post-mining soils: low humus black soil (BS) and red-brown clay (RBC). Meadow black soil was taken in top of salinated stratum (0–20 cm) in flood plain of Kilchen river (Samara river tributary). Red brown clay was taken from quarry board 15 yeas ago to create reclaimed mine land in site near Blagodatnaya coal mining tailing in Pavlogradsky district (Western Donbass coal ming region). 40 cm stratum of brown clay was replaced over salinated and polluted with heavy metals stratum consisting of 4 m mass of mining rocks mix (Kharytonov & Kroik, 2011; Klimkina, Kharytonov, & Zhukov, 2018). Biochar was applied to test its effect on plant growth, the ability of plants to accumulate of heavy metals and the thermal characteristics of biomass. Treatments included control and nutshell biochar (3% by weight).

Germinating ability (for Helianthus) and growth parameters were studied by biometric methods. The content of heavy metals in above-ground biomass was determined. For analysis, biomass samples weighing 2 g each were combusted in a muffle furnace at 450 °C by means of drying method and then dissolved in 5 ml of 6N spectral purity hydrochloric acid. The content of mineral elements in obtained mineralizes was measured by atomic absorption spectrophotometric analysis at Varian Cary-50. The received data represented the arithmetic means of three replicates of each sample, their ranges and standard deviations values. The thermal characteristics of biomass were studied by thermogravimetric analysis. The analysis was performed using the derivatograph Q-1500D of the "F. Paulik-J. Paulik-L. Erdey" system. Differential mass loss and heating effects were recorded. The results of the measurements were processed with the software package supplied with the device. Samples of biomass were analyzed dynamically at a heating rate of 10 °C/min in an air atmosphere. The mass of samples was 100 mg. The reference substance was aluminum oxide.

Results

It was revealed that growth parameters of both Miscanthus and Helianthus were 35–44% higher on the black soil compared with the red-brown clay. The biochar addition to substrates favoured the seed germination of Helianthus. Germinating ability on the black soil increased by 15.6%, on the red-brown clay by 20.0%. As for the growth characteristics, the greatest effect was observed for the leaf biomass parameter. It was increased by 21–31% (Helianthus) and 60–89% (Miscanthus), respectively (Fig. 1). The stem biomass increment was also greater in Miscanthus than that of Helianthus, and amounted to 20–25%.

The plant ability to accumulate of heavy metals depend on both genetic features and chemical and physical properties of the soil. In our study, Helianthus cumulated most of the heavy metals more actively than Miscanthus (Fig. 2). On the black soil, the Fe content was higher by 72–98%, Cu by 102–105%, and Pb by 67–87%. Zn content was higher only in the stems, but not in the leaves. On red-brown clay, the content of heavy metals in the leaves was higher by 40–132%, and in the stems by 40–158%. Unlike other metals, the Mn content in the biomass of Miscanthus was higher than that of Helianthus by an average of 37–47%.

It was revealed that in Miscanthus, more heavy metals are accumulated in the leaves than in the stems. This difference is 13–50%

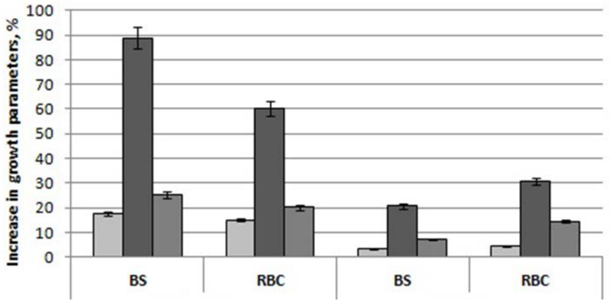

Fig. 1. Biochar effect on the growth parameters

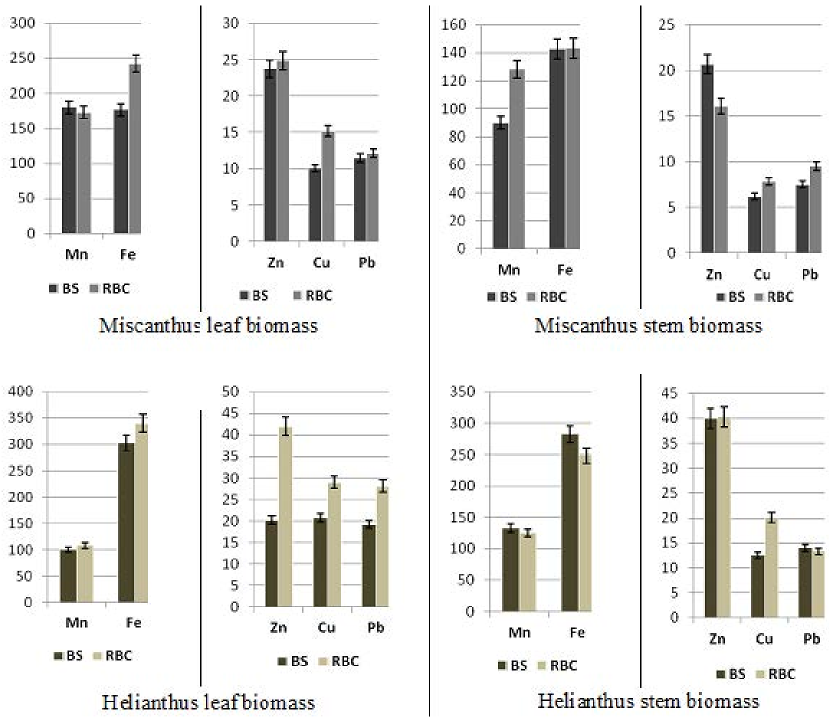

Fig. 2. Heavy metal content in energy crops biomass, mg/g

on black soil, and 21.5–49% on red-brown clay. In Helianthus, the content of Fe, Cu and Pb in leaves was higher than in the stems by 27–40%. Mn was accumulated more in stems (by 15–32%). The content of Zn was almost identical in the leaves and stems of plants grown on red-brown clay, and significantly higher (by 98%) in the stems of plants grown on the black soil

The use of biochar affected the ability of plants to accumulate heavy metals (Fig. 3). Its addition to black soil led to a decrease in the cumulative intensity of Miscanthus by 14–32%. In Helianthus, the effect was less noticeable. The content of heavy metals has reduced by only 3–14%. On red-brown clay in Miscanthus, the heavy metal accumulation decreased from 10% (Zn) to 25% (Cu). In leaves of Helianthus, the greatest influence of biochar was noticed for Pb (28.5%), in stems for Mn (18.4%) and Cu (19.6%).

Thus, the biochar has a double effect on energy crops: it increases biomass growth and reduces the ability to accumulate

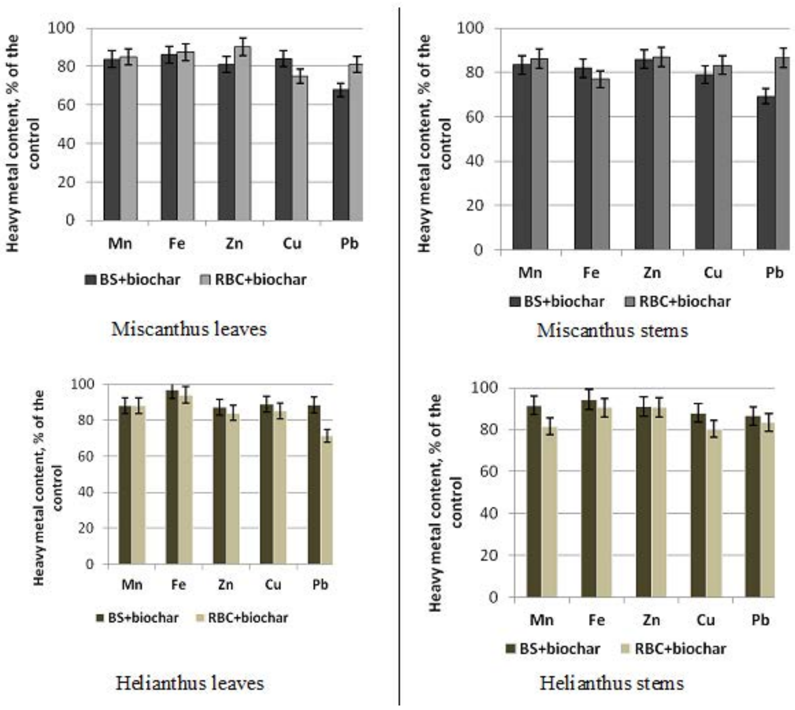

Fig. 3. The effect of biochar on the heavy metal accumulation

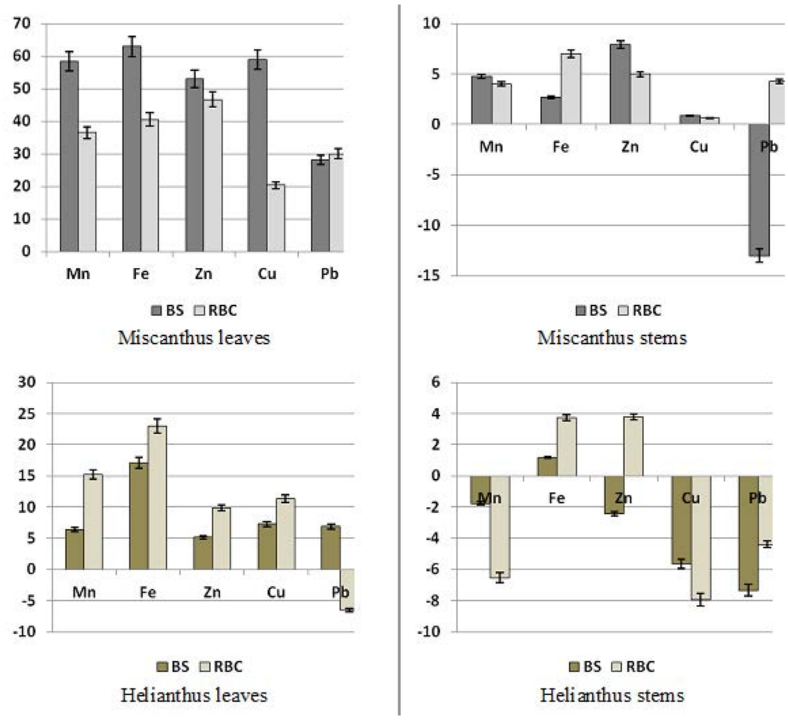

Fig. 4. The effect of biochar on the dynamics of the heavy metals uptake, % relative to control

heavy metals. Depending on the action strength, the level of heavy metals uptake changes in the direction of increase or decrease (Fig. 4). It was revealed that the uptake of heavy metals by leaf biomass of Miscanthus increased from 28.1% (Pb) to 62.9% (Fe) on the black soil, and from 20.3% (Cu) to 46.6% (Zn) on the red-brown clay. In stems, the changes were insignificant, within range 0.6–7.9%. Only on the black soil the uptake of Pb decreased by 13.0%. The Fe uptake by leaf biomass of Helianthus increased by 17.1% (black soil) and 23.0% (red-brown clay). The uptake of other metals rose to 5.1–15.2%. However, on red-brown clay, it was observed that the absorption of Pb reduced by 6.5%. The uptake level of Fe and Zn by stem biomass almost did not change the absorption of Cu, Pb and Mn decreased by 5.6–8.0%.

Thermogravimetric analysis was carried out to assess the effect of biochar on the thermal characteristics of energy crops biomass. According to the results obtained, the process of thermal decomposition of Miscanthus biomass took place in four stages. The first stage was characterized by endothermic processes caused by the water and volatile components evaporation. In the leaf biomass, this phase began earlier than in stems, and lasted longer (Table 1). Besides, rate and mass loss were higher. In plants grown on the red-brown clay, temperature range was shorter (55(70)–150 ºC) than in plants grown on the black soil. However, the process was more active in leaves taken from black soil and in stems taken from red-brown clay.

The phase of exothermic hemicelluloses decomposition proceeded in the temperature range 150–270 ºC. The degradation rate was higher in plant biomass grown on the red-brown clay. One peak was observed in this region. The weight loss varied in leaves from 17.4% (BS) to 17.6% (RBC), in stems from 20.2% (BS) to 26.5% (RBC).

Table 1. Thermal decomposition of Miscanthus biomass for plant grown on different substrates

Stage	Black soil (BS)				Red-brown clay (RBC)			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Leaves								
I	40–170	100	10.8	10.5	55–150	90	9.0	6.8
II	170–270	260	21.0	17.38	150–260	250	22.8	17.6
III	270–390	300	28.2	37.16	260–360	290	28.6	34.4
IV	390–600	470	9.0	29.9	360–570	420	11.0	30.8
Stage	Black soil				Red-brown clay			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Stems								
I	65–160	100	8.8	6.2	70–150	100	9.8	6.46
II	160–270	260	23.0	20.2	150–280	260	25.6	26.47
III	270–380	300	28.8	33.8	280–380	290	28.4	30.5
IV	380–630	470	10.0	32.0	380–610	460	9.52	31.51

Table 2. Thermal decomposition of Miscanthus biomass for plant grown on different substrates with the biochar addition

Stage	Black soil (BS)				Red-brown clay (RBC)			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Range, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Leaves								
I	60–160	90	10.6	8.08	55–150	90	10.0	7.07
II	160–270	250	23.2	20.12	150–270	260	24.0	19.19
III	270–380	300	27.4	34.42	270–380	290	28.6	33.76
IV	380–590	430	10.0	30.70	380–580	420	11.0	32.09
Stage	Black soil				Red-brown clay			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Range, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Stems								
I	60–150	90	12.0	8.89	70–160	90	9.4	6.8
II	150–270	260	22.6	22.22	160–280	260	25.2	25.0
III	270–380	300	31.6	32.92	280–390	300	30.4	33.8
IV	380–590	460	9.32	30.51	390–600	440	10.0	29.6

The third stage of termolysis (260–390 ºC) was associated with cellulose and lignin destruction. One peak of cellulose decomposition (28.2–28.8%/min) occurred at the temperature 290–300 ºC. The lignin degradation passed without pronounced peaks.

During the fourth stage lignin thermal destruction was completed and carbonate residue burning took place. On the black soil, more complete combustion was observed in leaf biomass, where the share of residual mass was 5.06% versus 10.4% on the red-brown clay. Conversely, the stem biomass taken from clay burned better than that taken from black soil.

The addition of biochar had a slight effect on thermolysis passing (Table 2). So, duration of the process has grown shorter. The rate of thermal degradation in the leaf biomass was greater, which is especially noticeable in the region of hemicelluloses destruction (Fig. 5). However, if the share of residual mass in biomass from red-brown clay was reduced by 24.1%, then in the biomass from black soil more complete combustion was not observed.

In the stem biomass a pronounced increase in the thermolysis rate was noted in the region of volatile components evaporation (on the black soil) and during the cellulose decomposition (Fig. 6). Besides,

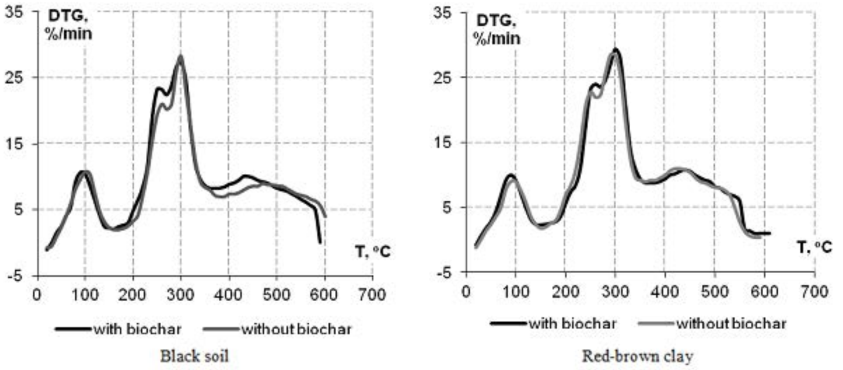

Fig. 5. DTG curves of Miscanthus thermolysis in the leaf biomass

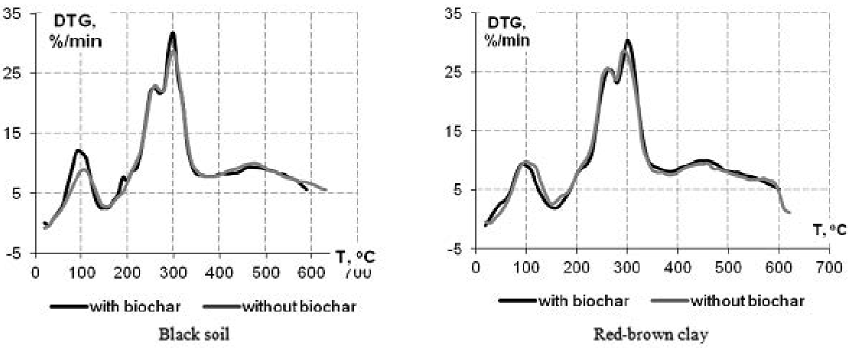

Fig. 6. DTG curves of Miscanthus thermolysis in the stem biomass

under the impact of biochar, biomass combustion was more complete (by 5.1% on the red-brown clay and by 30% on the black soil).

According to the activation energy data (Table 3), the addition of biochar led to a decrease in the thermal stability of the biomass at the initial stage of destruction (by 14.4–22.6%) and an increase at the stage of main components decomposition (by 4.5–6.3%).

Thermogravimetric analysis of Helianthus biomass showed that thermal decomposition of the leaves occurred in three stages: water and volatile components evaporation, hemicelluloses and cellulose destruction, and lignin degradation. In the biomass grown on black soil, thermolysis began at higher temperatures than on red-brown clay (Table 4). Subsequently, degradation proceeded similarly in samples taken from both substrates. However, the rate of mass loss in the biomass from black soil was slightly higher (by 4.5–15.5%), and the share of residual mass was more by 11%.

In the stems, thermolysis passed in four stages. Water and volatile components removal proceeded in the temperature interval 60–160 ºC. The endothermic processes took place in this phase. The hemicellulose destruction in stems taken from both substrates occurred in the same temperature range. However, the rate of the process in biomass grown on red-brown clay was much lower, and consequently the weight loss was insignificant (Table 4). Essential distinctions in the destruction of cellulose and lignin between samples taken from both substrates were not observed. The greatest exothermic effect was revealed at a temperature of 450–460 ºC. More complete biomass combustion was observed on the black soil, where the share of residual mass was 7.89%, in contrast to 16.2% on the red-brown clay.

The addition of biochar influenced the thermal properties of the leaf and stem biomass of Helianthus (Table 5). In leaf biomass, the onset of thermolysis has shifted toward higher temperatures. In addition, the magnitude of the thermal effect was greater at almost all stages of decomposition. (Fig. 7). In stem biomass, thermal effects also increased, but only slightly. Under the influence of biochar, the first stage of decomposition was faster. In biomass taken from red-brown clay, the rate of hemicellulose degradation also increased (Fig. 8). At the stage cellulose destruction, no significant changes were noted. In biomass taken from black soil, biochar application contributed to more intensive decomposition of lignin. After combustion, the share of residual mass in stem of plants grown on black soil with the biochar addition increased by 30%. The opposite effect was observed on red-brown clay: the share of residual mass decreased by 49%. Besides, the thermal stability of stem biomass grown on the substrates using biochar lessened by 8–16% (Table 6).

Discussion

Results of some researchers showed benefit of biochar application to soils on crop productivity in average 10%. The greatest positive effects with regard to soil analyses were seen in acidic (14%) and neutral pH soils (13%), and in soils with a coarse (10%) or medium texture (13%) (Jeffery, Verheijen, van ger Velde, & Bastos 2011; Bird, Wurster, de Paule Silva, Paul, & de Nys, 2012; Biederman & Harpole, 2013). The results obtained in our experiment are slightly higher (by 10–15%) than the published data. However, the difference in the results of field and vegetation experiments almost always takes place. In addition, it is necessary to take into account the genetic characteristics of plants.

It is known that biochars have the ability to immobilize heavy metals, thereby reducing their mobility and bioavailability in con-

Table 3. Activation energy of Miscanthus biomass thermal decomposition

Experiment variant	Leaf		Stem	
	Activation energy, kJ/mol			
	Initial	Main components	Initial	Main components
Black soil without biochar	89.88	40.16	78.23	43.48
Black soil with bio-char	76.93	41.97	62.80	39.51
Red-brown clay without biochar	78.16	42.32	55.69	42.03
Red-brown clay with biochar	60.50	44.23	53.88	44.68

Table 4. Thermal decomposition of Helianthus biomass for plant grown on different substrates

Stage	Black soil (BS)				Red-brown clay (RBC)			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Leaves								
I	60–180	110	7.88	8.89	30–170	110	7.6	8.45
II	180–370	290	15.8	41.61	170–370	280	14.2	44.80
III	370–630	440	3.8	29.49	370–630	440	3.4	28.95
Stage	Black soil				Red-brown clay			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
Stems								
I	60–160	110	8.6	7.47	80–160	120	6.4	5.8
II	160–240	220	23.2	16.37	160–230	200	9.0	9.2
III	240–380	290	16.2	36.15	230–370	300	16.6	37.6
IV	380–590	410	2.0	32.12	370–610	420	3.6	31.2

Table 5. Thermal decomposition of Helianthus biomass for plant grown on different substrates with the biochar addition

Stage	Black soil (BS)				Red-brown clay (RBC)			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
				Leaves				
I	80–170	110	7.4	7.14	70–170	110	7.4	7.4
II	170–370	290	15.0	40.11	170–360	280	13.6	41.8
III	370–600	420	3.8	28.64	360–610	430	3.2	29.0
Stage	Black soil				Red-brown clay			
	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %	Interval, ºC	Extremum point, ºC	Maximum rate, %/min	Weight loss, %
				Stems				
I	70–150	100	9.8	8.28	70–160	110	7.2	6.73
II	150–230	200	16.8	16.16	160–240	210	18.0	16.61
III	230–380	290	16.8	35.76	240–370	290	16.6	36.23
IV	380–630	440	4.8	29.49	370–600	410	3.2	32.23

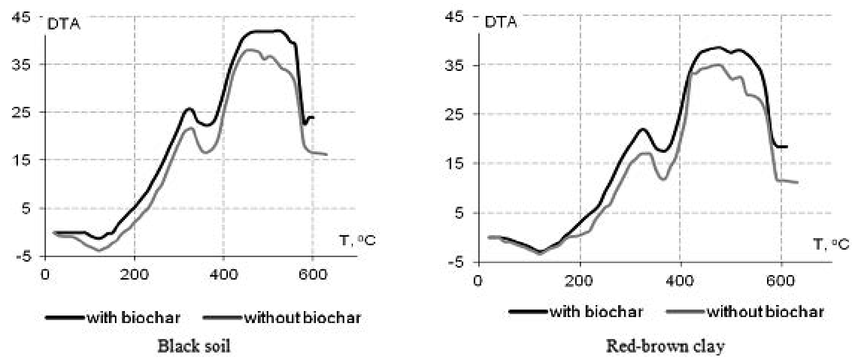

Fig. 7. Thermal effects of Helianthus leaf biomass thermal degradation

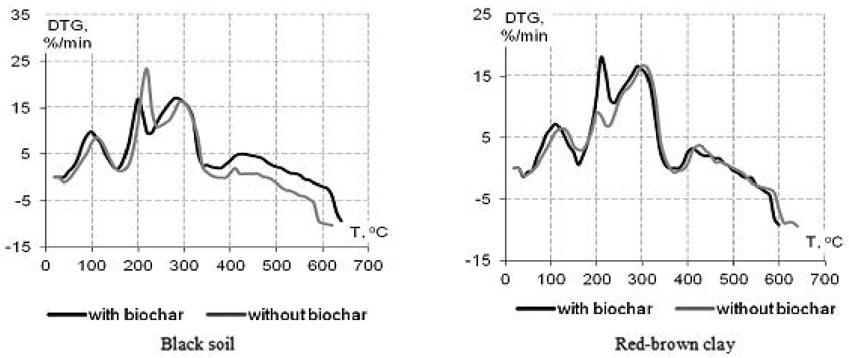

Fig. 8. DTG curves of Helianthus thermolysis in the stem biomass

Table 6. Activation energy of Helianthus stem biomass thermal decomposition

Experiment variant	Stem	
	Activation energy, kJ/mol	
	Initial	Main components
Black soil without biochar	58.72	31.85
Black soil with biochar	52.23	26.73
Red-brown clay without biochar	78.95	33.22
Red-brown clay with biochar	72.40	32.51

taminated soils (Park, Choppala, Bolan, Chung, & Chuasavathi, 2011; Al-Wabel et al., 2015; Lu et al., 2017). In our experiment, this effect was observed as well. The heavy metal content in leaves and stems has reduced by an average of 10–25%.

The results obtained on the influence of soil characteristics on the features of the thermal behavior of plant biomass are quite consistent with data published by other researchers (Zabaniotou, Kantarelis, & Theodoropoulos, 2008; Kok & Özgür, 2013; Cortes & Bridgwater, 2015; Osman, Adbelkader, Johnston, Morgan, & Rooney, 2017; Oginni & Singh, 2019).The main differences are mainly in the duration of the process of thermal degradation, the rate of some stages passing and in the amount of non-combustible residue. There is an obvious lack of data on the thermal characteristics of plant biomass grown on substrates with the addition of biochar.

Conclusions

The growth parameters of both Miscanthus and Helianthus are 35–44% higher on the black soil compared with the red-brown clay. The plant ability to accumulate of heavy metals depend on both genetic features and chemical and physical properties of the soil. Helianthus cumulates the heavy metals more actively than Miscanthus. The application of biochar has a double effect on energy crops: an increase in biomass growth and a reduction in the ability to accumulate heavy metals. In general, a larger yield increment is observed for leaf biomass. The biochar addition led to a decrease in the accumulation of heavy metals in Miscanthus from 19.6% to 30.7% and in Helianthus from 5.6% to 28.5%.

Biochar indirectly affects the thermal characteristics of Miscanthus and Helianthus biomass. Different soils have their own distinct physical and chemical properties depending on the nature of mineral and organic components, their relative amounts and the ways in which minerals and organic matter interact. By-turn, soil characteristics affect the thermal behavior of plant biomass. Adding biochar can change these properties and, thus, have an impact upon plant growth, development and biomass quality. However, in our experiment, the biochar influence on the thermal features of Miscanthus and Helianthus biomass was insignificant.

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