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Effects of Three Different Biochars Enriched with Dairy Effluent on Wheat Growth

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ABSTRACT

Biochars produced from agricultural residues can be used to increase nutrient uptake of plants by improving physical, chemical and biological quality of soils. This study was conducted to investigate the effects of three biochar types (corn cob, bean residues and rice husk) combined with different mineral fertilizer levels and dairy effluent (DE) added to sandy loam and loamy textured soils on wheat growth. The biochars immersed with nutrient rich DE were applied at 0, 0.5, 1.0, 2.0 and 3.0% (w/w) and combined with five fertilization levels (0%, 75%-low and 50% - low, 100% - complete and 100% - complete + biochar without DE). Biochar type had no effect on dry matter yield (DM) of wheat except 3.0% dose. Biochar (both with and without DE) combined with the highest fertilizer rate led to a higher DM compared to low fertilizer rates. The highest DM yield (307 mg plant^{-1}) was recorded in sandy loam x 1% biochar x 100%-complete fertilizer interaction. Biochar addition to a nutrient poor, slightly alkaline soil had a little effect on DM in the absence of adequate fertilizer. The difference in DM yield between 0% and 50%-low fertilizer doses in 0.5, 1.0, 2.0 and 3.0% biochar doses was 12.8, 24.4, 48.8 and 55.2%, respectively. The increase in DM yield difference between the fertilizer doses indicates that the availability of nutrients increases with the increase in biochar doses. The results revealed that biochars don't contain sufficient plant nutrient even enriched with DE, therefore, nutrients should be co-applied with biochar to obtain expected crop yield.

1. Introduction

Sustainable disposal of wastes from agricultural lands and agricultural industry is important in all over the world. Application of agricultural wastes to soil has significant benefits, while application of all the wastes generated in agricultural or forestry activities to soils is not possible. The agricultural wastes are a potential feedstock for the production of biochar, which is a carbon rich material produced by thermal degradation of biomass in an oxygen free or limited environment (Lehmann and Joseph 2015). Application of biochars in agricultural fields have been studied due to high water and nutrient retention capacity (Günal et al., 2018), porosity, cation exchange capacity, benefits to microorganisms as habitat, promoting the release and uptake of nutrients by plants, etc. (Atkinson et al. 2010; Foster et al. 2016; Razzaghi et al. 2020). Therefore, biochar amendment may enhance soil quality and increase crop yield by improving several physical, chemical and biological properties of soils (Olmo et al. 2014; Cybulak et al. 2019), and solve the waste problem generated in agricultural production, food industry or forestry activities.

Global cereal production is under serious threat due to increasingly impacts climate change resulting in severe droughts and intensive rainfalls. The temperature and frequency of extreme events are expected to increase more even in the near future (Ummenhofer and Meehl 2017; Kilic

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and Gunal 2021). In addition, the decrease in soil fertility and organic matter content significantly constrains grain production in arid and semi-arid regions. Soil organic matter content in surface layer (0-30 cm) in regions, where winter wheat-summer fallow is practiced, is usually very low. Biochar is as a promising source of soil organic matter and has been recommended to increase organic matter content due to the resistance to the decomposition (Lehmann and Joseph 2015).

The plant response to biochar application varies depending on feedstocks used in biochar production, characteristics of soils and plant species used in the experiments, and fertilization status (Unger et al. 2011; Kamau et al. 2019). Plant litter, wood residue, manure, crop residue and several other organic wastes can be used for biochar production (Brown 2012; Gunal et al. 2019). In a recently published meta-analysis, Farhangi-Abriz et al. (2021) reported significant positive effects of biochar applications on wheat ($P<0.05$) and corn ($P<0.01$) yields, while no significant effects on rice and soybean yields ($P>0.05$). In general, nutrient content of biochars produced from woody materials under similar production conditions is lower compared to the biochars obtained from manure (Kamau et al., 2019; Günal et al., 2019). Therefore, application of biochar and inorganic fertilizers together is a sustainable practice to increase organic matter content and also improve soil fertility and crop yield. Recent studies revealed significant positive interactions between biochars and mineral fertilizers on selected soil physical and chemical properties and crop yields (Laird et al., 2010; Oladele et al., 2019).

Turkey is one of the main producers of hazelnuts, cherries, apricots, figs, quinces and many other crops in the world (OECD, 2016). The amount of biomass residues originated from agricultural activities was estimated as 75,084 kilotons (Avcioglu et al. 2019). Some of agricultural wastes are burned in the field, stored at the edges of fields, used as fuel or broken into small pieces and mixed to soil. Disposal of agricultural wastes, which are an important source of soil organic matter, causes to decompose and disappearance of organic matter very quickly, and at the same time cause significant water and air pollution (Günal, 2018). However, pyrolysis of organic wastes is an alternative to energy production due to the flammable gas and bio-fuel produced, and application of biochar to soil improves carbon sequestration and provides nutrients to soils (Laird 2008). In addition, the wastewater generated in dairy cattle farms is rich in plant nutrients, especially nitrogen and phosphorus. Biochar can be used to reduce the nutrient load in dairy effluent (Sarkhot et al. 2013). Saturation of biochars with dairy effluent prevents both air pollution caused by the burning of agricultural wastes and pollution of surface and subsurface waters caused by the direct application of dairy effluent to agricultural fields or discharging to the surface waters.

The interactive effects of biochars produced different harvest residues, biochar doses, dairy effluent and mineral fertilizer applications on wheat growth in contrasting soil types have been scarcely studied. In this study, the effects of five different doses of three different biochars enriched with dairy effluent on wheat growth were investigated. The biochars were applied to two soils with different particle size distributions, and mineral fertilizer dose was also included to the experiment as a factor in addition to soil, biochar type and biochar doses.

2. Material and methods

A greenhouse experiment was conducted to evaluate the effects of different biochar types on dry matter yield of wheat grown in two different texture classes (loamy and sandy loam). The experimental soils were collected from 0 to 30 cm of an apple orchard and a vegetable production field in Kazova Basin of Tokat province, Turkey. The purpose of using two soils with different soil texture was to compare the effects of biochar applications on dry matter yield of wheat grown in different soils. Both soils were moderately alkaline (pH 8.22 and 8.15), low in organic matter content (1.13 and 0.75%), and calcareous (2.36 and 5.98%) (Table 1). The soils were air-dried and sieved to obtain a fraction of 2 mm to eliminate the skeleton materials.

2.1 Production and characterization of biochar types

The feedstocks used in biochar production were selected based on their availability in Tokat province, Turkey. Common bean (*Phaseolus vulgaris* L.) residues, corn cobs (*Zea mays* L.) and rice husk (*Oryza sativa* L.) were used to produce biochars. Slow pyrolysis (a rate of approximately 10 °C min^{-1} and long residence times) process at 500 °C was used to obtain biochars. The biochars were kept in the unit until pyrolysis gas disappeared and allowed to cool to room temperature.

The characteristics of biochars are given in Table 2. The pH and EC were measured in biochar and deionized mixture (1:10; wt wt^{-1}) using an Orion 720 pH-EC meter electrode. Total carbon (C) and nitrogen (N) contents of biochar materials were analyzed using a Leco CN-2000 analyzer (Leco Corp., St. Joseph, MI, USA) at 1200 °C. Specific surface area was determined using the method described by Cerato and Lutenegger (2002). Ammonium acetate method of Chapman (1965) was used to determine the cation exchange capacity of biochars.

Table 1. Selected basic properties of soils used in the experiment

Property	Soil 1*	Soil 2**
pH	8.22	8.15
EC (dS m^{-1})	0.17	0.17
$CaCO_3$ (%)	2.36	5.98
Organic Matter (%)	1.13	0.75
Sand (%)	40.6	65.0
Silt (%)	39.2	23.0
Clay (%)	20.2	12.0
Texture Class	Loam	Sandy Loam

*: Hereinafter will be written as loamy soil, **: hereinafter will be written as sandy loam soil; EC: Electrical Conductivity

The C:N ratio of rice, corn and bean biochar were 124, 110 and 416, respectively. The pH values of bean residue, rice husk Aand corn cobs biochars were 12.1, 10.2 and 9.21, respectively. The biochars were enriched with dairy effluent (DE) as described by Sarkhot et al. (2013). The DE was homogenized by centrifugation at 8000 rpm for 10 min and mixed with the biochars (2 mm diameter). The ratio of optimum biochar/DE ratio was 1 kg biochar/3 L DE. The enriched biochars were dried in room temperature and mixed with the experimental soils. Nutrient content of dairy effluent

Table 2. Some physical and chemical properties of biochars used in the study (N, C, P, K, Fe and Zn concentrations are total values)

Biochar	CEC	Surface Area	N	C	C/N	P	K	Fe	Zn	pH	EC
	me 100 g^{-1}	$m^2 g^{-1}$	%	%		%	%	mg kg^{-1}			dS m^{-1}
Bean	74.7	118	0.19	79	416	0.56	3.65	2247	80	12.1	8.75
Rice	15.2	212	0.45	56	124	0.01	0.39	308	37	10.2	3.29
Corn	10.0	398	0.77	85	110	0.04	0.95	321	84	9.21	9.30

CEC: Cation Exchange Capacity; EC: Electrical Conductivity

is given in Table 3. The amount of biochar and DE in 1.0% biochar treatment was 2.25 t ha^{-1} biochar and 67.50 t ha^{-1} DE which supplies approximately 3.04 kg NH_4-N ha^{-1}, 8.76 kg NO_3-N ha^{-1}, 0.38 kg P ha^{-1}, 26 kg K ha^{-1}, and 0.04 kg Zn ha^{-1}, respectively (Günal, 2018).

2.2. Pot experiment

The experiment was carried out in a greenhouse at Tokat Gaziosmanpasa University in Tokat province, Turkey (40.33 °N, 36.47 °E, 640 m above sea level). The size of pots used in the experiment was 2.25 L (17 x12 x 16 cm), and 1.7 kg of sandy loam and loamy soils were filled into the pots. The layout of the experiment was a factorial with 3 replicates and the experiments were repeated in two different seasons. Biochars were applied only at the beginning of the first experiment. Mineral fertilizers were dissolved in pure water and the solutions were applied at the beginning of each experiment. Soil, biochar and nutrients were mixed, and transferred to the plastic pots. Particle size distribution of soils (sandy loam and loam) was main factor, the sub factor was the biochar types. The treatments were; 2 particle size distributions, 3 biochar types, 5 biochar doses and 5 fertilizer doses (Table 4). Biochar doses were considered as the sub-sub factor, and the rates of mineral fertilizers were sub-sub-sub factor in the experiment. Nitrogen was applied as NH_4NO_3, and P was as $CaH_4O_8P_2$. In addition, 50 mg K kg-1 (K_2SO_4), 2 mg Zn kg-1 ($ZnSO_4.7H_2O$) and 2 mg Fe kg-1 (Fe-EDTA) were applied in all treatments. Wheat seeds were sown on October 28 and March 16 in the first and second experiments, respectively. Deionized water was used in irrigation and soil moisture was kept close to field capacity. The harvest in both seasons was carried out at stem elongation stage.

Table 3. The average NO_3^- and NH_4^+, P, K and Zn concentrations of dairy effluent used in the study

NH_4-N	NO_3-N	P	K	Zn	pH
mg kg^{-1}					
450	1300	58	483	6.0	7.24

2.3. Data analysis

The distribution of data was checked prior to statistical analysis. All the data used had normal distribution. Since the experiment had four treatments, 4-way analysis of variance (ANOVA) was used to determine the effects of the treatments on dry matter yield. The mean values obtained for different treatments were grouped using Least significant difference test (LSD $p<0.05$). Statistical analyses were performed using SPSS 21 (SPSS Inc., Chicago, IL, USA).

Table 4. The treatments used in the study

Biochar Type	**Bean residue**	**Corn cobs**	**Rice husk**		
Soil Type	Loamy	Sandy loam			
Biochar Dose (%)	0 (BR1)	0.5 (11.25 ton ha^{-1}); (BR2)	1.0 (22.5 ton ha^{-1}); (BR3)	2.0 (45 ton ha^{-1}); (BR4)	3.0 (67.5 ton ha^{-1}); (BR5)
Nutrient Dose	Biochar saturated with dairy effluent (BDE) without mineral fertilizers; (FR1)	BDE+1/4th of fertilizer needed for wheat (50 mg N kg^{-1} and 25 mg P kg^{-1}); (FR2)	BDE+1/2 fertilizer (100 mg N kg^{-1}, 50 mg P kg^{-1}); (FR3)	BDE+complete fertilizer (200 mg N kg^{-1} and 100 mg P kg^{-1}); (FR4)	Biochar without DE with complete fertilizer (200 mg N kg^{-1} and 100 mg P kg^{-1}); (FR5)

3. Results and Discussion

The effects of biochar type (BC), biochar dose (BR) and fertilizer dose (FR) and soil type on dry matter yield (DM) of wheat plants were statistically significant ($P<0.01$). The DM yield in the first period (232.47 mg $plant^{-1}$) was significantly higher (17.8%) compared to the second period. The difference between two periods can be attributed to the application of biochars at the beginning of the first period and enrichment of biochars with nutrient rich dairy effluent (DE). The DE applied to biochars was rich in nitrogen, phosphorus and potassium (Table 3). In addition, the bean biochar contained significant amounts of phosphorus (0.56%), potassium (3.65%) and iron (2247 mg kg^{-1}) (Table 2). Therefore, significant difference between two periods can be attributed to high nutrient contents of biochars in addition to nutrient rich DE enrichment of biochars.

3.1. Effects of individual factors on dry matter yield of wheat

The effects of BC, BR, FR and soil type on the DM yield of wheat plants are given in Figure 1-3. In both periods, all individual treatments had significant ($P<0.05$) effect on DM yield of wheat. Numerous conflicting research reports have been published on the effects of biochar applications on plant growth. In a one-year greenhouse experiment, Kloss et al. (2014) reported that 3 different biochars obtained from wheat straw, mixed wood pieces and vineyard pruning wastes reduced the yields of barley and mustard, while the effect on alfalfa was not significant (Kloss et al., 2014). The findings of Borchard et al. (2014) in a greenhouse experiment and Güereña et al. (2013) in a field experiment indicated no significant effect of biochar application on maize yield. In another study, Sänger et al. (2017), who applied wood and corn silage biochars together with nitrogen fertilizer in a 3-year field experiment established using a sandy soil, reported no significant effect of biochar applications winter wheat, winter rye and corn yields. In addition, the researchers did not report a significant interaction in the nitrogen fertilizer applications. In contrast, some studies reported an increase in crop yield with the application of a biochar enriched with nutrients (Reverchon et al., 2014). Contrary to the reports stating a nonsignificant effect of biochars on plant growth and crop yield, Liu et al. (2017) showed that application of biochar produced from pyrolysis of wheat straw at 450 ºC, caused an increase in the yields of corn, soybean and peanut grown both monoculture and as intermediate cultivation compared to non-biochar treatment. The researches stated that maize yield increased by 6.1 and 6.8% in 20 and 40 tons ha^{-1} biochar applications under monoculture and by 9.0 and 11.1% in corn/soybean intermediate crop systems. In the same study, soybean yield increased by 7.2 and 7.6% under monoculture and 14.7 and 13.7% under intermediate cropping system.

3.1.1. Soil type

The DM yield of wheat grown in two soils with different textures regardless of biochar type, biochar dose and fertilizer dose is shown in Figure 1a. The average DM yield recorded in loamy and sandy loam soils was significantly different in both periods. The DM in sandy loam soil, which was poor in nutrients and contained 65% sand (Table 1), at the end of the first period was 268 mg $plant^{-1}$, while the DM yield decreased to 161 mg $plant^{-1}$ in the second period. The DM yield in loamy soil at the first period was 47.8% lower compared to sandy loam soil, while the DM yield at the second period increased by 18.2% compared to the first period. The DM yield at the second period for loamy soil was 36.9% higher than that of the sandy loam soil. The results revealed that sandy loam soil responded much faster to biochar and liquid fertilizer applications in the first period compared to loamy soil. The positive effect of biochar applications in loamy soil, which had a finer texture, continued in the second period. The positive effect of biochar applications on DM yield was almost completely diminished in the second growing period for sandy loam soil. Biochar application probably improved the availability of plant nutrients, which are critical in improving wheat growth, especially on infertile soil (Xu et al., 2015) as in sandy loam soil. Short term benefits of biochar application in coarse textured soils due to the increase in available nutrient contents have also been reported by Omondi et al. (2016).

3.1.2. Biochar type (BC)

The effect of BC on DM yield was statistically significant in both periods, but in a different manner (Figure 1b). The DM yield in the second period for three biochar types significantly decreased compared to the first period. The highest mean DM yield in the first period (245 mg kg^{-1}) was obtained in bean biochar applications, while the highest DM yield in the second period was recorded in rice biochar applications (201 mg kg^{-1}). Bean biochar contained a higher available P, K and Fe contents compared to corn and rice biochars (Table 2). The nutrients in bean biochar transferred to the soil in the first period increased the DM yield in bean biochar applications. The results reported by Lentz and Ippolito (2012) are in agreement with our findings. The researchers sated that biochars produced from feedstocks rich in nutrients promote plant growth especially on soils with low nutrient contents. The decrease in mean DM yield in the second period was 26.9% for bean, 14.1% for rice and 9.9% for maize biochar applications.

3.1.3. Biochar application rate (BR)

The effect of BR regardless of soil, BC and FR on wheat DM yield is shown in Figure 2. The lowest mean DM yield in the first period was obtained from the control (BR1) treatment (220 mg $plant^{-1}$) and the DM yield compared to BR1 increased by 55.5% in BR2 (232 mg $plant^{-1}$) and 9.6% in BR3 (241 mg $plant^{-1}$). Further increase in biochar dose increased the DM yield by 8.9% in the BR4 (239 mg $plant^{-1}$) and by 5.3% in BR5 (231 mg $plant^{-1}$) compared to BR1. However, the DM yield in BR4 and BR5 treatments was decreased slightly compared to the DM yield in the BR3. In the second period, the mean DM yield in BR2 (201 mg $plant^{-1}$) and BR3 (200 mg $plant^{-1}$) doses were 2.6% and 2.0% higher than the mean DM yield in BR1 (196 mg $plant^{-1}$). The mean DM yield in BR4 (188 mg $plant^{-1}$) and BR5 (170 mg $plant^{-1}$) doses decreased by 4.4% and 13.1% compared to the BR1. Prapagdee and Tawinteung (2017) reported that excessive biochar application may cause a decrease in yield and a long-term alkalinity problem in soils due to the high alkalinity nature of biochar materials. The researchers pointed out that very low biochar application doses would not meet the nutrient requirements of crops for an optimum growth and yield. Conflicting results have been published on the increase in biochar dose and the changes in crop yield. Gaskin et al. (2010) investigated the effects of biochar produced from peanut shells and pine wastes on nutrient uptake and maize yield for two growing periods. Similar to our findings, increasing doses of pine biochar (doses 0, 11 Mg ha^{-1} and 22 Mg ha^{-1}) caused a decrease in corn yield in the first year of the experiment, and the highest dose (22 Mg ha^{-1}) of peanut shell biochar caused a significant decrease in yield.

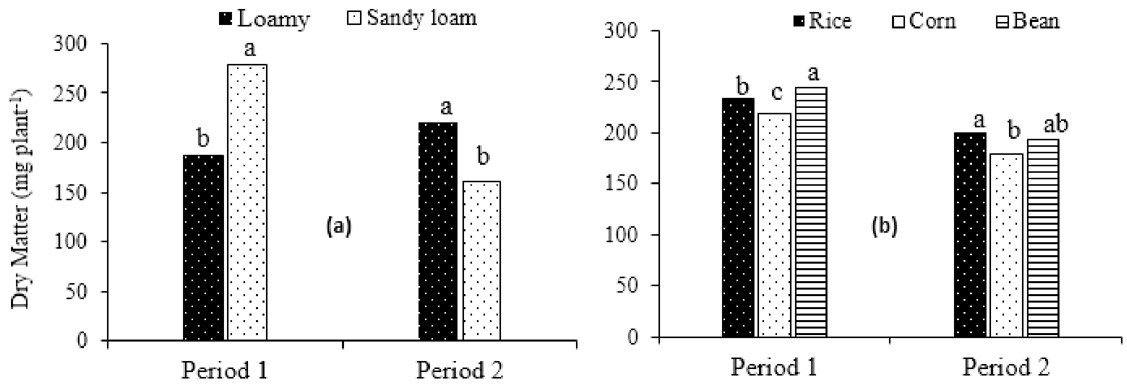

Figure 1. Effects of biochar applications on dry matter yield (mg plant^{-1}) in (a) two different soils, and (b) three different biochar types. Histogram bars labeled by the same letters are not significantly different (p<0.05).

3.1.4. Fertilizer application rate (FR)

The effect of FR treatments on DM yield was statistically significant (P<0.05) (Figure 3). The lowest mean DM yield (185 and 88 mg plant-1) in both periods was obtained in FR1 treatment that composed of biochar saturated with DE. The result clearly showed that biochars saturated or not saturated with DE do not meet the nutrient requirement of crops. The highest DM in the first period was obtained in FR4 and FR5 treatments (278 and 281 mg plant-1, respectively). In FR4 and FR5 treatments, all the nutrients required for wheat growth were added to soil as mineral fertilizers. In the second period of the experiment, the DM yield in the FR1 treatment decreased by 52.4% compared to the first period. The DM yield in the second period increased regularly with the increase of fertilizer rate until FR3 (254 mg plant-1) treatment, while the DM significantly decreased in FR4 and FR5 treatments (Figure 3). The results of Khan et al. (2021) were consistent with our findings. They also reported statistically higher wheat dry matter in full fertilizer dose (104 kg N ha−1) either with biochar alone or biochar enhanced with biofertilizers.

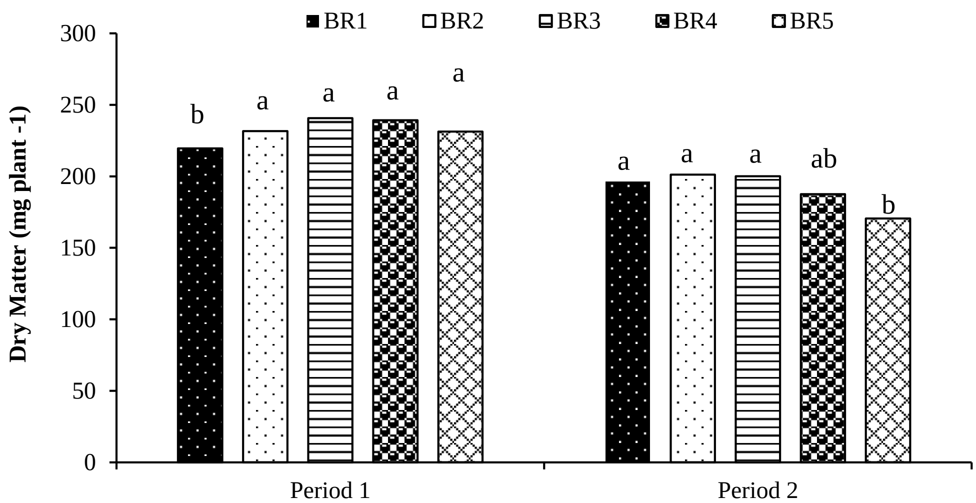

Figure 2. Effects of biochar doses on dry matter yield of wheat plants (mg plant^{-1}) in two different periods BR1, Control (%0 Biochar); BR2, %0.5 Biochar; BR3, %1.0 Biochar; BR4, %2.0 Biochar; BR5, %3.0 Biochar. Histogram bars labeled by the same letters are not significantly different (p<0.05).

3.2. Effects of interactions on dry matter yield of wheat

3.2.1. Interactions of factors on dry matter yield of wheat

In the first period, all interactions, except soil x BR and soil x BC x BR x FR, did not have a statistically significant effect on the DM yield. In the second period, the interactions of soil x BR, BC x BR, soil x BC x BR, soil x BR x FR, BC x BR x FR and soil x BC x BR x FR did not have a significant effect on the DM yield, while all other interactions had a significant effect on the DM yield. Biochar and accompanying DE applied at the beginning of the first period increased the DM yield. The amount of nutrients transferred to soil from these sources decreased in the second year. Therefore, the differences between the growing periods can be attributed to the effect of residual nutrients from these sources, and the improvement of soil physical properties due to the biochar applications (Gunal et al., 2018).

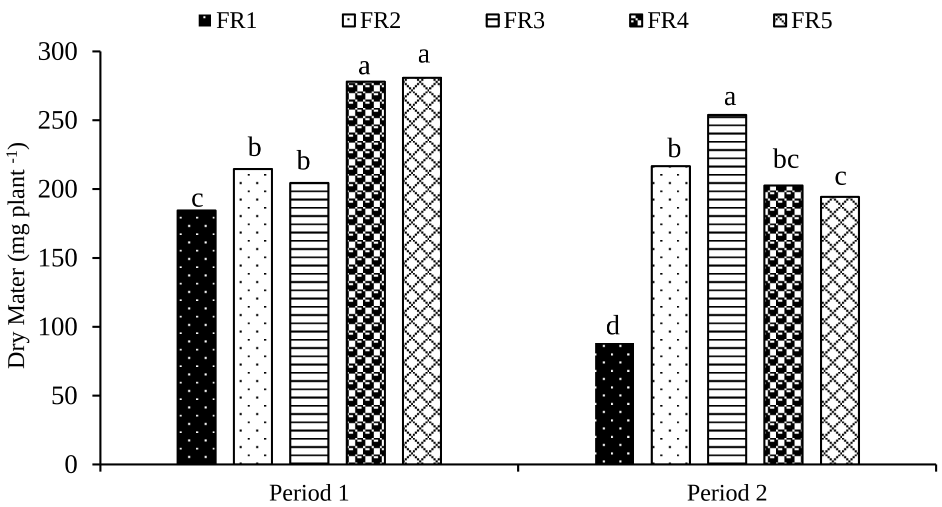

Figure 3. Effects of fertilizer doses on dry matter yield (mg plant^{-1}) of wheat plants in two different periods FR1 control biochar saturated with dairy effluent without mineral fertilizers; FR2 biochar saturated with dairy effluent (BDE)+1/4 of mineral fertilizer; FR3 BDE+1/2 fertilizer; FR4 BDE+complete fertilizer and FR5 biochar without dairy effluent but with complete fertilizer. Histogram bars labeled by the same letters are not significantly different (p<0.05).

3.2.2. Interaction of soil type and biochar type

The effects of BC on DM yield in two different soils regardless of BR and FR are shown in Figure 4. In the first period, the DM yield in sandy loam soil was between 267 (corn) and 291 mg plant^{-1} (rice), while the DM yield ranged from 171 (corn) to 215 mg plant^{-1} (bean) in loamy soil. The DM yield in the second period decreased significantly in all biochar types applied to sandy loam soil compared to the first period. Contrary to sandy loam soil, the DM yield recorded in loamy soil at the second period significantly increased in all biochar types compared to the first period. In sandy loam soil, the increase in available nutrients contents with biochar applications significantly increased the wheat growth in the first period. The addition of biochar not only increases the nutrient contents in soil, but also promotes the activities of soil microorganisms responsible for activating nutrients in the soil (Schmalenberger and Fox, 2016). Similarly, Subedi et al. (2017) also reported that biochar applications increased the availability of nutrients and contributed positively to crop yield by promoting root development. The lowest DM yield in both soils was obtained in corn biochar applications (Figure 4). Biederman and Harpole (2013), who reviewed 114 independent publications including 371 studies investigating the effects of biochar on crop production and nutrient cycle, showed that possible effects of biochar applications on plant growth has been associated with various factors. In this study, significant effect of biochar on wheat DM yield in two different soils is closely related to soil properties such as the particle size distributions, cation exchange capacities, water holding capacities, and clay type of soils used in the experiments.

3.2.3. Interactions of Soil Type and Biochar Application Rate

The mean values of DM yield recorded in soil x BR interactions for different biochar types are given in Table 5. In the first period, the DM yield obtained in sandy loam soil for all biochar doses was significantly higher than the DM in loamy soil. The highest DM yield in both soils was obtained in BR3 and BR4 doses, while the lowest DM was recorded in BR1. The DM yield increased up to BR3 and was almost stable at BR4 dose, but decreased at higher dose in both soils. Biochar application provided greater benefits to coarse-textured soil compared to the fine textured soil. The DM yield in sandy loam soil for all biochar doses was higher than the DM yield in loamy soil. The decrease in DM yield with BR5 dose compared to BR4 was 1.3% in loamy soil and 4.7% in sandy loam soil. Negative impacts of excessive biochar application on plant growth have been attributed to the immobilization of nitrogen due to high volatile content, toxic or harmful substance content, increased alkalinity and low microbial activity and nutrient uptake at high biochar doses (Ding et al., 2016). In the second period, the DM yield increased in loamy soil for all biochar doses compared to the first period, while the DM yield decreased significantly in sandy loam soil. The DM yield did not change significantly in BR1, BR2 and BR3 doses in loamy soil, but the DM yield decreased significantly in BR4 and BR5 doses. In sandy loam soil, the difference in DM yield between BR doses was not statistically significant. The lowest DM yield (170 mg plant^{-1}) was obtained in BR5, while the highest DM yield (148 mg plant^{-1}) was recorded in BR2 dose.

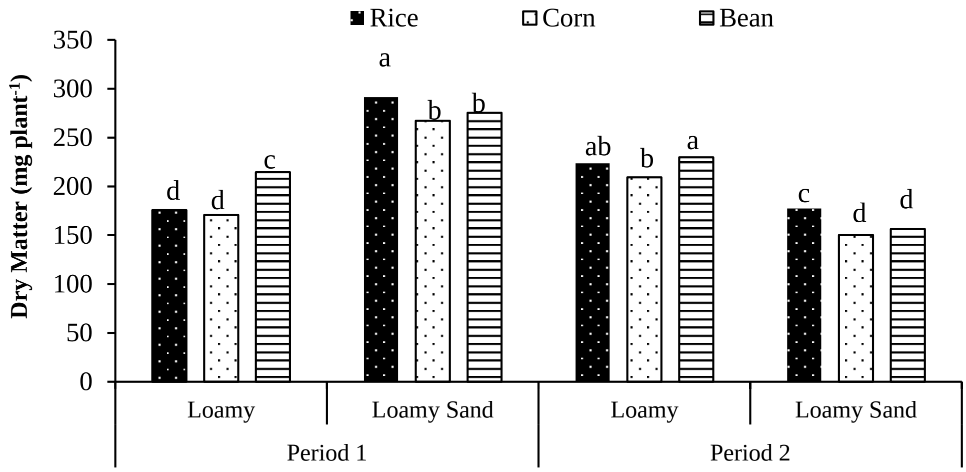

Figure 4. Effects of biochar types on dry matter yield (mg plant^{-1}) of wheat plants grown in loamy and sandy loam soils. Histogram bars labeled by the same letters are not significantly different (p < 0.05).

3.2.4. Interactions of soil type and fertilizer application rate

The highest DM yield in both soils was obtained in FR4 and FR5 doses, and the lowest in FR1 dose in the first period. The DM yield difference between FR4 and FR5 doses (full fertilization) in both soils was not statistically significant. In addition, the effect of full fertilization compared to FR1 was greater in loamy soil compared to sandy loam soil (Table 5). The DM yield in FR5 dose was 144 and 13.6% higher in loamy and sandy loam soils compared to control (FR1) where only DE was applied. Similar to the first period, the lowest DM yields in the second period were recorded in FR1 (82 and 94 mg plant^{-1} in loamy and sandy loam soils). The DM yield in loamy soil was 82 mg plant^{-1} in FR1 and increased to 274 mg plant^{-1} in FR3 dose. The DM yield slightly decreased at higher fertilizer doses. The changes in DM yield in sandy loam soil with the increase in FR was similar. However, the decrease in DM yield with FR4 and FR5 treatments compared to FR3 was 40 and 45%.

Table 5. The effects of soil type x biochar application rate (BR) and soil type x fertilizer application rate (FR) interactions on dry matter yield (mg plant^{-1})

	Period 1		Period 2	
	Loamy	**Sandy loam**	**Loamy**	**Sandy loam**
BR1	171 f	268 c	**232 a**	161 d
BR2	182 ef	282 ab	**232 a**	170 cd
BR3	196 d	**285 a**	**232 a**	168 cd
BR4	194 d	**284 a**	**215 a**	160 d
BR5	192 de	271 bc	193 b	148 d
SxBR (P value)	0.0835^{ns}		0.4641^{ns}	
FR1	**109 e**	260 c	**82 e**	**94 e**
FR2	150 d	279 b	221 bc	212 c
FR3	143 d	266 c	**274 b**	234 b
FR4	266 c	290 ab	**265 a**	140 d
FR5	267 c	**295 a**	**262 a**	127 d
SxFR (P value)	0.001		0.001	

Means followed by different letters are significantly different by each other P < 0.05.

3.2.5. Interaction of biochar type and biochar application rate

The effect of five different biochar doses of three different biochar types on DM yield of wheat was significant in the first period, while it was not significant in the second period (Table 6). The highest mean DM yield was obtained in BR3 x bean (261 mg plant-1), BR4 x bean (256 mg plant-1), BR2 x bean (247 mg plant-1) and BR5 x rice (245 mg plant-1) interactions. The lowest DM yield in the first period was obtained in rice x BR1 (214 mg plant-1) and maize x BR5 (215 mg plant-1) treatments. The DM yields obtained for other biochar doses, except for BR5, of bean biochar applications were higher than rice and corn biochars. The DM yield increased with the increasing rice biochar doses, and the DM yield, which was 214 mg plant-1 in the control treatment, increased to 245 mg plant-1 with BR5 dose. Corn biochar doses did not have a significant effect on the DM yield. Application of BR2 and BR3 corn biochar doses slightly increased the DM yield, further increase in biochar doses caused a decrease the DM yield. The DM yield at BR5 dose was lower than the DM yield in control treatment. The DM yield in bean biochar increased up to BR3, similar to corn biochar, and the DM yield decreased significantly at higher doses. Olmo et al. (2016) reported that high biochar (produced from olive tree pruning wastes) doses caused an increase in the specific root length of wheat, regardless of the fertilization level, while the root diameter and root tissue mass density decreased, resulting in an increase in fine roots. The results have been associated with biochar-root interaction and increased fertilizer efficiency. In contrast to the effects of biochar produced from olive tree pruning waste, biochar produced from wheat straw did not cause any positive effect on rot development. In this study, the DM yield increased with increasing bean biochar doses, however, a similar effect was not observed in corn biochar applications.

In the second period, the lowest DM yield was obtained in corn x BR5 (157 mg plant-1) and the highest DM yield was in rice x BR2 (213 mg plant-1) interactions (Table 6). The effects of rice and bean biochar doses on DM yield were similar. The DM yield increased slightly with the increase in BR, but the DM yield decreased significantly in high doses of biochar applications. Increasing dose of corn biochar led to a decrease in DM yield. The mean DM yield in BR1 was 198 mg plant-1 which was decreased by 20.6% in BR5 and became 180 mg plant-1 (Table 6)

3.2.6. Interaction of biochar type and fertilizer application rate

The effect of BC x FR interactions in two different soils on DM yield was significant in both growing periods (Table 6). The highest DM yield in the first period was recorded in bean x FR4 (291 mg plant^{-1}) and the lowest DM yield was in corn x FR3 (172 mg plant^{-1}), FR1 (178 mg plant^{-1}) and FR2 (188 mg plant^{-1}) interactions. The highest DM yield in rice and corn biochars was obtained in FR5 dose. In the second period, the highest DM yield (272 mg plant^{-1}) was obtained in rice x FR3 interaction, while the lowest DM yield was recorded in FR1 treatment of bean, corn and rice biochars. The DM yield increased regularly in all three biochar types until FR3 dose and decreased in higher doses.

Table 6. Effects of biochar type x biochar dose (BR) and biochar type x fertilizer dose (FR) interactions on dry matter yield (mg plant^{-1})

	Period 1			Period 2		
	Rice	**Corn**	**Bean**	**Rice**	**Corn**	**Bean**
BR1	**214 g**	219 fg	227 d-g	203 abc	198 a-d	188 b-e
BR2	228 def	219 fg	247 abc	**213 a**	190 a-d	200 abc
BR3	238 cd	223 fgh	**261 a**	206 ab	189 b-e	206 ab
BR4	243 bc	219 fg	256 ab	201 abc	165 ef	197 a-d
BR5	245 bc	215 fg	234 cde	180 c-f	**157 f**	175 def
BC x BR (P value)	0.001			0.5481^{ns}		
FR1	189 f	178 fg	187 f	**100 e**	**85 e**	**80 e**
FR2	219 e	188 f	236 d	248 b	209 c	193 cd
FR3	207 e	**172 g**	234 d	**272 a**	235 b	254 ab
FR4	272 bc	271 c	**291 a**	190 cd	180 d	237 b
FR5	280 abc	285 ab	277 abc	193 cd	188 cd	201 cd
BC x FR (P value)	0.001			0.001		

Means followed by different letters are significantly different by each other P < 0.05.

3.2.7. Interaction of biochar application rate and fertilizer application rate

The mean values of DM yield in BR x FR interactions are given in Table 7. In the first period, the highest average DM yield was obtained in BR3 x FR4 (294 mg plant^{-1}) interactions. However, the lowest average DM yield was recorded in BR1 x FR3 (171 mg plant^{-1}) interactions. Although there are some exceptions, the DM yield of wheat in almost all biochar doses increased regularly with the increase in fertilizer dose. In the second period, the DM yield decreased significantly in all BR x FR interactions compared to the first period. The highest DM yield (275 mg plant^{-1}) was recorded in BR2 x FR3 interaction, while the lowest DM yield (73 mg plant^{-1}) was in FR1 treatments where only dairy effluent was used.

3.2.8. Interaction of soil type, biochar type and biochar application rate

The interaction of five different doses of three different biochars in two different soils had significant effect (P<0.01) on DM yield of wheat (Table 8). In the first period, the highest DM yields were obtained in sandy loam soil for rice x BR5 (309 mg plant^{-1}) and rice x BR4 (305 mg plant^{-1}) interactions. Different doses of rice and corn biochars in loamy soil did not have a significant effect on DM yield. The DM yield was 171 mg plant^{-1} in corn x BR1 interaction, and it was 174 mg plant^{-1} in corn x BR5 interactions. Corn biochar did not have a significant effect on DM yield in sandy loam soil either. The mean DM yield in BR3 (274 mg plant^{-1}) slightly increased compared to the control (267 mg plant^{-1}), however, the DM yield in BR5 dose (256 mg plant^{-1}) was lower than the control. The highest yield in loamy soil with bean biochar was obtained in BR4 dose (235 mg plant^{-1}), while the highest yield in sandy loam was obtained in BR3 dose (256 mg plant^{-1}) (Table 8). The results show the importance of soil texture in determining the most appropriate dose.

Table 7. Effects of biochar application rate (BR) x fertilizer application rate (FR) interaction on dry matter yield (mg plant^{-1})

Period 1					
	BR1	**BR2**	**BR3**	**BR4**	**BR5**
FR1	172 jk	184 ijk	193 ghi	190 hij	182 ijk
FR2	193 ghi	209 fg	219 ef	224 ef	229 e
FR3	**171 k**	194 ghi	207 fgh	228 e	222 ef
FR4	280 abc	283 abc	**294 a**	275 bcd	258 d
FR5	282 abc	288 ab	290 ab	280 abc	265 cd
BR x FR (P value)	0.001				
Period 2					
FR1	**73 h**	**88 h**	**90 h**	**89 h**	**101 h**
FR2	222 b-e	214 cde	218 cde	215 cde	214 cde
FR3	252 ab	**275 a**	**271 a**	238 bc	233 bcd
FR4	220 cde	202 def	223 b-e	196 ef	172 f
FR5	213 cde	227 b-e	199 ef	200 ef	133 g
BR x FR (P value)	0.001				

Means followed by different letters are significantly different by each other P < 0.05.

In the second period, the highest DM yield (245 mg plant^{-1}) was obtained in loamy x bean x BR3 interaction, while the lowest DM yield (121 mg plant^{-1}) was recorded in sandy loam x corn x BR5 interaction (Table 8). The DM yield difference between rice and bean biochar doses was not significant in sandy loam soil, except corn x BR5 interaction which led to a significantly lower DM yield compared to other interactions.

Table 8. The effects of soil type x biochar type x biochar application rate (BR) interaction on dry matter yield (mg plant^{-1})

Period 1						
	Loamy			**Sandy loam**		
	Rice	**Corn**	**Bean**	**Rice**	**Corn**	Bean
BR1	**159 k**	171 jk	183 jk	268 cde	267 cde	271 b-e
BR2	166 jk	170 jk	209 hi	291 abc	269 cde	285 abc
BR3	191 ij	173 jk	226 gh	285 abc	274 b-e	296 ab
BR4	181 jk	167 jk	235 fgh	**305 a**	271 b-e	277 bcd
BR5	181 jk	174 jk	220 h	**309 a**	256 def	248 efg
SxBCxBR (P value)	0.001					
Period 2						
BR1	222 a-e	**241 ab**	233 abc	185 e-h	154 ghi	143 hi
BR2	**240 ab**	221 a-e	235 abc	187 d-h	160 ghi	1658 ghi
BR3	235 abc	217 a-f	**245 a**	176 e-h	161 ghi	167 gh
BR4	230 a-d	175 fgh	240 ab	171 g-h	155 ghi	153 ghi
BR5	191 c-g	193 c-g	196 b-g	168 g-h	**121 i**	154 ghi
SxBCxBR (P value)	0.1277^{ns}					

Means followed by different letters are significantly different by each other P<0.05.

3.2.9. Interaction of soil type, biochar type and fertilizer application rate

The interactions of soil type x biochar type x fertilizer application rate (FR) had a statistically significant effect on DM yield in both growing seasons (Table 9). The highest DM yield in the first period was obtained in sandy loam x rice x FR2 (305 mg plant^{-1}) and FR5 (304 mg plant^{-1}) interactions (Table 9). The increase in the amount of fertilizers in both soils caused an increase (with some exceptions) in the DM yield for all biochar types. The highest DM yields were mostly obtained in FR4 and FR5 applications. The result indicates that biochar applied with or without DE does not supply the nutrients needed by wheat plants. Alburquerque et al. (2013) reported that addition of biochar alone to a nutrient-poor sandy loamy soil had a little effect on wheat yield in the absence of mineral fertilization. However, wheat grain yield increased approximately 20-30% with the addition of biochar at the highest mineral fertilizer ratio compared to the use of mineral fertilizers alone. In consistent with the findings of Alburquerque et al. (2013), the highest DM yield in the second period was obtained at loamy x bean x FR3 (303 mg plant^{-1}) and FR4 (302 mg plant^{-1}) interactions. In this period, the lowest DM yield was recorded in FR1 applications for both soil types.

3.2.10. Interaction of soil type, biochar application rate and fertilizer application rate

The effect of BR x FR interaction on DM yield was significant (P<0.01) in two different soils (Table 10). In the first period, the DM yield in loamy soil under control (FR1) treatment was quite low compared to sandy loam soil. The lowest DM yield was obtained in loamy x BR1 x FR1 (93 mg plant^{-1}) and FR3 (95 mg plant^{-1}) interactions, and the highest

DM yield was recorded in sandy loam x BR3 x FR4 (307 mg plant^{-1}) interaction. Mean DM yield in loamy soil at FR1 and FR3 was similar. However, the DM yield in FR4 and FR5 treatments was 189.5 and 199% higher compared to FR3 dose. Co-application of fertilizer with biochar has improved the utilization of plant nutrients in soils. The DM difference between FR1 and FR3 in BR1 application was negligible (2.1%), while the difference in DM yield between FR1 and FR3 doses in BR2 was 12.8%, 24.4% in BR3, 48.8% in BR4 and 55.2% in BR5 (Table 9). The increase in the DM yield difference between the fertilizer doses indicates that the availability of nutrients increases with the increase in the biochar doses. The biochars produced from wood and agricultural crop wastes are generally low in plant nutrients. However, previous studies have also revealed that enrichment of biochars with plant nutrients before application, or fertilizer application along with biochars increases the availability of nutrients and promotes plant growth (Deenik et al., 2010; Kammann et al., 2015).

Table 9. The effects of soil type x biochar type x fertilizer application rate (FR) interaction on dry matter yield (mg plant^{-1})

Period 1						
	Loamy			**Sandy loam**		
	Rice	**Corn**	**Bean**	**Rice**	**Corn**	**Bean**
FR1	**105 kl**	**98 l**	124 jk	274 b-g	257 e-h	249 g-h
FR2	133 j	119 jkl	198 i	**305 a**	257 e-h	274 b-g
FR3	125 jk	107 jkl	196 i	289 abc	238 h	272 c-g
FR4	259 d-h	257 e-h	282 a-e	285 abc	285 a-d	299 ab
FR5	256 fgh	272 c-g	272 cg	**304 a**	299 ab	282 a-f
SxBCxFR (P value)	0.001					
Period 2						
FR1	**82 kl**	**76 kl**	**90 k-l**	118 ijk	95 kl	**69 l**
FR2	213 d-g	239 b-e	211 d-g	282 ab	180 fgh	175 fgh
FR3	266 ab	253 bcd	**303 a**	278 ab	218 c-f	205 efg
FR4	274 ab	219 c-f	**302 a**	106 jkl	142 hij	172 gh
FR5	283 b	260 abc	243 b-e	103 jkl	117 ijk	160 hi
SxBCxFR (P value)	0.001					

Means followed by different letters are significantly different by each other P<0.05.

At the same biochar doses, the DM yield of wheat in FR1 treatments where biochars were saturated with DE and no mineral fertilizers applied, was significantly lower compared to the treatments with mineral fertilizers applied. High DM yield in biochar + fertilization applications, compared to only biochar application, clearly reveals that biochar should be considered as an additive that increases the availability of nutrients or improves soil properties, rather than acting as a fertilizer. Previous studies have also indicated that biochar improves physical properties and fertility of soils; thus increases wheat yield (Olmo et al., 2014).

The DM yield in FR1, FR2 and FR3 treatments where nutrients in soil were not sufficient for plant growth increased with the increase in the biochar doses. The DM yield in FR4 and FR5 treatments, where sufficient nutrients added as fertilizers, was significantly similar to the yield in BR1, BR2 and BR3 doses. However, the DM yield in BR4 and BR5 treatments was significantly lower than the DM yield in BR1 treatment. The decrease in DM yield especially at the BR5 dose compared to BR1 was 10.9 and 22.9% in FR4 and FR5 applications, respectively (Table 10). The difference in DM yield between biochar doses is also evident in published research reports. Yield increase with biochar application has been reported in many studies (Subedi et al., 2016; Usman et al., 2016; Genesio et al., 2015; De La Rosa et al., 2014; Lin et al., 2015; Laghari et al., 2015), however, some researchers reported that biochar did not affect the yield (Subedi et al., 2016; Tammeorg et al., 2014; Bass et al., 2016). Contrary to the increase or non-significant effect of biochar applications, some researchers reported that biochar applications cause a decrease in crop yield (Deenik et al., 2010; Marks et al., 2014; Nelissen et al., 2015; Bass et al., 2016; Laghari et al., 2015). The results revealed that the yield increase with biochar applications can vary significantly depending on the factors such as biochar, soil, crop, fertilizer, application doses of biochar and fertilizers and other environmental conditions.

In sandy loam soil, the mean DM yield between FR1 (252 mg plant^{-1}) and FR3 (247 mg plant^{-1}) applications was similar. The mean DM yield in FR4 and FR5 treatments compared to FR3 increased by 15.8 and 13.4%, respectively (Table 10). The DM increase in loamy soil was quite low compared to sandy loam soil. The DM yield in sandy loam soil unlike loamy soil increased in FR4 and FR5 applications with the increase in biochar doses. The aforementioned results clearly show that soil type is a very important factor in biochar applications. In the second period, the lowest mean DM yield was recorded in loamy x BR1 x FR1 (68 mg plant^{-1}), while the highest mean DM yield was obtained in loamy X BR2 X FR5 (310 mg plant^{-1}) and BR1 X FR4 (310 mg plant^{-1}) interactions. The lowest average DM yield was observed in FR1 treatment at all biochar doses in both soils. In loamy soil, the DM yield in FR1, FR2 and FR3 treatments increased with the increase in biochar doses, however, the increase in DM yield was less pronounced compared to the first period (Table 10).

Table 10. Effects of soil type x biochar dose (BR) x fertilizer dose (FR) interaction on dry matter yield (mg plant^{-1})

Period 1										
	Loamy					**Sandy loam**				
	BR1	**BR2**	**BR3**	**BR4**	**BR5**	**BR1**	**BR2**	**BR3**	**BR4**	**BR5**
FR1	**93 o**	**102 no**	115	121	116	252	267	271	260	248
FR2	**107 no**	134	164	161	184	278	283	274	287	273
FR3	**95 o**	115	143	180	180	247	274	271	276	264
FR4	275	275	281	252	248	286	291	**307 a**	298	268
FR5	284	282	279	258	231	280	294	**301ab**	**301ab**	**300abc**
SxBRxFR (P value)	0.001									
Period 2										
FR1	**68 r**	**76 qr**	89	**84pqr**	95	**78 qr**	100	90	93	107
FR2	225	209	228	216	228	220	219	207	215	200
FR3	266	**293 ab**	280	268	262	238	257	261	208	204
FR4	**310 a**	271	**285 abc**	248	211	130	133	161	144	133
FR5	**290 abc**	**310 a**	278	260	172	137	143	120	1403	93
SxBRxFR (P value)	0.1138^{ns}									

Means followed by different letters are significantly different by each other P<0.05.

3.2.11. Interaction of biochar type, biochar application rate and fertilizer application rate

Regardless of soil type, BC x BR x FR interactions had a significant (P<0.01) effect on DM yield in the first growing season, while it was not significant in the second degrowing period (Table 11). In the first period, the highest mean DM yield (319 mg plant^{-1}) was obtained in bean biochar x BR3 x FR4 treatments. The DM yield of wheat increased with the fertilizer applications at all biochar doses of rice biochar, and the highest DM yields were recorded in FR4 and FR5 treatments. Similar to rice biochar, the DM yield increased with the increase in fertilizer doses, except FR5 in bean biochar. In the second period, the lowest DM yield was obtained in bean biochar x BR1 x FR1 (56 mg plant^{-1}) interaction, while the highest DM yield was recorded in rice biochar x BR1 (305 mg plant^{-1}) and BR2 (299 mg plant^{-1}) x FR3 interaction.

Table 11. Effects biochar type x biochar dose (BR) x fertilizer dose (FR) interaction on dry matter yield (mg plant^{-1})

Period 1						
		BR1	**BR2**	**BR3**	**BR4**	**BR5**
Rice	**FR1**	**155 y**	194	194	201	203
	FR2	195	208	224	230	238
	FR3	178	191	194	230	242
	FR4	277	277	287	262	258
	FR5	262	272	290	291	286
Corn	**FR1**	183	171	196	180	**159 xy**
	FR2	184	186	193	185	194
	FR3	**165 wxy**	167	167	186	177
	FR4	264	271	277	260	283
	FR5	298	**302 ab**	283	285	260
Bean	**FR1**	179	189	190	1900	185
	FR2	199	232	239	257	255
	FR3	170	225	260	267	248
	FR4	300	**301 a-d**	**319 a**	**301 abc**	233
	FR5	285	289	298	263	250
Biochar typexBRxFR (P value)		0.0038				
Period 2						
Rice	**FR1**	82	100	107	103	106
	FR2	245	2467	242	262	243
	FR3	**305 a**	**299 a**	**269 a-d**	247	240
	FR4	201	184	200	195	171
	FR5	184	236	210	197	139
Corn	**FR1**	81	83	81	90	92
	FR2	242	203	206	190	205
	FR3	215	259	**279 ab**	202	222
	FR4	214	206	194	152	136
	FR5	236	202	183	192	129
Bean	**FR1**	**56 t**	**82 rst**	**82 rst**	**73 st**	105
	FR2	180	193	204	194	193
	FR3	237	268	265	265	237
	FR4	246	216	**274 abc**	241	209
	FR5	220	241	204	211	130
Biochar typexBRxFR (P value)		0.7621^{NS}				

Means followed by different letters are significantly different by each other P<0.05.

3.2.13. Interaction of soil type, biochar type, biochar application rate and fertilizer application rate

The interaction of four factors did not have a significant effect on DM yield in both periods (P=0.5601). The size of the table was too large; therefore, the table of 4-way interaction has not been presented in the paper. In the first period, the DM yield obtained in sandy loam soil with all treatment was significantly higher compared to loamy soil. The lowest DM yield was recorded in BR1 x FR1 (77 mg plant^{-1}) of rice biochar in loamy soil and BR1 x FR1 (83 mg plant^{-1}) of corn biochar in loamy soil. The highest mean DM yield was obtained in BR3 x FR4 (343 mg plant^{-1}) interaction of bean biochar, BR5 x FR5 (342 mg plant^{-1} and BR4 x FR5 (331 mg plant^{-1}) interaction of rice biochar in sandy loam soil. In the second period, the lowest mean DM yield was obtained in BR1 x FR1 interaction of bean biochar (42 mg plant^{-1}) in sandy loam soil and the highest mean DM yield in loamy soil was obtained in the BR2 x FR5 interaction of rice biochar (358 mg plant^{-1}). The results showed that the lowest mean DM yield in all biochar doses of biochar types applied in both soils was obtained in FR1 treatment.

4. Conclusions

Plant available nutrient contents of biochars can be increased by the use of dairy effluents, which may be otherwise could create serious environmental problems. Application of biochars enriched with nutrient rich dairy effluent along with mineral fertilizers needed by the crop improved wheat growth in addition to benefits for management of agricultural waste. The effects of a biochar on crop growth may vary depending on biochar application rate, nutrient contents of feedstock that is used in biochar production, and the characteristics of soil. Biochars produced from nutrient rich feedstocks may provide more nutrients to soil solution compared to the biochars poor in nutrients. The lowest dry matter yield in different biochar applied soils with different textures reveals that biochars alone should not be considered as fertilizers, but can used as soil improvers due to significant positive effects on availability of nutrients, activities of soil microorganisms, improvement of soil physical properties.

Declaration of Competing Interest

Elif Gunal and Halil Erdem declare that they have no competing interests.

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