



CO₂ Emissions and Soil Organic Carbon in Calcareous Soils as Affected by Bone char and Phosphate Rock



Maher. E. Saleh^{1*}, Ahmed A. El-Refaey² and Yasser A. El-Damarawy³

¹Department of Soil and Water Science, Faculty of Agriculture, Alexandria University, Postal Code 21545 El-Shatbi, Alexandria, Egypt

²Department of Soil and Water Science, Faculty of Desert and Environmental Agriculture, Matrouh University, MarsaMatrouh, Egypt

³Soils and Water Use Department, National Research Centre, Cairo, Egypt

THIS STUDY aims to identify the role of bone char (BC) application to calcareous soils in reducing CO₂ emission and improving soil fertility compared to phosphate rock (PR). The bovine bone was subjected to anaerobic thermal decomposition (pyrolysis) for two hours at a temperature of 650 °C to produce bone char. A closed-system incubation experiments were conducted to follow the CO₂ emission from the soil treated with BC or PR by rates 1.25 and 2.5%. CO₂ emissions were tracked over 90 days at two different ambient temperatures (15±2 and 27±2°C). Results of elemental composition of BC were similar to PR, but BC was characterized by the presence of organic carbon. The active surface groups of bone char are very similar to the phosphate rock groups, but the presence of organic matter resulted in the existence of C = C and O = C groups. Application of BC to soil increased phosphorus solubility and retention of CO₂ compared to phosphate rock (PR). Carbon dioxide (CO₂) immobilization was very high in high temperature (27±2°C) reached 3274-3870 mg/kg soil compared to 101-242 mg/kg soil in low temperature (15±2 °C) in BC-treated soils. BC application to the soil in winter increased the organic carbon from 1.1 to 1.52%, while the percentage dropped from 0.79 to 0.55 in high temperature, with increasing of the dissolved organic carbon form by 40-60 mg/kg soil.

Keywords: Bone char, Phosphate fertilizer, CO₂ emissions, Soil organic carbon, Calcareous soils.

Introduction

Greenhouse gases (GHG), as anthropogenic emitted gases, causing global warming (Ricke and Caldeira, 2014) are among major environmental threats issued by scientists and policymakers on a daily timescale around the world. Carbon dioxide (CO₂) represents the major partner of GHG (Tietenberg and Lewis, 2018). Its emissions are increasing continuously because of the economic development and nowadays it reaches a critical level of growth (Ridzuan et al., 2020). Accordingly, it is necessary to reduce CO₂ emission in all productive sectors, whether agricultural or industrial.

In the agricultural sector, organic residues are usually used to increase and sustain soil productivity (Getahun et al., 2020 and Schils et al., 2020), especially in low fertile soils (Elshony et al., 2020) and calcareous ones (Simpson and Simpson, 2017; Hye et al., 2019 and Motaghian et al., 2020). On the other hand, these amendments emit significant amounts of CO₂ upon their decomposition (Farid et al., 2018). Probably, such agricultural activities contribute to 30-35% of the global GHG emissions (Foley et al., 2011). Alternatively, the addition of pyroletic form of carbon to the soil, as a soil amendment, improves soil physical and chemical characteristics

*Corresponding author: maher.saleh@alexu.edu.eg.

DOI: 10.21608/ejss.2020.32612.1363

Received: 17/6/2020; Accepted: 9/9/2020

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(Mohamed and Hammam, 2019; Bassouny and Abbas, 2020); while; significantly reduces the emissions of carbon dioxide (CO₂) and other greenhouse gases into the atmosphere (Lin et al. 2015 and Chang et al. 2016). This is probably because carbon produced by pyrolysis has a significant adsorption capacity for greenhouse gases (Liu et al., 2019) and this may greatly increase the adsorption capacity of carbon and its long-term stabilization in soils.

Global high rates of consumption of phosphate resources (phosphate rocks) have led agricultural producers to seek alternative P-resources (Cordell et al., 2009 and 2011), especially that this non-renewable resource is going to deplete within 50 to 100 years (Ahmed et al., 2013 and Mukherjee et al., 2020). Animal bone is an important and renewable resource for calcium phosphate (Ahmed et al., 2013). Previous studies (Warren et al., 2009; Wang et al., 2012; El-Refaey et al., 2015 and Mahmoud et al., 2017) revealed that water soluble and available forms of phosphorus derived from the bone char (animal bone burned anaerobically for 2 hours at 650 °C) are much higher than of the corresponding ones detected in phosphate rock. These studies also showed that bonechar contains very low levels of some heavy metals such as cadmium (Cd), lead (Pb) and chromium (Cr) compared to phosphate rock, which adds another advantage for using bone char vs rock phosphate (Siebers and Leinweber 2013; El-Refaey et al. 2015). It is also known that bone char contains, in addition to its content of calcium phosphate as a major component, about 5.86% of organic carbon, which may also increase P-availability in soil when added as a phosphate fertilizer.

Organic matter in soil is important fraction in solid phase because of its beneficial properties which reflected on soil quality (Hayes and Swift, 2020 and FAO, 2005). On the other hand, dissolved organic matter plays a crucial role in improving nutrients availability and diminishes the reactivity of solid phase toward the nutrients immobilization in soil (Bolan et al., 2011). Based on the evidence

of bone char in the previous study (90% inorganic and 5.86% organic fractions, El-Refaey et. al., 2015), besides BC consideration as sustainable source of phosphorus, current study investigates its role in both reducing CO₂ emissions from soil and improving the levels of soil organic matter forms.

Materials and Methods

Bovine bones were collected from local slaughter shops, cleaned from meat residues and rinsed several times with distilled water, placed in porcelain vessels and isolated from oxygen by metal foil. The vessels were then transferred to the muffle furnace. The temperature was gradually raised to 650 °C and pyrolysis continued for two hours. After cooling to ambient temperature, the produced bone char was weighed to calculate the volatile biomass then crushed and sieved using 0.5-mm polypropylene sieve and stored in plastic jars. Phosphate rock (PR) was purchased from El-Nasr Mining Company, Aswan; Egypt. PR was treated for pyrolysis conditions similar to BC.

Bone char Characterization

The tested materials were analyzed for total P and Ca contents (Pansu and Gautheyrou, 2006). Total organic carbon in both BC and PR was determined by wet oxidation method according to Walkley-Black method (Nelson and Sommers, 1982). Total carbonate content was determined in BC and PR according to Pansu and Gautheyrou (2006). Other some selected physical and chemical properties were determined (Table 1). These properties included pH, surface area, and elemental analysis (CHNS),

Surface area measurements for the examined BC and PR were obtained from analysis of nitrogen adsorption isotherms at 77 °K using Beckman Coulter SA(TM) 3100 Surface Area and Pore Size Analyzer, Beckman Coulter, Nyon, Switzerland. Specific surface area (BET, Brunauer–Emmett–Teller) was determined from adsorption isotherms using the BET equation. The pore size distribution was determined by Barret–Joyner–Halender method from the N₂ desorption isotherms (Nader, 2015).

TABLE 1. Characteristics of bone char (BC) and phosphate rock (PR)

Total content, %	BC	PR
P ₂ O ₅	36.07	33.21
CaO	38.08	35.24
Ca/P	1.73	1.74
TOC	10.02	Nd*
N	1.95	0.18
Total carbonate	6.21	10.45
SSA (m ² /g)	117.00	9.30

* Nd: not detected

Total carbon, hydrogen, nitrogen content and sulfur in bone char were determined by CHNS analyzer (Elementar, Vario EL, Germany). Fourier transform-infrared (FTIR) technique was used to determine the surface functional groups of BC and PR samples. The tested materials were recorded in the range 400 – 4000 cm⁻¹ using SHIMATZU infra-red spectrophotometer, model FT/IR-5300, JASCO Corporation, Japan. Samples were prepared using KBr pellet method (Smith, 2011). X-ray diffraction (XRD) analysis was performed on BC and PR using SHIMATZU XRD-7000. The sample preparation for XRD followed the method described by Hughes et al. (1994).

The surface morphologies of the prepared bone char was examined by conducting a scanning electron microscopy (SEM) experiment using a Phillips SEM-505 scanning electron microscope (Phillips, Eindhoven, Netherlands). The micrographs were recorded at different magnification scales to characterize the morphology of the examined bone char.

Laboratory Incubation Experiment

Soil respiration study (a soil CO₂ efflux) was carried out under laboratory incubation for 90 days under ambient laboratory temperatures (15.0±2 in winter (Temp1) and 27±2 in summer (Temp2)). These experiments included two levels of BC or PR (1.25% and 2.5%). Soil sample for incubation experiments was taken from the top 15 cm of Bangar Essokkar area located in the northwest of the Nile Delta, Egypt (30°46'58.6"N and 29°33'53.4"E). Some physicochemical properties of the soil were analyzed in accordance with Pansu

and Gautheyrou (2006) and listed in Table 2. The soil has sandy texture with 93.44 % sand, a pH of 7.91 and electrical conductivity (EC) equals 0.9 dS/m (Table 2). Soil available phosphorus (Olsen P) was determined as described by Olsen et al., (1954) and Murphy and Riley (1962).

The air-dried soil was crushed and passed through 2-mm polypropylene sieve before used it in incubation experiment. A series of 500-mL Erlenmeyer flasks with 200 g of soil sample (on an oven-dried basis) were prepared. These flasks included control (only soil) and soil with two application rates of BC or PR (1.25% and 2.5%). Three replicates in each treatment and all materials were mixed well with the soil. Soil moisture content was adjusted to 60% of saturation percent by adding distilled water. All flasks were covered with aluminum foils to maintain darkness and prevent algae growth and sealed using an airtight butyl rubber stoppers perforated by centered Perspex tubes and flushed with steady flow of fresh air by air pump after passing onto sodium hydroxide solution, to prevent carbon dioxide from getting into the soil, as shown in Fig. (1).

The emissions of CO₂ from every flask were captured onto sodium hydroxide solution in order to determine CO₂ concentrations by titration with diluted hydrochloric acid (HCl). For continuously monitoring, CO₂ efflux concentrations were measured every 2 days. At the end of the experiments (90 days), a sample from each incubation flask was sampled and used for the determination of pH, dissolved organic carbon and total organic carbon. The pH was measured in a solid-to-water ratio of 1: 2.5 (McLean, 1982).

TABLE 2. Some soil physicochemical properties

Particle size distribution (%)			pH (1: 2.5)	EC (dSm ⁻¹)	O.M (g kg ⁻¹)	DOC %	CaCO ₃ %	Olsen P (mgkg ⁻¹)
Sand	Silt	Clay						
93.44	1.56	5.00	7.91	0.90	5.4	0.05	25.09	2.66

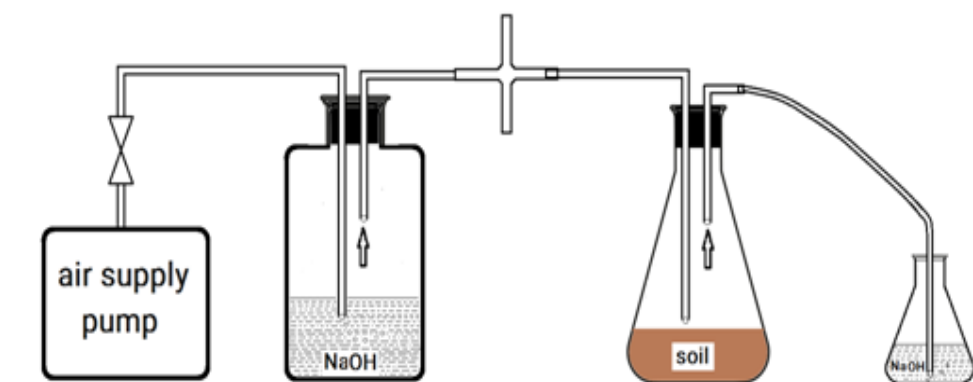


Fig. 1. Schematic diagram of designed laboratory experiment system

To measure concentration of dissolved organic carbon (DOC), 5 g soil (on an oven-dried basis) was suspended in 50 mL of distilled water and stirred for two hours at 200 rpm and filtered through 0.45 μm membrane filters (Gelman Sciences, USA). DOC concentration of extracts and total carbon content in soil samples was determined by oxidation method (Walkley-Black method) using potassium dichromate solution (0.50 M) and back titration of the excess dichromate by ammonium ferrous sulfate solution (0.50 M) in the presence of ferroin (*1,10,0*-phenanthroline) indicator (Allison, 1965).

Olsen P fraction

Available phosphorus was determined in the incubated soil samples in the absence and presence of BC and PR before and after the incubation period. 2.0g sample was shaken for 30 min with 40.0 mL 0.5 M sodium bicarbonate (NaHCO_3) solution adjusted to pH 8.5 with 0.01 mol/L NaOH or 0.01 mol/L HCl. Suspensions were then filtered through filter papers (Whatmann No. 42) and P was then measured in supernatants (Murphy and Riley, 1962). The measured emitted CO_2 variable was statistically analyzed using analysis of variance (ANOVA) according to the effect of applied rates of BC (R1 and R2) and temperature (Temp1: 15 ± 2 °C and Temp2: 27 ± 2 °C).

Results and Discussion

The results of the pyrolysis of bone and phosphate rock showed that about 17.7% of the bone weight was lost by volatilization, while about 1.98% of the weight of the phosphate rock was lost. The results of the elemental analysis (Table 1) showed that bone char (BC) contains approximately 10.05% total organic carbon, 36% phosphorus pentoxide (P_2O_5) and 38.08% calcium oxide (CaO). Compared with phosphate rock (PR), BC contained higher phosphorus and calcium content while the calculated calcium (Ca): phosphorus (P) ratio was comparable with PR. On the other hand, organic carbon was not detected in PR compared to BC.

X-ray diffraction (XRD)

As shown in Fig. 2, the X-ray diffraction (XRD) curves for both bone char (BC) and phosphate rock (PR) showed an approximate similar degree of lattice between the structure and content (peaks intensity). XRD patterns confirmed that the diffraction peaks correspond to

the crystal structure of PR with a lower degree of crystallization of BC compared to PR. This may be due to the presence of 10% organic carbon associated with the structural composition of BC. The current results agree with the results of El-Refaey *et al.* (2015) and Younesi *et al.* (2011).

Fourier transform-infrared (FTIR)

The results of infrared absorption spectra of the bone char (BC) and phosphate rock (PR) are shown in Fig. 3. Results demonstrate that bands of hydroxyl apatite are characterized by two strong peaks at bands 1039.67 cm^{-1} (PR) and 1037.74 cm^{-1} (BC) which represent peaks of PO_3^{3-} and bands 578.66 cm^{-1} (PR) and 572.88 cm^{-1} (BC) which refer to P-O. Similar results were obtained from samples of Tunisian phosphate rock (Elouea *et al.* 2008) and Togo phosphate rock (Tchangbeddji *et al.* 2003). The fundamental bands of calcium carbonate (calcite) appeared at 875.71 cm^{-1} and 704.64 cm^{-1} in PR sample and only at 875.71 cm^{-1} in BC sample and at 1429.3 and 1460.62 cm^{-1} in PR and BC, respectively (Fig. 3). Similar bands were identified in hard waters containing crystals of calcium carbonate (Plavsic *et al.*, 1999) and in phosphate rock of Togo (Tchangbeddji *et al.*, 2003). With respect to organic phase accompanied with bone char structure, the mild peak at 1637.62 cm^{-1} refer to C=O and C=C of organic constituents (protein and collagen) of bone materials as stated by Patel *et al.* (2015). This band did not appear in the phosphate rock spectrum (Fig. 3). Increasing temperature over 650°C may lead to the disappearing of this band from bone char. The presence of effective aggregates on the surface of BC such as hydroxyl alcohols, hydroxylmetal, carboxyl and carbonyl due to the participation of organic carbon in its structure, gives an importance to the surface activity of BC.

Scanning electron microscopy (SEM)

Morphology of the bone char and rock phosphate samples are shown in Fig. 4. The expected porous structure of bone char was not clear and SEM images of both tested samples (BC and PR) look dense, possibly due to solid state sintering phenomena causing a considerable increment in the crystal size and grain growth, which results in densification of the BC and PR samples. The porous structures of BC were found at a pyrolysis temperature of 400 °C and residence time of 2 hr (Patel *et al.* 2015).

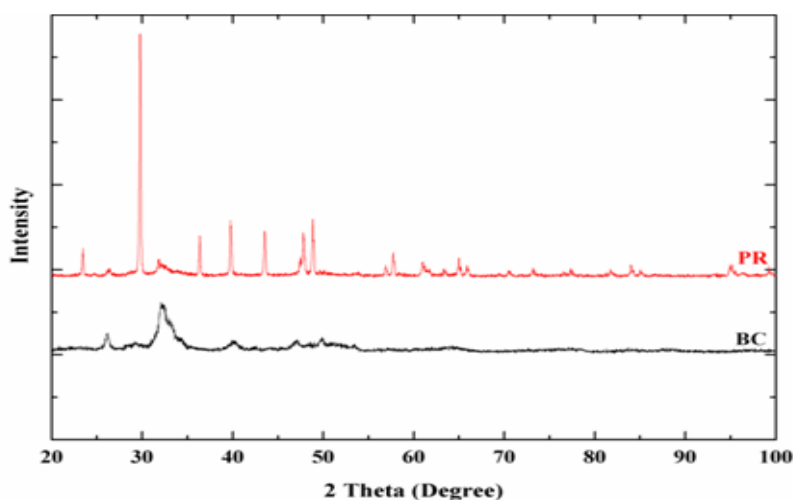


Fig. 2. XRD patterns of bone char (BC) compared to phosphate rock (PR)

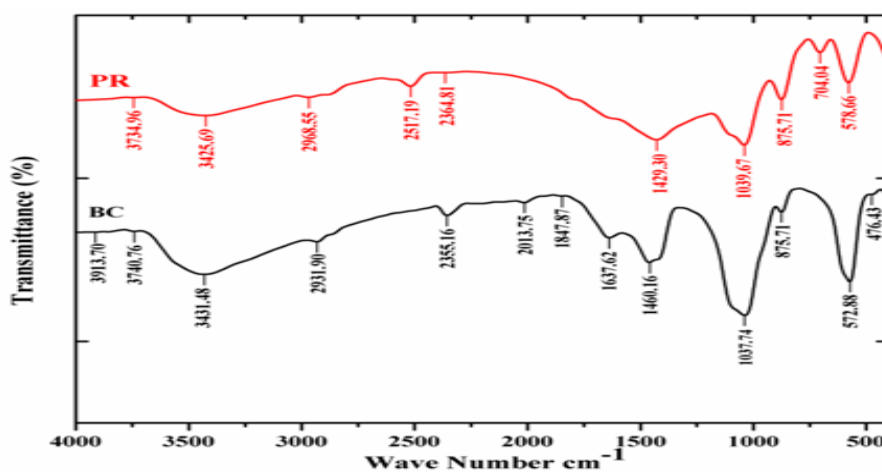


Fig. 3. FTIR spectra of bone char (BC) compared to phosphate rock (PR)

Effect of Incubation Temperature on Carbon Dioxide Emission

The results of BC incubation with soil under low temperature conditions (15 ± 2 °C) did not result in noticeable variation in CO₂ emission between the two rates of added BC which were relatively lower than the control (Fig. 5). Moreover, the higher rate of BC (2.5%) emitted more CO₂ than the lower one (1.25%), where cumulated emitted CO₂ decreased from 4489.73 mg CO₂/kg soil in non-treated soil to 4397.25 and 4255.90 mg/kg soil in BC1- and BC2-treated soils, respectively. It is necessary to point out that when organic components involved in the structure of the bone are exposed to high temperatures in anaerobic conditions (pyrolysis), lead to volatilization of some of the easily oxidized organic carbon and transform the rest into an aromatic structure, which gains valuable properties of adsorption (Krzyszewska et al, 2006; Wang et al, 2009 and Lin et al., 2014).

At higher temperature (27 ± 2 °C) the cumulative emissions of CO₂ were lower than those attained at the lower temperature conditions (Fig. 5). The incubation experiment showed that the summer (27 ± 2 °C) CO₂ emission rate was 6.003, 5.396 and 5.435 times higher than the winter averages in the control, BC1 and BC2-treated soil, respectively. The reduction in cumulative CO₂ emission in summer incubation (27 ± 2 °C) reached to 12.13 and 14.30 % compared to 2.26 and 5.40% in BC1 and BC2-treated soil with respect to the control along with the 90-day incubation. Depending on the results of our laboratory experiment, the computed reduction in CO₂ emissions per hectare, application of bone char to the top 15 cm of soil (bulk density 1.52 kg/m³) by 1.25 and 2.5%, has reduced the emission by 0.23 and 0.55 ton/hectare, respectively, in lower temperature (15 ± 2 °C) and by approximately 7.46 and 8.83 tons/hectare in higher temperature (27 ± 2 °C).

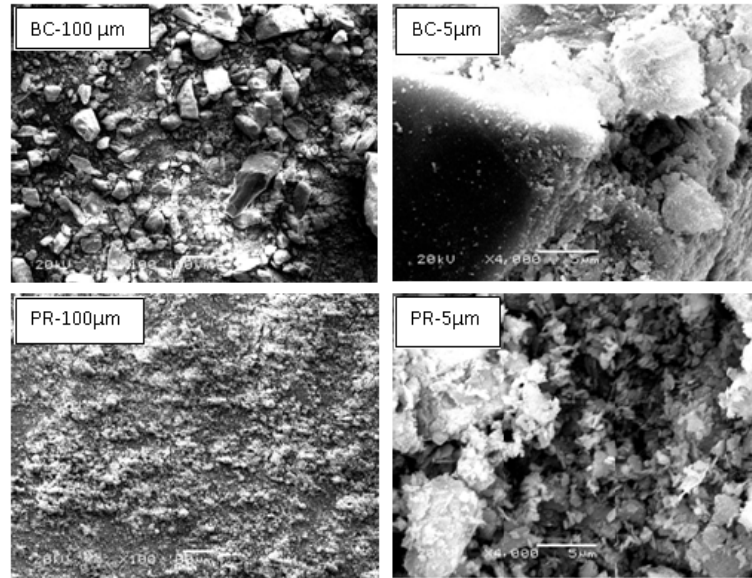


Fig. 4. SEM Images of bone char (BC) and phosphate rock (PR)

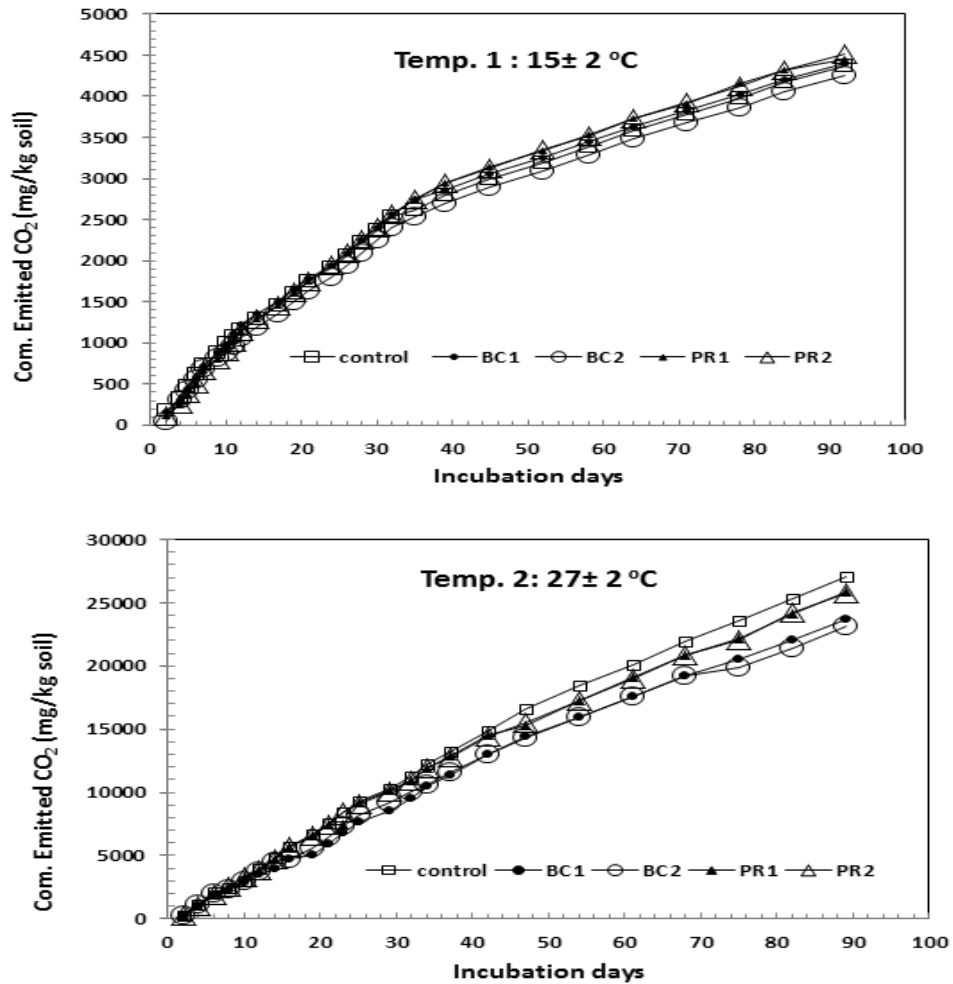
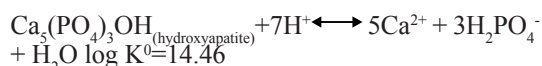


Fig. 5. Effect of incubation temperature (Temp. 1: $15 \pm 2^\circ\text{C}$ and Temp. 2: $27 \pm 2^\circ\text{C}$) of soil amended with two levels of bone char (BC1=1.25% and BC2=2.5%) and two levels of rock phosphate (PR1= 1.25% and PR2= 2.5%) on carbon dioxide emission

Effect of Bone Char Application on P- availability and Soil Organic Matter

Our previous studies (El-Refaey et al., 2015 and Mahmoud et al., 2017) showed that bone char (BC) gave high concentrations of available phosphorous extracted by Olsen, formic acid and citric acid methods compared to the same images extracted from phosphate rock (PR). The amounts of available-phosphorus increased after incubation for 90 days for both of BC1 and BC2 treatments compared to the control treatment (17.6 mg/kg). Available P measurements (Olsen-P) were 1146.63 mg/kg for BC1 and 2255.64 mg/kg for BC2 as results of BC application and increasing of application rate from 1.25 to 2.5%. Mahmoud et al. (2017) reported similar results when extracted P from BC and PR using Olsen method. On the other hand, the concentration of available phosphorus in soil incubated in presence of phosphate rock did not exceed the concentration determined in control treatment. It is known that the solubility of phosphorus is linked to soil pH as well as phosphorus availability is associated, in addition to pH, to a number of other factors such as soil organic matter and soil texture (Amer, 1995; Hou et al., 2018). It is known that phosphate rock minerals (hydroxyl-, fluoro- and carbonate-apatite) are highly basic, therefore, these minerals are available in acid soils below pH 6 but are unavailable to plants growing on alkaline soils (Lindsay, 1979). The solubility of P requires high availability of protons (H⁺) according to the following reaction (Lindsay, 1979).



The results showed that the phosphate rock did not contain organic carbon (Table 1), and also there was no change in the soil organic carbon content after the incubation period of the soil treated with phosphate rock. Hence, Figure 6 shows only the effect of adding bone char to the soil on its content of total organic carbon and dissolved organic carbon as a result of incubation. Both the total organic carbon (TOC) and dissolved organic carbon (DOC) in the

soil were affected by the addition of BC to the soil and also by the temperature of the soil incubation with BC as shown in Fig. 6. After 90 days, the addition of BC to the soil and incubating it at low temperature (15 °C) led to a significant increase in TOC reaching 2.62% and 2.55% in BC1- and BC2-treated soils, respectively compared to untreated soil (TOC = 1.1%). The opposite trend occurred when the incubation experiment was repeated with the same treatments but at the temperature of 27 °C (Fig. 6), where the proportion of TOC decreased about 0.1 and 0.24 % less than control treatment in the soil incubated with BC1 and BC2, respectively.

The results of the total organic carbon in both bone char (BC) and phosphate rock (PR) showed that the bone contains 10% organic carbon (Table 1) that is resistant to biodegradation and the rock is almost devoid of organic carbon. This content in BC has specific properties in terms of giving BC the ability to absorb CO₂ and, hence, it has a potential role in improving the level of soil organic matter on the long term. Although soil dissolved organic carbon (DOC) constitutes only a tiny fraction of the total soil organic carbon, it is a highly reactive and labile fraction very important for the soil quality (Wei et. al. 2015). The results showed that addition of BC to the soil increased DOC and there was no apparent effect of the incubation temperature or the rate of BC added to the soil (Fig. 6).

Since the effect of phosphate rock (PR) added to the soil had no effect on both carbon dioxide emissions and also on improving the level of organic matter in the soil - as is the case in the control treatment - it was excluded from the variance analysis and we were satisfied with studying the effect of bone char only. Table 3 presents the results of the analysis of variance (ANOVA) of the effect of both the incubation temperature and the rate of addition of BC and the interference between them on the cumulative emission of carbon dioxide. Both factors, temperature and BC rate, and their interaction had significant effects (P < 0.01).

TABLE 3. Mean Square for ANOVA to explore the significance of incubation temperature and the rates of applied bone char to calcareous soil on cumulative CO₂ emission to the atmosphere.

Source of variation	Degree of Freedom	Mean Square
Reps	2	81**
Temperature (T)	1	5495150648**
Bone char rate (R)	2	21516959**
T*R	2	19736112**
Error "a"	10	12
Period time (P)	9	440944853**
T* P	9	229108226**
R*P	18	939295**
P*T*R	18	971635**
Error "b"	108	5

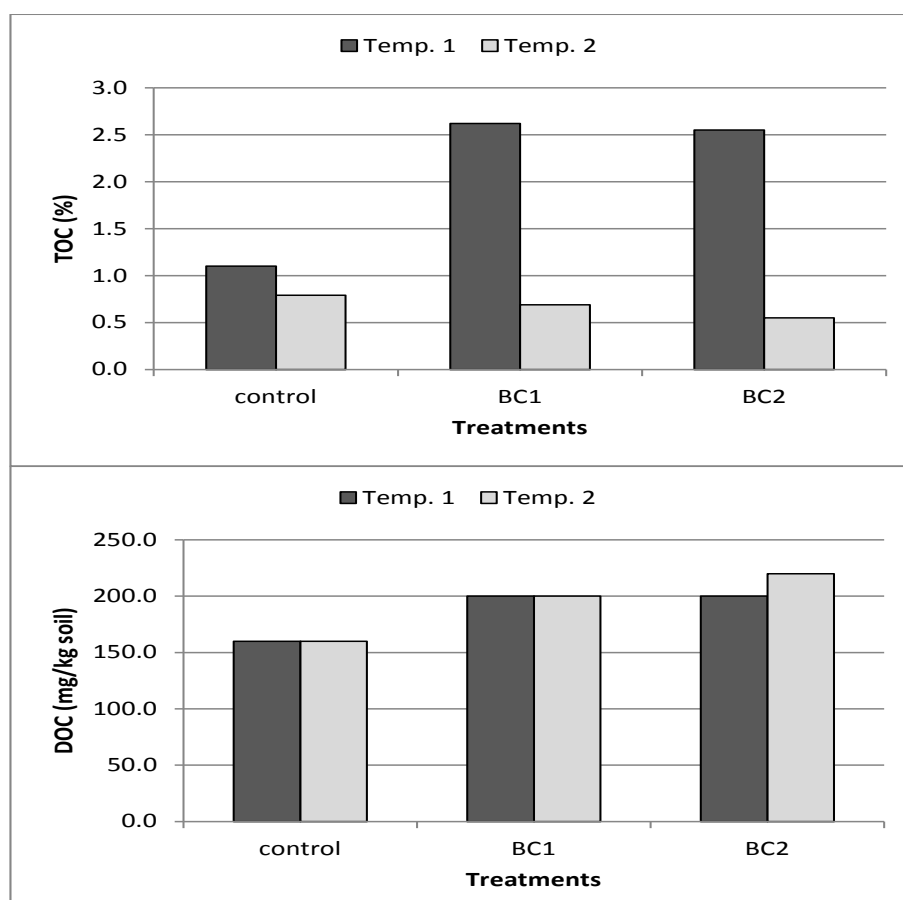


Fig. 6. Effect of incubation temperature (Temp 1:15±2°C and Temp 2:27±2°C) of soil amended by two levels of bone char (1.25% and 2.5%) on total organic carbon (TOC) and dissolved organic carbon (DOC)

Conclusion

X-ray diffraction (XRD) results showed that bone char (BC) is less crystallized than phosphate rock (PR) and this may be due to the presence of 10% of the organic carbon associated with the structural composition of BC. According to the results of FTIR, in addition to similar active groups in both phosphate rock and bone char, BC was characterized by the presence of active groups of C = O and C = C. The application of BC to calcareous soils reduced emissions of carbon dioxide (CO₂) into the atmosphere. However, these emissions increased with increasing temperature. Besides the higher surface area of bone char (117 m²/g) compared to phosphate rock (9.3 m²/g), the mentioned organic active groups may have a major role in binding to carbon dioxide and working to reduce its emissions from soil. The concentration of available phosphorus in soil incubated with BC increased compared to incubate with PR and it was positively with increasing the rate of added BC. The addition of BC to the soil increased the soil content of total organic carbon and dissolved

organic carbon compared to the content of soil treated with PR properties. It appears that bone char, as a sustainable source of phosphorous, will have a great future in its use as a soil amendment for the multiple benefits of agricultural soils. More research is needed to understand the behavior and chemistry of BC in different soils to confirm its benefits.

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انبعاثات ثاني أكسيد الكربون والكربون العضوي للتربة في التربة الجيرية نتيجة لإضافة فحم العظم وصخر الفوسفات

تعد إدارة النفايات المحتوية على المغذيات أحد الاتجاهات المهمة لتقليل الضغط على الموارد غير المتجددة. تعتبر عظام الحيوانات مصدراً متجدداً للفوسفور، التي يشبه محتواها من الفوسفور محتوى صخور الفوسفات ولكنها لا تزال غير مستغلة في هذا الصدد. وتهدف هذه الدراسة إلى تحديد دور فحم عظام المضاف إلى التربة في تقليل انبعاثات ثاني أكسيد الكربون وتحسين خصوبة التربة مقارنة بصخور الفوسفات. ولتحقيق ذلك عرضت عظام حيوانات الأبقار للتحلل الحراري اللاهوائي (الانحلال الحراري) لمدة ساعتين عند درجة حرارة 150 درجة مئوية لإنتاج الفحم العظمي (BC (bone char)). وقد تم تنفيذ تجربة تحضين معملية للتربة المعاملة في نظام مغلق بمستويين من فحم العظام أو صخر الفوسفات (1.25 و 2.5%) عند درجتى حرارة محيطية مختلفتين (15 ± 2 و 27 ± 2 درجة مئوية). وتتبع انبعاث ثاني أكسيد الكربون حتى 90 يوم. كانت نتائج التركيب الكيماوي للعناصر للـ BC مشابهة للـ PR، لكن BC تميزت بوجود الكربون العضوي. وايضا تتشابه المجموعات الفعالة السطحية في الفحم العظمي إلى حد كبير مع مجموعات صخور الفوسفات. ولكن أدى وجود المادة العضوية إلى وجود مجموعات O = C, C = C و قد أظهرت تجربة التحضين المعملية لمدة 90 يوم للتربة المعاملة فحم العظام أو صخر الفوسفات وتتبع انبعاثات ثاني أكسيد الكربون. حيث أدت إضافة BC إلى زيادة قابلية الذوبان للفوسفور في التربة واحتفاظه بثاني أكسيد الكربون مقارنة بصخور الفوسفات (PR). وكما هو متوقع أدت إضافة فحم العظم إلى التربة والتحضين لفترات تصل إلى 90 يوم (على درجة حرارة المعمل) إلى زيادة الاحتفاظ بثاني أكسيد الكربون (CO₂) من التربة إلى الغلاف الجوي .. كانت هذه الزيادة كبيرة جداً في فصل الصيف (وصلت درجة الحرارة 27 ± 2 درجة مئوية) إلى 3274 - 3870 ملجم / كجم من التربة مقابل 101 - 242 ملجم / كجم من التربة في فصل الشتاء (2 ± 15 درجة مئوية). من ناحية أخرى، أدت إضافة فحم العظم إلى التربة في فصل الشتاء إلى زيادة نسبة الكربون العضوي من 1.1 إلى 1.52%. في حين انخفضت هذه النسبة من 0.79 إلى 0.55% في درجات الحرارة العالية خلال فصل الصيف (2 ± 27 درجة مئوية). حيث تم عرض نتائج تقليل انبعاثات ثاني أكسيد الكربون فقط في معاملات الكتلة الحيوية مقارنة بمعاملات صخور الفوسفات. كما أدى الانخفاض في انبعاث ثاني أكسيد الكربون من التربة إلى الجو نتيجة إضافة فحم العظم إلى زيادة في تركيز المادة العضوية الذاتية في محلول التربة بنسبة 40-60 ملجم / كجم تربة مقارنة بالتربة غير المعاملة أو التربة المعاملة بصخور الفوسفات. وبالتالي يقدم العمل الحالي فحم العظام - إلى جانب دوره كمصدر مستدام للأسمدة الفوسفاتية - كمحسن محتمل للتربة وذلك من خلال دوره في تقليل انبعاثات ثاني أكسيد الكربون وتحسين خصوبة التربة وذلك من خلال زيادة المادة العضوية بالأرض.