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Article

No Effect Level of Co-Composted Biochar on Plant Growth and Soil Properties in a Greenhouse Experiment

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Abstract: It is claimed that the addition of biochar to soil improves C sequestration, soil fertility and plant growth, especially when combined with organic fertilizers such as compost. However, little is known about agricultural effects of small amounts of composted biochar. This greenhouse study was carried out to examine effects of co-composted biochar on oat (*Avena sativa* L.) yield in both sandy and loamy soil. The aim of this study was to test whether biochar effects can be observed at very low biochar concentrations. To test a variety of application amounts below 3 Mg biochar ha^{-1}, we co-composted five different biochar concentrations (0, 3, 5, 10 kg Mg^{-1} compost). The biochar-containing compost was applied at five application rates (10, 50, 100, 150, 250 Mg ha^{-1} 20 cm^{-1}). Effects of compost addition on plant growth, Total Organic Carbon, N_{tot}, pH and soluble nutrients outweighed the effects of the minimal biochar amounts in the composted substrates so that a no effect level of biochar of at least 3 Mg ha^{-1} could be estimated.

Keywords: biochar; compost; no-effect-level; greenhouse; C management

1. Introduction

Many studies on biochar effects in different soil substrates have been scientifically examined during the last decade, the majority thereof proving positive effects on plant growth and soil properties [1–3].

In a recent meta-analysis study, *Jeffery et al*. [4] reviewed 177 treatments from 16 individual studies and found only one with negative impacts on plant growth but several studies showing no biochar effect on plant growth.

Usually biochars are low in nutrients, depending on feedstock and pyrolysis temperature [5,6]. This limited supply of nutrients implies additional fertilization if biochar is applied for agricultural purposes. Recent studies suggested adding biochar to compost [7] or even better co-composting biochar [8,9] as a preferable alternative to input intensive or finite (phosphorus) fertilizer. Another study claims that biochar increases the nutrient retention of the existing nutrients in compost due to the increase of biochar surface oxidation when biochar is applied into the fresh compost mixture. In other words: abiotic and biotic processes during composting lead to the formation of oxygen-containing functional groups and therewith to an increase of nutrient holding capacity [10].

Research already opposed maximum biochar application amounts, as shown by Schulz and Glaser [9] who applied biochar amounts of up to 90 Mg ha^{-1} in the form of co-composted biochars, which induced increased plant growth, and the more biochar added to the soil, the more carbon storage potential there was. However, from a farmer's perspective minimal biochar amounts are desirable due to economic reasons. The economic cost of biochar is in a range of $200–$2,000 per Mg (worldwide, data from online market research). In addition, companies being able to supply more than 1 Mg per day are still rare in Europe [11].

Due to our knowledge, little is known on threshold amounts of biochar for positive agronomic effects. Only one other study is published with similarly small biochar application amounts, still this is not comparable to our setup as they calculated per hectare amounts but applied the biochar in relatively small bands only surrounding the sown seeds (approximately one Mg ha^{-1}[12]).

Our study was designed by combining the knowledge of synergistic effects that composting has on biochar with the need to find no effect level (NOEL) for biochar amendments. Therefore, we investigated the effects of both (i) biochar addition rate and (ii) co-composted biochar application amount on oat (*Avena sativa* L.) yield. We hypothesized that (1) co-composted biochar amended soil increases the TOC (with positive effects on soil water status); (2) retains more nutrients in the available form and (3) results in higher crop yields.

2. Materials and Methods

2.1. Soil Substrates

For our study we used a sandy and a loamy substrate which had not been used for agricultural purposes prior to the experiment. The substrates were collected at Kiesgrube ZAPF, Weidenberg, Germany and Ökologisch Botanischer Garten, University of Bayreuth, Germany, respectively. Selected basic properties of soil substrates are given in Table 1. The very poor sandy substrate (which was washed sand-mix originally intended for concrete mixes) was representative of nutrient-poor infertile soil, while the loamy substrate represented soils with sufficient nutrient supply common in Central Europe. Strongly contrasting contents of organic material and clay size particles of the two substrates were supposed to induce different responses comparable to natural soil types.

Table 1. Chemical composition of the two soil substrates and the biochar composts are shown. "CO" is compost without biochar. The number following "BC-" denotes the approximate fraction of biochar in the composted product as "kg biochar per Mg". "n.a." means not analyzed. "BET" is BET surface area, "±se" means plus minus standard error (n = 5).

	Al [g kg^{-1}]	**Ca** [g kg^{-1}]	**K** [g kg^{-1}]	**Mg** [g kg^{-1}]	**Na** [g kg^{-1}]	**P** [g kg^{-1}]	**Biochar** [g kg^{-1}]	**TOC** [g kg^{-1}]	**N** [g kg^{-1}]	**C/N**	**Ash**	**NO3** [g kg^{-1}]	**NH4** [g kg^{-1}]	**BET ± se** [m^2 g^{-1}]
Sand	0.068	0.118	0.008	0.025	0.007	0.008	0	0.96	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Loam	0.683	2.511	0.202	0.333	0.030	0.091	0	16.09	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CO	11.0	3390	302	103	45.4	24.7	0	112.83	9.46	13.41	78.40	0.25	0.06	2.3 ± 0.3
BC-03	7.9	3610	312	103	46.7	22.0	3	120.52	9.85	13.63	77.80	0.32	0.04	11.6 ± 0.8
BC-05	8.0	3510	292	100	44.4	25.3	5	117.36	9.69	13.48	77.40	0.34	0.03	12.7 ± 0.1
BC-10	7.8	3590	325	107	51.0	23.9	10	122.11	9.43	14.31	76.20	0.36	0.06	12.9 ± 0.7

2.2. Biochar Composts

The biochar was an activated carbon from a commercial producer (carbopal®, Donau Carbon GmbH, Frankfurt, HE, Germany, ash content <6%, bulk density ~0.6 g/cm^3, surface area ~900 m^2/g, specific surface 1200 m^2/g, bulk density ~375 kg/m^3). Compost input material consisted of 50% sewage sludge (25% dry matter), 35% chopped wood (60% dm) and 15% rest soil or woody debris (leftovers from composting). After piling 20 Mg compost raw material to six meter wide and three meter high piles for two weeks, the piles were diverted into three meter wide and 1.5 m high mounds and mixed twice a week. After the biochar was added to respective piles in amounts of 3.5 and 10 kg biochar per Mg compost (BC-03, BC-05 and BC-10, respectively) and composted together for two weeks (mixed once a week) before the final phase of composting was induced by piling six meter wide and three meter high mounds (mixed every third week). Properties of individual biochar-amended composts are given in Table 1.

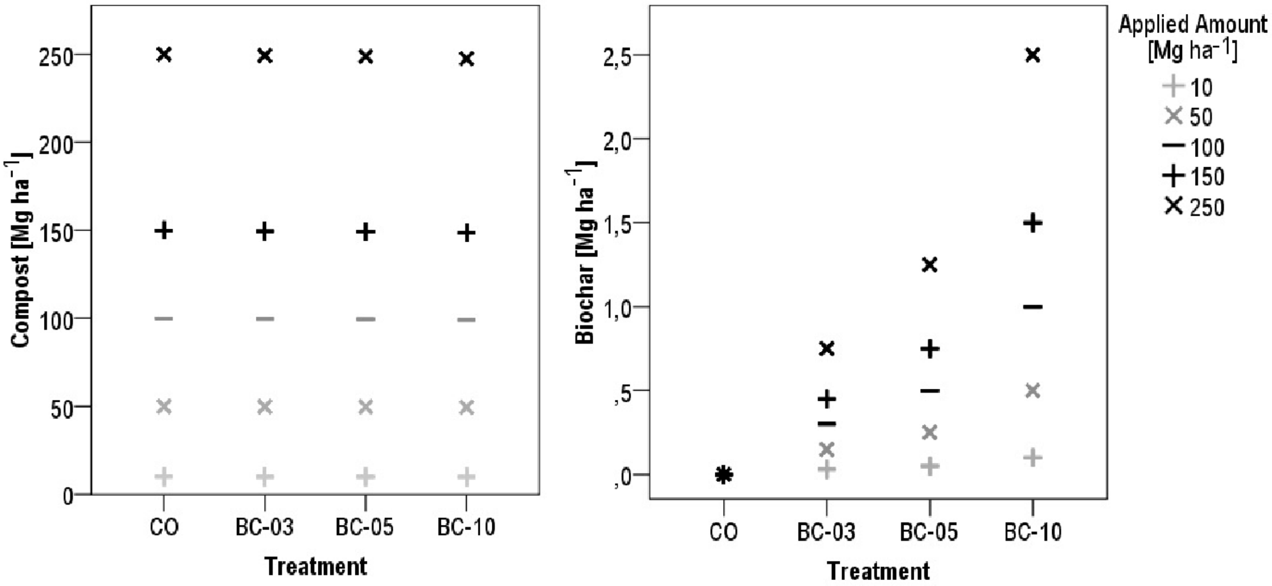
2.3. Greenhouse Experiment

The study was set up in a greenhouse at an average temperature of around 22 °C, with 200 mL of water irrigation every other day, and constant light conditions (400 W sodium discharge lamp, 8 h per day) for the whole duration of the experiment. For the experiment, we used commercial plastic pots with a total volume of 1000 cm^3 and a diameter of 13 cm, with a surface area of 133 cm^2. The perforated bottoms were covered with fine gauze, hindering the loss of particulate matter but allowing leaching of water. One kilogram of dry matter of the substrate was placed in the pots. The biochar compost types were applied in five application rates (equivalent to 10, 50, 100, 150, 250 Mg ha^{-1} 20 cm^{-1} in five replicates); hence, the respective biochar component application rates were between 0.03 and 2.5 Mg ha^{-1} (Figure 1). Soil samples were taken at time zero, after mixing and before sowing. All pots were arranged in a randomized block design and 10 oat (*Avena sativa* L.) seeds were sown in each pot, similar to common oat sowing in the field at 500–700 seeds per square meter. The survival rate was noted at harvest time and plants were cut just above the ground leading to the biomass data. Seeds were separated manually afterwards and weighed separately.

2.4. Soil and Plant Analyses

Three months after sowing, the plants' heights were recorded and we harvested above-ground biomass. Plant biomass was dried at 65 °C and then weighted. Results were scaled up to Mg ha^{-1} using the pot surface area. Composted biochars and soil samples were analyzed using the Mehlich-III-extraction method [13]. To do so, 2.5 g of soil was passed through a 2 mm sieve into 125 mL Erlenmeyer flasks, and 30 mL of Mehlich-III-extractant (0.2 M CH_3COOH, 0.25 M NH_4NO_3, 0.015 M NH_4F, 0.013 M HNO_3 and 0.001 M EDTA.) added. The suspension was shaken for 5 min on a rotating shaker with 120 rpm. After filtrating through No. 42 Whatman filter paper, filtrates were analyzed by ICP–OES (BayCEER, University of Bayreuth). Total organic carbon (TOC) and total nitrogen (N) were measured by dry combustion with a VARIOMAX CNS elemental analyzer (Elementar, Hanau, Germany).

Figure 1. Individual amounts of applied compost and biochar (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar) at 5 application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) calculated as per hectare amounts (in Mg ha^{-1}).



2.5. Statistical Analysis

Data were analyzed using simple linear regressions (SLR) with the equivalent per hectare amounts of composted biochars or composts to analyze biochar and compost effects separately; regression coefficients are indicated if significant (justification for this procedure is found in setup description, Figure 1). Asterisks *, **, *** indicate $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively; not significant data is indicated by "n.s." in the tables. The values behind "±"symbols in the text represent one standard error of the mean ($n = 5$). All analyses were performed with SPSS Statistics 17 (IBM).

3. Results

3.1. Plant Growth

3.1.1. Oat Grain Yield

The oat grain yield ranged between 0.00 and 0.14 Mg ha^{-1} on sandy substrate (control: 0.02 ± 0.00 Mg ha^{-1}) and between 0.04 and 0.19 on loamy substrate (control: 0.06 ± 0.00 Mg ha^{-1}; Figure 2). Compost significantly increased grain yield (sandy: $p < 0.001$; loamy substrate: $p = 0.001$; Table 2), while no effect of biochar on oat yield could be proven ($p > 0.05$ at all applied amounts and on both substrates; Table 2).

Figure 2. Grain biomass (**top**) and plant biomass (**bottom**) of oat (Avena sativa L.) in Mg ha^{-1} on sandy (**left**) and loamy substrate (**right**) depicted for five treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar, in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = no amendment) (*n* = 5).

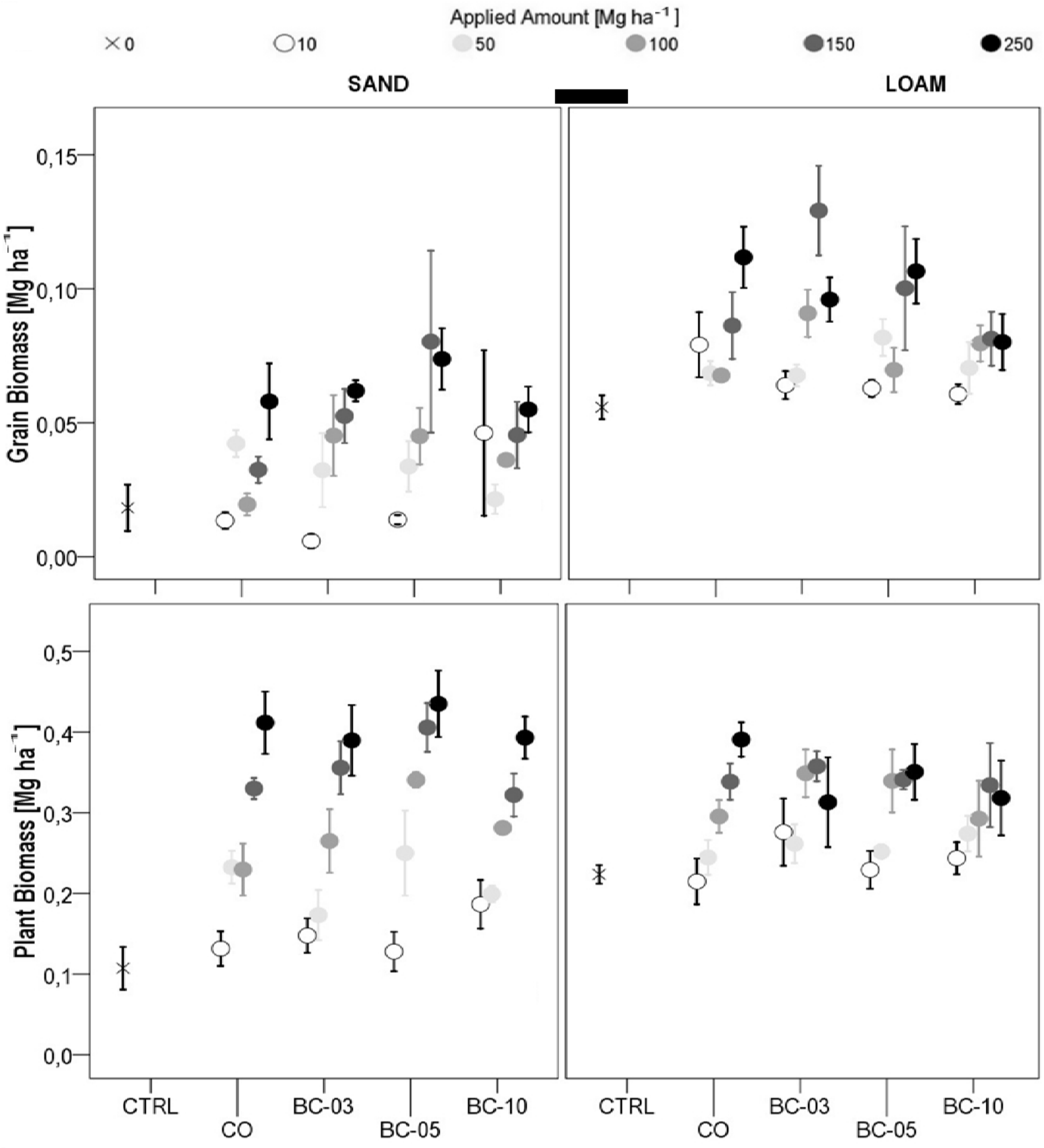


Table 2. Linear regression of plant and soil data calculated with per hectare amounts of the applied biochar composts. "CO" stands for regressions with the compost amounts and the variables, "BC" for the biochar amount and the variables. If "BC" had significant influence on the variables, the respective application amount is indicated by the superscript number.

Substrate	Variable	Regression (CO)		Regression (BC)	
Sand	Seed yield	1.85 + 0.02 × CO	***	n.s	
	Biomass	16.48 + 0.10 × CO	***	n.s.	
	Plant height	73.00 + 0.11 × CO	***	$101.31 - 8.11 \times BC^{150}$	*
	TOC	2.71 + 0.01 × CO	***	$0.97 + 33.50 \times BC^{10}$	**
	TN	0.22 + 0.00 × CO	***	n.s.	
	pH	8.54 + 0.00 × CO	***	n.s.	
	P	0.056 + 0.001 × CO	***	n.s.	
	K	0.009 + 0.000 × CO	***	$0.018 - 0.130 \times BC^{10}$ $0.011 + 0.011 \times BC^{50}$ $0.030 + 0.008 \times BC^{250}$	* * *
	Mg	0.043 + 0.000 × CO	***	$0.079 + 0.015 \times BC^{250}$	*
	Ca	0.574 + 0.008 × CO	***	n.s.	
	Na	0.011 + 0.000 × CO	***	n.s.	
	Al	0.105 − 0.000 × CO	n.s.	n.s.	
Loam	Seed yield	6.66 + 0.01 × CO	**	n.s	
	Biomass	26.18 + 0.04 × CO	***	$41.04 - 4.69 \times BC^{250}$	*
	Plant height	87.49 + 0.02 × CO	n.s.	n.s.	
	TOC	18.99 + 0.03 × CO	***	$25.19 - 9.79 \times BC^{100}$	*
	TN	1.66 + 0.00 × CO	***	n.s.	
	pH	7.21 + 0.00 × CO	***	n.s.	
	P	0.131 + 0.001 × CO	***	n.s.	
	K	0.193 + 0.000 × CO	***	$0.240 - 0.662 \times BC^{50}$	**
	Mg	0.345 + 0.000 × CO	***	n.s.	
	Ca	2.942 + 0.009 × CO	***	$3.105 + 0.897 \times BC^{50}$	*
	Na	0.04 + 0.000 × CO	***	$0.043 - 0.174 \times BC^{10}$	**
	Al	0.668 − 0.000 × CO	***	n.s.	

Significant differences are marked with asterisks: *, **, *** indicate $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively; n.s. indicates "not significant". Seed yield = separated seeds, Biomass = complete above ground biomass.

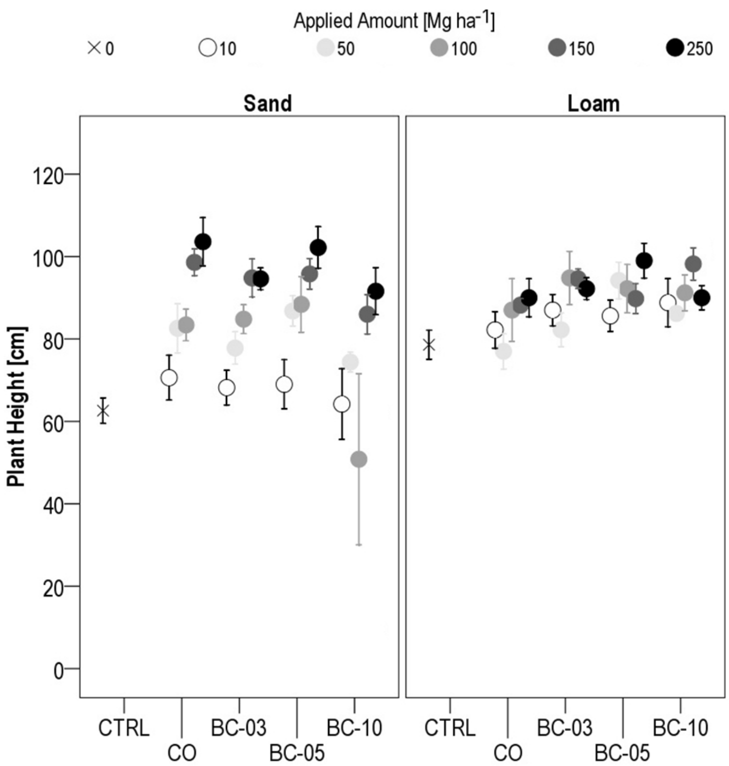
3.1.2. Plant Biomass

Total above-ground biomass yield ranged between 0.02–0.54 Mg ha^{-1} on sandy substrate (control: 0.11 ± 0.01 Mg ha^{-1}) and between 0.10–0.48 Mg ha^{-1} on loamy substrate (control: 0.22 ± 0.01 Mg ha^{-1}; Figure 2). Compost application significantly increased oat biomass both on sandy ($p < 0.001$) and loamy substrates (Table 2). Biochar showed no significant effect on plant biomass on sandy substrate, while on loamy substrate biomass yield was significantly lower at the highest applications amounts (250 Mg ha^{-1}; $p = 0.04$) but no clear tendency was detected looking at increasing biochar amounts (Table 2).

3.1.3. Plant Height

Plant height increased on both substrate types with nearly all amendments resulting in heights between 31.0–119.0 cm on sandy substrate (control: 62.6 ± 3.1 cm) and between 50.0–122.0 cm on loamy substrate (control: 78.6 ± 3.5 cm; Figure 3). Raising the total amounts of compost significantly increased plant heights only on sandy substrate ($p < 0.001$), on loamy substrate the effect was only visible as a tendency ($p = 0.15$; Table 2). Biochar showed only significantly negative effect on plant heights in one application amount on sandy substrate (150 Mg ha^{-1}; $p = 0.04$), leading to the conclusion there was no trend or tendency of biochar influencing plant heights.

Figure 3. Plant height of oat (*Avena sativa* L.) in cm on sandy (**top**) and loamy substrate (**bottom**) depicted for five treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar) in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = no amendment) (*n* = 5).



3.2. Changes in Soil Properties

3.2.1. Total Organic Carbon (TOC)

The TOC contents of sandy substrate ranged between 0.2 and 8.9 g kg^{-1} (control: 1.1 ± 0.3 g kg^{-1}) and between 4.0 and 31.1 g kg^{-1} on loamy substrate (control: 18.1 ± 0.4 g kg^{-1}; Figure 4). Compost amendments significantly increased TOC contents on both sandy and on loamy substrates ($p < 0.001$), while no significant biochar effect could be observed (Table 2).

3.2.2. Total Nitrogen (N_{tot})

N_{tot} ranged from 0.00–0.71 g kg^{-1} on sandy substrate (control: 0.0 ± 0.0 g kg^{-1}) and from 0.20–2.49 g kg^{-1} on loamy substrate (control: 1.52 ± 0.27 g kg^{-1}; Figure 5). Significant influence on N_{tot} content was proven for compost on sandy and loamy substrate equally ($p < 0.001$; Table 2). Differences between the compost and the respective biochar compost applications were marginal and not significant; hence the applied low amounts of biochar did not influence N_{tot}. (Figure 5).

Figure 4. Total organic carbon (TOC) in g kg^{-1} on sandy (**top**) and loamy substrate (**bottom**) depicted for five treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w/w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w/w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w/w* biochar) in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = no amendment) (*n* = 5).

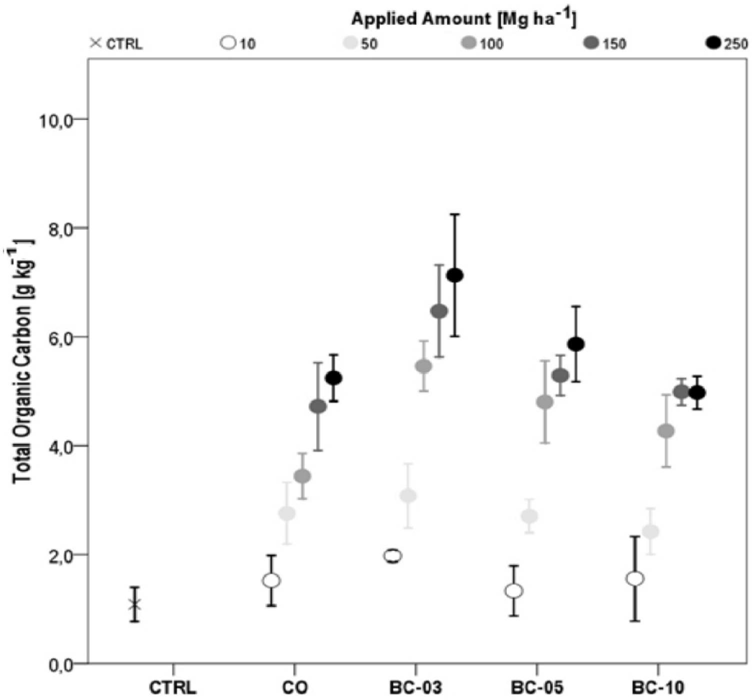


Figure 4. *Cont.*

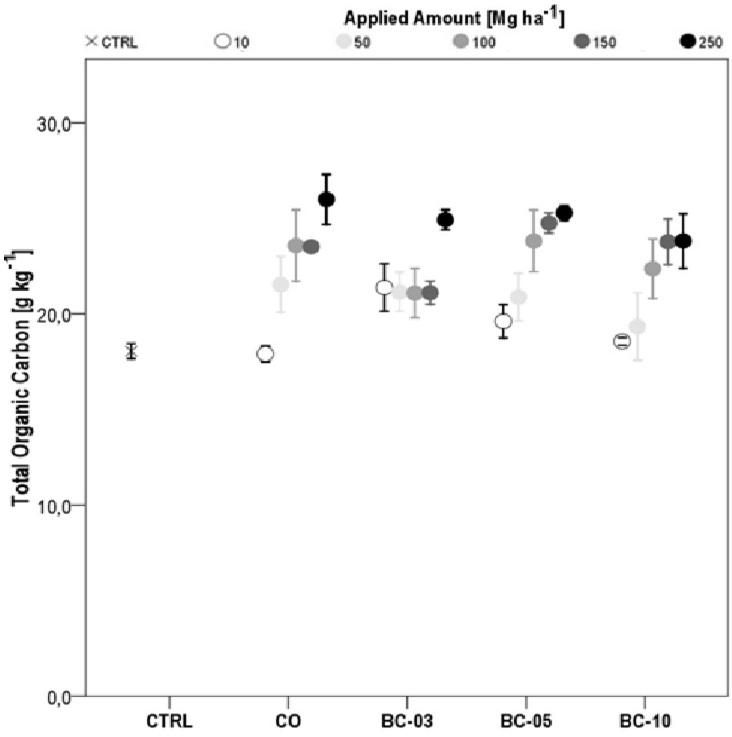
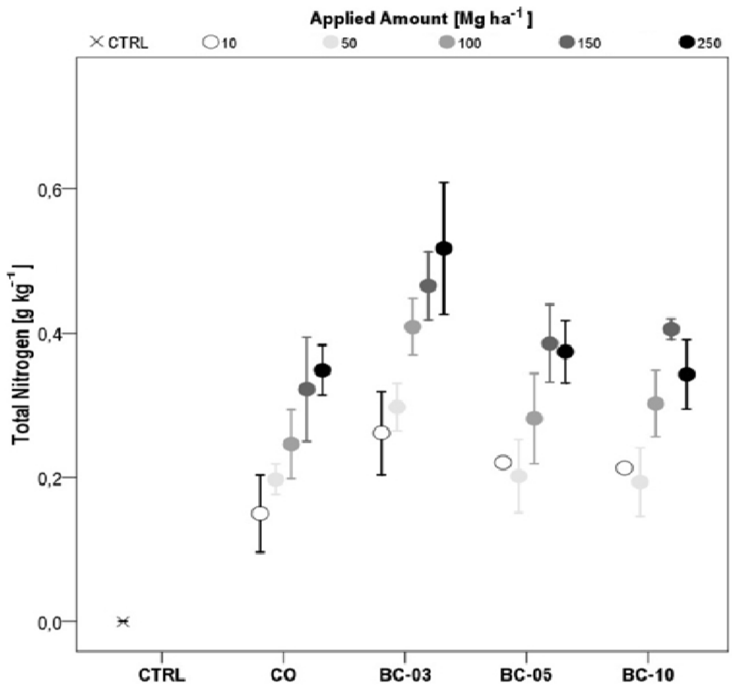


Figure 5. Total nitrogen (N_{tot}) in g kg^{-1} on sandy (**a**) and loamy substrate (**b**) depicted for 5 treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar) in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = no amendment) (n = 5).



3.2.3. Soil Reaction (pH)

PH values ranged from 6.95–8.80 (sandy substrate control: 8.53 ± 0.04; mean: 8.33 ± 0.03) and 6.76–8.14 (loamy substrate control: 6.88 ± 0.04; mean: 7.31 ± 0.02). Alkalinity (rising pH) was significantly influenced to a similar degree in both substrates by compost ($p < 0.001$).

3.2.4. Plant-Available Nutrients and Aluminum

Compost amendment enriched both substrate types significantly with phosphorus ($p < 0.001$ on both substrates) boosting the phosphorus (P) content by factors of 2.3–30.1 compared to sandy control with factors of 1.2–3.4 compared to loamy control; however, there was no biochar effect. The contents of available potassium (K) were elevated by factors of 1.4–3.0 on sand which was very significant in relation to compost additions; biochar amendments were proven to elevate K contents significantly at 50 and 250 Mg ha^{-1} application amounts while they showed a negative impact at 10 Mg ha^{-1} which brings us to the conclusion that there is no clear effect of biochar on K status in sandy substrate. Potassium load was increased only by factors 1.0–1.2 on loamy substrate, where compost contents significantly increased K at all application amounts and biochar amounts at 50 Mg ha^{-1} significantly decreased K with no other statistically significant influences in biochar. Plant-available calcium (Ca), magnesium (Mg) and sodium (Na) contents were elevated with the highest statistical significance by the compost content of our amendments on both substrates ($p < 0.001$, respectively); on sandy substrate biochar showed one exceptional significant response and elevated Mg contents at one particular application level (Figure 6, Table 2) while biochar increased Ca and decreased Na content significantly at one particular application level in each case on loamy substrate (Figure 7, Table 2). Contents of available Aluminum (Al) decreased the more compost was added to our two substrates ($p < 0.001$ respectively); biochar did not show an effect that was statistically discernible on both substrates. Calcium content rose significantly after all applications especially on sandy substrate, leading to 17.7 times higher Ca contents at the highest application amounts, whereas on loamy substrate the factor was 2.1 at the same rate. This definitely had a positive influence on the Al-Ca-ratio, neutralizing the Aluminum. Ratios of Al to Ca were not critical to plant growth at any treatment level whatsoever.

Figure 6. Plant-available nutrients and Aluminum (in cmolc kg^{-1} soil) on sandy substrate depicted for five treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar) in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = pure sandy substrate) (*n* = 5).

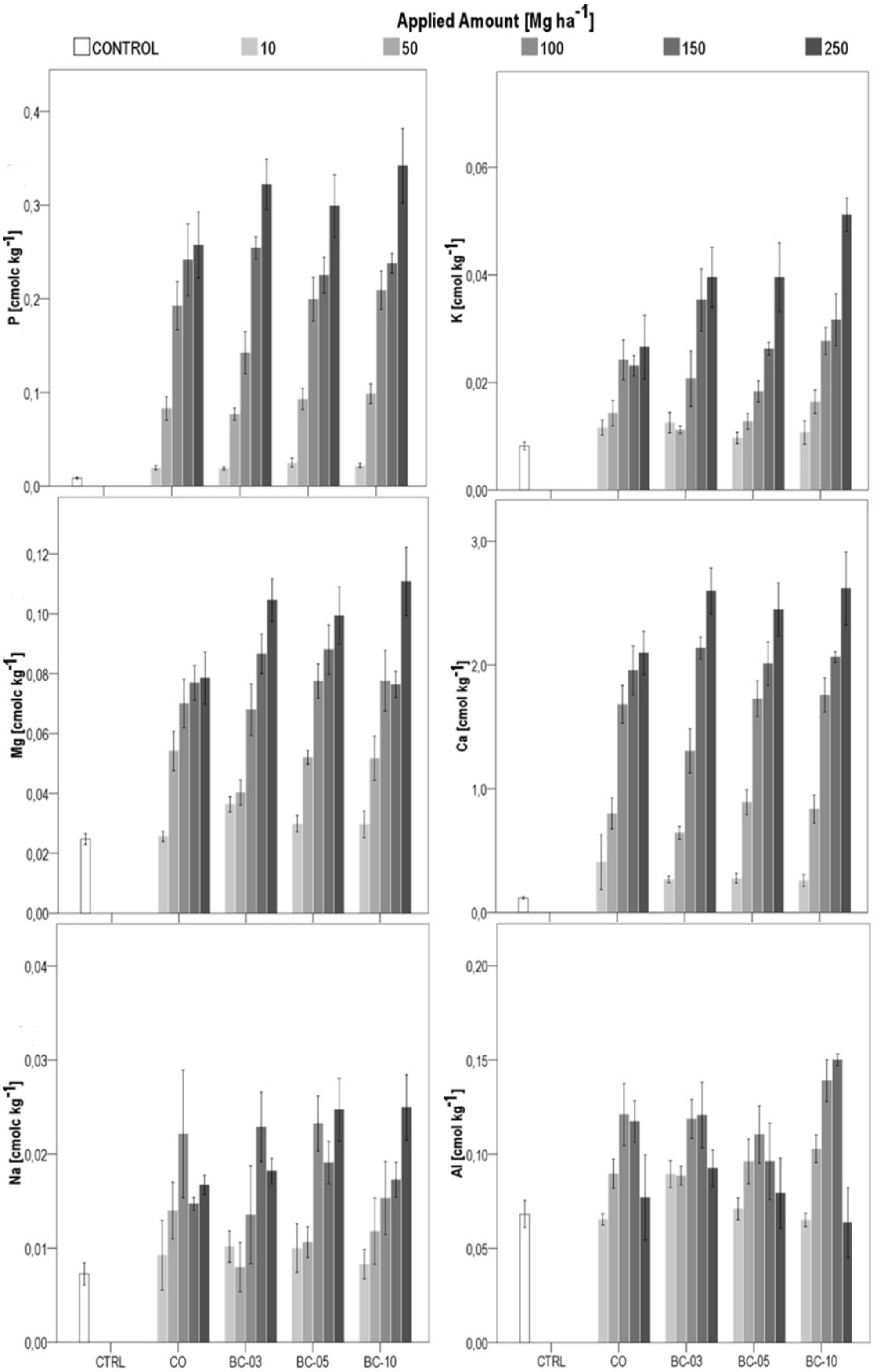
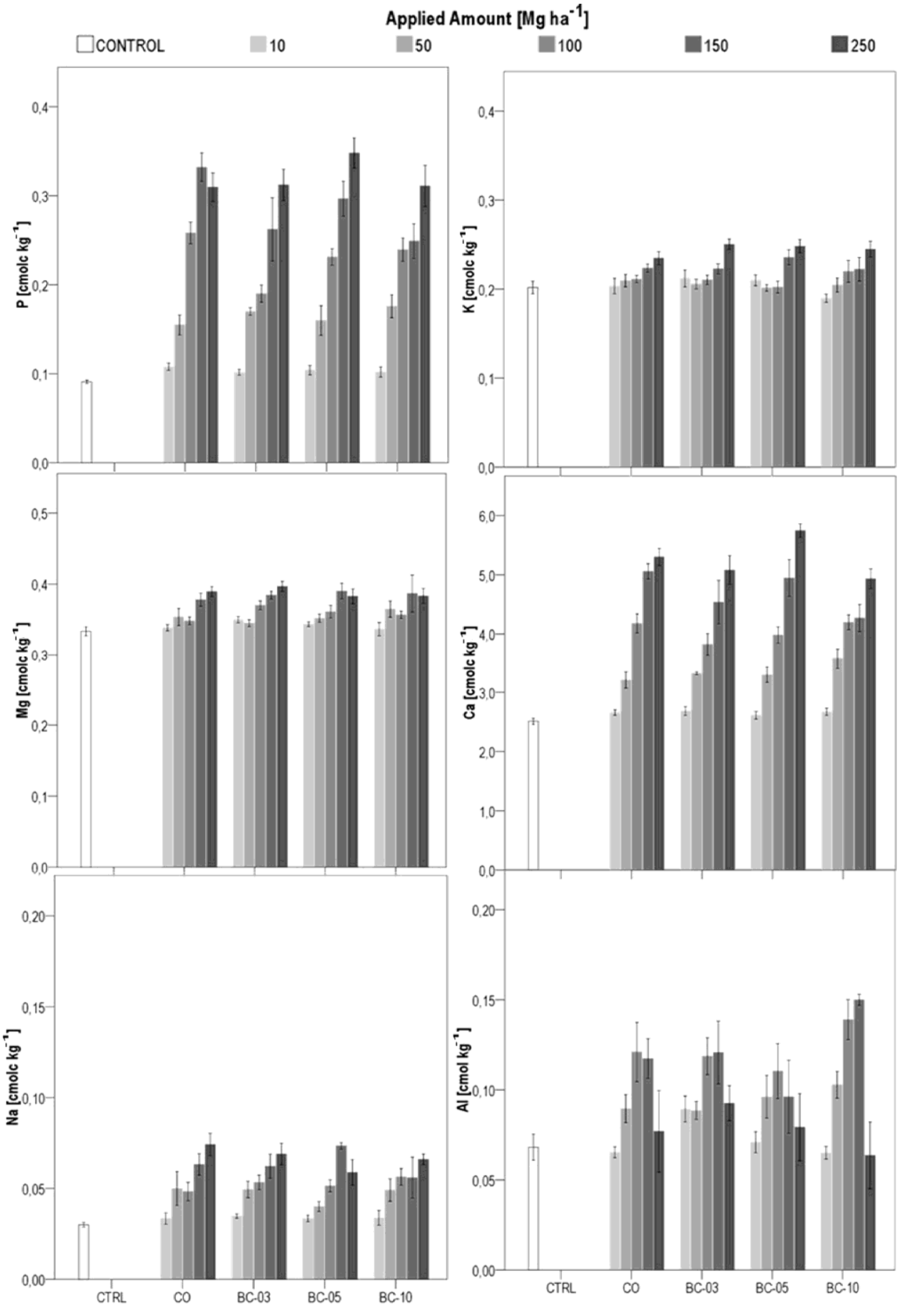


Figure 7. Plant-available nutrients and Aluminum (in cmolc kg^{-1} soil) on loamy substrate depicted for five treatments (CO = pure compost, BC-03 = compost with 3 kg Mg^{-1} *w*/*w* biochar, BC-05 = compost with 5 kg Mg^{-1} *w*/*w* biochar, BC-10 = compost with 10 kg Mg^{-1} *w*/*w* biochar) in five application amounts (10, 50, 100, 150, 250 Mg ha^{-1}) *versus* control (CTRL = pure loamy substrate) (*n* = 5).



4. Discussion

Plant growth significantly increased with increasing compost amendment in both soil substrates (Figures 1–3). However, we could not prove any biochar effect on plant growth in our study which is in contrast to most other reported biochar research [2–4,7]. This is probably due to the extremely low amounts of biochar of 0.03–2.5 Mg ha^{-1} used in the different compost application amounts. The biochar effect is masked by compost. Additionally, a special type of biochar was used (activated carbon) which is known to be valuable for element sorption but perhaps this is not the case in a plant-available form. Another reason why we could not detect a significant influence by the biochar could be the limited duration of our trial. Several authors discussed reactions of biochar in soils over time increasing its impact through surface oxidation and bio-activation with soil microbes and fungi growing on the biochar [14–16].

Plant growth results of the different biochar composts showed increases in much larger magnitudes on sandy substrate than on loamy substrate, which was suggested by [17] who wrote that soil fertility of poorer soils would improve more in reaction to organic amendments. The different reactions of the two soil substrates could be also proven in a further greenhouse study by Schulz and Glaser [7] by using similar soil substrates and gaining similar results comparing the soil substrates' differing responses. In the study mentioned, we found the alterations of TOC, N_{tot}, soil reaction and plant-available nutrients appearing in much bigger orders on sandy substrate following compost and composted biochar applications. This difference in the effects could be related to the low baseline of the pure sand regarding initial nutrient status, clay minerals and organic components. It could also be connected to the initially high soil reaction of the sandy substrate (pH around 8 in sandy substrate, contrasting a pH around 7 in loamy substrate).

It is difficult to relate the results of our minimal biochar additions to the frequently published proofs that biochar applications to soil increase agricultural productivity (e.g. [1,3,4,18–20] due to the higher biochar application amounts used in these studies and because their biochar effects were not masked with the compost effects. Steiner *et al.* [21] reported cumulative yield increases of rice and sorghum on a Brazilian Amazon Oxisol of approximately 75% after four growing seasons over two years, when 11 Mg ha^{-1} biochar was applied at the beginning of the experiment. In a degraded Kenyan Oxisol, Kimetu *et al.* [22] found a doubling of cumulative maize yield after three repeated biochar applications of 7 Mg ha^{-1} over two years corresponding to a total of 21 Mg ha^{-1}.

If biochar was applied in higher amounts than in our study, soil nutrient availability has repeatedly been increased in highly weathered tropical soils comparable (Lehmann *et al.* [23] with ~560 Mg ha^{-1}; Lehmann *et al.* [18] with 67.6–135.2 Mg ha^{-1}; Steiner *et al*. [21] 2008 with 11 Mg ha^{-1}). Similar amounts as in our study were tested in the trial from Iswaran *et al.* [24] where they showed increased biomass production in a poor sandy soil after adding small amounts of charcoal of 0.5 Mg ha^{-1} together with sufficient artificial fertilization. The positive effect of charcoal was attributed to its positive effect on Rhizobium abundance by poisoning Rhizobium antagonists with charcoal inherent phenolic substances. As we did not apply legumes and, furthermore, did not experience other negative effects of biochar induced poisoning of soil biota, we cannot relate the data from Iswaran *et al.* [24] to our results.

In many studies, biochar incorporation has been shown to induce soil alkalization which can increase soil nitrification [18,25–30], moreover also the high sorption capacity caused by aromaticity of the biochar could have an influence on nutrient cycling[1]—none of these effects could be achieved by our small application amounts in relation to amounts of compost added and the initial alkaline substrates. Neither did the increased porosity (indicated by the BET surfaces of the co-composted biochars, Table 1) significantly influence the sorption capacity as suggested by the marginal and non-linear differences in our nutrient data.

The compost addition positively and significantly influenced plant growth and soil properties as expected after long-term experience in compost applications [30,31]. Compost improved oat yield significantly stronger on sandy substrate than on loamy substrate, which could be attributed to the very low content of nutrients and organic matter in the pure sandy substrate where any low amendment would alter the conditions for plant growth [7]. Nitrogen loads of our compost products were designed for optimum nitrogen supply from the first year on, because—unlike natural/agricultural conditions—we did not need to consider water protection guidelines (adding 100–2500 kg N ha^{-1} at one time, as we did, would be far above the European guidelines). The same total application amounts of composted biochars (BC-03, -05, -10) and the pure composts (CO) improved the soils to a similar degree; there are no statistical differences regarding plant biomass or seed yield, nutrient loads, organic matter or soil reaction between the treatments containing biochar and those that lack of it. Clearly, we owe the effects our amendments had on all measured parameters to the compost shares of our amendments. We attribute this absent biochar effect to the low amounts of added biochar (<3 Mg ha^{-1}). It can be stated that investments for biochar amendments below €2,000 per hectare are irrelevant for improving plant growth and soil quality at given actual costs for biochar of around €300–800 per Mg biochar. Farmers' costs could be lowered if the biochar is produced locally and from farmyard waste or in a projected future when biochar would be accounted for actual carbon offset. Around €27.600 per hectare would be necessary to invest for the biochar application amounts which showed the biggest effect on grain yield (*Avena sativa* L.) in the study from Schulz and Glaser [9]. There, the strongest effect on grain yield (*Avena sativa* L.) was measured after applications of composted biochar comprising of 92 Mg biochar ha^{-1} and 107 Mg compost ha^{-1} (leading to a 300% higher yield on sandy substrate compared to the pure compost) leaving us with impossible investments for farmers. The meta-analysis study of Jeffery *et al.* [4] marked the best results at application amounts of 100 Mg biochar ha^{-1}, which requires investments of money no farmer would spend easily. One feasible option might be the application of 1 Mg every year until a certain stock is established, or as discussed in Blackwell *et al*. [12] in form of bandings and thereby closer to the plants growing space. Agronomic considerations including increased crop productivity, reduced fertilizer and pesticide use need to be made at the farm scale.

5. Conclusions

We proved that low level biochar applications had no immediate effects on plant growth and soil fertility both in sandy and loamy soils. Our data suggests that co-composted biochar application could only be a better way to enhance plant yields and soil parameters if applied in doses higher than

2.5 Mg ha^{-1} or applied differently, e.g. as suggested by Blackwell [32], or loaded with nutrients (biochar activation). We found no negative effects of the applied activated carbon.

Due to the proclaimed longevity of the biochar in soils, all commercial "Terra Preta" producers should be obliged to thoroughly test their products and to provide convincing results of the claimed benefits, e.g. by providing scientific results with proper experimental setup and statistical design.

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Conflicts of Interest

The authors declare no conflict of interest.

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