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Enhance alkaline soil properties and phosphorous availability for Fennel-Baladi growth induced by fish wastes-derived biochar

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Abstract

Agricultural management of alkaline calcareous soils is considered challenging issues. For alkaline calcareous soil fertility, it is important to understand the action mode of organic amendments such as acidic biochar (ABC). Pot experiment was carried out under the greenhouse condition on 15th of October 2020, at the Experimental Farm, Faculty of Agriculture, Al-Azhar University, Assuit, Egypt, to investigate the effect of ABC application rates on calcareous sandy soil properties and Fennel-Baladi plant growth. The soil treatments were control without any addition of biochar or fertilizers (CK), the recommended dose of granular superphosphate 12% (CF), and 1%, 2% and 3% of ABC per kg of soil, respectively. The acidified biochar enhances soil chemical properties (soil reaction pH, soil salinity EC and organic matter content). Available NPK were significantly increased by increasing ABC doses. The treatment of 3% acidic biochar (ABC3) recorded the highest value of available N (38.1 mg kg^{-1}), P (24.0 mg kg^{-1}) and K (112 mg kg^{-1}). The highest value of N, P and K uptake (8.34, 6.83 and 9.53 g pot^{-1}) was recorded with the treatment ABC3.The addition of acidified biochar enhanced the growth parameters (fresh and dry weights, plant height, stem diameter, branch number and chlorophyll A and B) of the fennel plant. Increasing biochar application rate caused an increase in NPK use efficiencies since they increased by 275, 275 and 275%, respectively, compared to the control treatment.

Keywords: biochar, alkaline calcareous soil, phosphorus availability, Fennel-Baladi plants.

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1. Introduction

Biochar is a solid product generated by pyrolysis of organic matter (straw, woody material, or livestock manure) under low anoxic conditions. Biochar is widely used as an amendment to improve soil quality for plant growth, resource for many nutrients, to reduce and/or mitigate environmental pollution (Kätterer *et al*., 2019; Lebrun *et al*., 2019; Norini *et al*., 2019; Pandey *et al*., 2016; Stefaniuk *et al*., 2017). Agriculture is the most widely cited sector for biochar use and its products have broad application prospects in ecological restoration and rehabilitation of barren lands such as degraded cultivated land, grassland, orchards and in new farmland (Li *et al*., 2018; Peake *et al*., 2014). Also, biochar application is an alternative fertilizer strategy, which has recently been characterized as a multi-effective soil amendment. When biochar is applied with other fertilizers, it works as a stimulator and increases the efficiency of mineral fertilizers (Blackwell *et al*., 2010). Therefore, low rates of biochar additions insignificantly impact the pH of alkaline soil (Song *et al*., 2014). Furthermore, high cation exchange capacity (CEC) that increased by biochar application might control soil salinization process in agricultural soils (Liu and Zhang, 2012). Also, it chelates macro nutrients, whether by boost up adsorption and soil cation exchange capacity (CEC), in addition this macro nutrient can retain on biochar surfaces itself causing an increase their availability (Karimi *et al*., 2020). The biochar is a beneficial soil amendment which increases moisture retention and effectiveness of fertilizer use and moderates drought stress at critical stages in arid environments (Blackwell *et al*., 2010; Van Zwieten *et al*., 2010). Phosphorus (P) is an essential macronutrient and its deficient causes a serious matter of concern for crop production especially in the alkaline and calcareous soil. The incorporation of organic soil amendment (animal dung) with different P fertilizers sources in alkaline soil significantly improved plant growth, nodulation, nutrient uptake and crude proteins content in chickpea plants (Khan *et al*., 2021). Glaser and Lehr (2019) found that phosphorus availability increased with adding biochar as a soil amendment. The mechanisms suggested for biochar influence on P availability are the change in soil pH which influences the interaction of P with other cations or enhances its retention through anion exchange (Bashir *et al*., 2018). Adding biochar to soil could enhance P availability and decrease its fixation (Chintala *et al*., 2014; Novak *et al*., 2009; Silber *et al*., 2010). Moreover, the biochar application could decrease P loss by leaching consequently reducing the pollution risk of ground water and soils (Kumari *et al*., 2014). Either physically or chemically activation of biochar can improve the surface properties by heating the feedstock in an oxidizing environment in the temperature range of 700–900 °C (Sakhiya *et al*., 2020). In general, the efficiency of chemical activation is higher than that of physical one. However, chemical activation efficiency is sensitive to activation temperature, type and concentration of activation agent, types of starting materials, etc. (Gogotsi *et al*., 2009; Strobel *et al*., 2006). Chemical activation is a heat treatment process in which raw biochar reacts with a chemical activation agent, and this process is still not clear until now. With regard to physical activation, dehydration and oxidation are two types of reactions that induce changes within biochar (Azargohar and Dalai, 2008). Acidification of biochar is one such process that enhances the physical and chemical properties of biochar (Sadegh *et al*., 2018). As a result of these processes, biochar has higher oxygenated surface functional groups (phenols, carboxyls, carbonyls) and higher carbon content (Ahmad *et al*., 2014). As a result of the and green revolution, which increased the production per unit area of agricultural soil, but excessive use of chemical fertilizers. Although mineral fertilization plays an important role in plant growth and increases soil fertility as a result of depletion. These plants contain chemicals that are dangerous to the food chain. (Kandpal, 2021; Kumar *et al*., 2019). Globally, the continuous use of mineral P fertilizers caused many environmental threats. Thus, innovative an eco-friendly fertilizer should be adopted for sustainable ecosystem (Biswakarma *et al*., 2018). Among various strategies used to overcome this constraint, application of processed organic residues known as biochar alone or in combination with inorganic P sources (Bashir *et al*., 2019; Bashir *et al*., 2021a). Adding of acidified biochar to soil can lower soil pH and improve physico-chemical and biological properties of soils (soil aggregation, water holding capacity and beneficial microbial populations) that ultimately enhance crop yields (Bashir *et al*., 2021b; Xu *et al*., 2014). Retention of P due to biochar application is owed to the sorption process that enhances P-availability and uptake byincreasing soil anion exchange capacity (De Luca *et al*., 2015). Farrell *et al*., (2014) reported significant influence of biochar on P availability in calcareous soil. Bhatnagar and Sillanpää (2011) indicated that the acidify biochar could increase the positive sites, so increase anions adsorption (Bashir *et al*., 2020). The study aims to assess the impact of adding acidified biochar, which is derived from fish waste P-rich, on alkaline calcareous sandy soils properties and on Fennel plant growth. Also, to elucidate the working mechanism of acidified biochar as an alternative material for increasing phosphorous availability on alkaline calcareous sandy soils.

2. Materials and methods

2.1 Site feature and soil sampling

The experimental site soil was calcareous sandy soil with low organic matter content located at the Experimental Farm, Arab Al-Awamer Agricultural Research Station, 30 km from the eastern province of Assiut, Egypt (27° 12- 16.67 = N latitude and 31° 09- 36.86 = E longitude). Surface soil samples (0-30 cm) were collected, crashed, air-dried, sieved through a 2 mm sieve and prepared to be used in pot experiment and laboratory analyses. Some relevant physical-chemical properties of the tested soil are listed in Table (1).

Table (1): Some chemical and physical properties of the studied soil.

Property	Unit	Soil
Sand	g kg^{-1}	877
Silt	g kg^{-1}	82
Clay	g kg^{-1}	41
Texture	---	Sandy
$CaCO_3$	g kg^{-1}	110
pH (1: 2.5)	---	8.42
EC (1:2.5)	dS m^{-1}	0.39
Organic matter	g kg^{-1}	3.50
Available-N	mg kg^{-1}	10.3
Available-P	mg kg^{-1}	3.16
Available-K	mg/kg	53.0
Total-N	g kg^{-1}	0.530
Total-P	g kg^{-1}	0.200
Total-K	g kg^{-1}	0.400

2.2 Biochar production

The used biochar (BC) was produced from fish wastes which were obtained from the Al-Sharq Company for feed, Quesna, Menoufia, Egypt. These wastes were dried, ground and pyrolized using the muffle furnace at a temperature of about 600 °C for 3h. The pyrolized materials were crushed and passed through 0.80 mm sieve. To maximize the phosphorous (P) percent, a 5 g of fine rock phosphate (33% P_2O_5) was mixed with 95 g biochar (W/W). In order to reduce alkalinity and increase surface area, the mixture was acidified with 2 M H_2SO_4 in a ratio of 1:1 and mechanically stirred for 12 h to homogenize. The acidified mixture was air-dried for 12 hours, oven dried for 2h at 105 °C, ground and sieved with a 0.80 mm sieve. The pH of biochar was measured in 1:2.5 suspension using a pH meter, while the electrical conductivity was measured in an extract of 1 biochar: 10 water by EC meter (Burt, 2004). The organic carbon content was measured according to Jackson (1958). Available nitrogen (N) was evaluated by micro-Kjeldahl method (Burt, 2004) While the available P was determined according to Olsen (1954) whereas available potassium (K) was determined using flame photometry, as described by Jackson (1958). Some chemical characterizations of the final prepared biochar are listed in Table (2).

Table (2): Some chemical properties of biochar.

Property	Unit	Biochar
pH (1: 2.5)	-------	4.40
EC (1:10)	dS m^{-1}	8.43
Organic matter	g kg^{-1}	540
Available-N	g kg^{-1}	6.67
Available-P	g kg^{-1}	9.13
Available-K	g kg^{-1}	2.32

2.3 Pot experiment

In this experiment, four kilograms from the collected composite sample were uniformly filled in plastic pots (20 × 25 cm) perforated at the bottom with 3 holes to establish the experiment under the greenhouse condition on 15^{th} of October 2020, at the Experimental Farm, Faculty of Agriculture, Al-Azahr University, Assuit, Egypt. The soil was mixed with biochar at a rate of 1, 2 and 3% (w/w) in comparison with superphosphate as recommended dose (300 kg $feddan^{-1}$, P_2O_5, 12%) (feddan = 4200 m² = 0.420 hectares = 1.037 acres) in addition to the control. The experiment was laid out in a randomized complete block with 5 treatments and 3 replicates for each as the following:

1. Control (without any biochar or fertilizers), CK.
2. Recommended dose (superphosphate 12%), CF.
3. 1% biochar, BC1.
4. 2% biochar, BC2.
5. 3% biochar, BC3.

In each pot, six seeds of Fennel-Baladi variety (*Foeniculum vulgare*) were sown, thinned to 2 seedlings per pot after 4 weeks from cultivation. Ammonium nitrate (NH_4NO_3, 33.5%) and potassium sulfate (K_2SO_4, 50%) were applied at a rate of 122 Kg N $feddan^{-1}$ and 50 Kg K_2O $feddan^{-1}$. The recommended amount of K was added once a month after planting, while the amount of N was divided into two equal doses; the first after a month and the second after 15 days from the first dose. The experiment was irrigated to almost soil field capacity using tab water (0.4 dS m^{-1}). The soil field capacity was estimated by gravimetric method, and it maintained throughout the experiment by daily pots weighting. The temperature in the greenhouse ranged between 18-25 °C and humidity was 60-70%).

2.4 Soil analysis

At the end of the experiment, soil samples were taken from all treatments, air-dried and stored for further analysis. Soil particle size distribution was estimated using the pipette method according to (Page, 1982). The pH and EC values were measured in soil-water suspensions (1: 2.5). Calcium carbonate was determined using the calcimeter according to (Burt, 2004). Total and available nitrogen (N) were determined according to the Kjeldhal method (Burt, 2004). Available inorganic P was determined spectrophotometrically in 0.5 M $NaHCO_3$–soil extract according to the Olsen method. The exchangeable K^+ was extracted using 1 N ammonium acetate and measured flame photometrically according to Jackson (1958). Total N, P, and K content in soil and biochar were analyzed as described by Parkinson and Allen (1975). The organic carbon was estimated as described by Jackson (1958).

2.5 Plant measurements

To estimate the pigment content of fennel, fresh plant samples were collected to evaluate chlorophyll-a, chlorophyll-b and carotenoids according to the protocol approved by Lightenthaler (1987). Fennel vegetative characteristics such as length and thickness of the shoot and root and fresh weight were obtained. The plant samples were washed with distilled water, air-dried and placed in an oven at 65 °C to a constant weight. A pure stainless-steel mill was used to grind the plant samples to be analyzed for the total content of N, P and according to Zarcinas *et al*. (1987).

2.6 Statistical analysis

The data of this study were analyzed using analysis of variance (ANOVA) and Duncan multiple range tests at a 5% level of probability were used to test the significance of differences between the treatments. Data statistical analyses were performed using Costat software version 6.303.

3. Results

3.1 Effect of biochar on soil chemical properties

A significant ($p<0.05$) changes in soil chemical properties such as soil reaction (pH), electrical conductivity (EC), soil organic matter (SOM) and total carbonate were observed due to biochar application (Table 3). The magnitude soil properties changes varied according to the biochar application rate compared to chemical fertilizer (CF) and control (CK) treatments. Applying BC to the studied soil decreased soil pH values from 8.48 for CK to 8.21, 7.61, 7.56 and 7.13, respectively for CF, BC_1, BC_2, and BC_3 treatments. The EC values were incrementally affected by increasing BC levels where the highest EC value (1.97 dS m^{-1}) was recorded at the highest BC rate. Although the recommended dose of superphosphate (CF) increased the value of SOM (4.26 g kg^{-1}) than the control (3.73 g kg^{-1}), this increase was less than the first biochar rate (BC1) (9.38 g kg^{-1}). The highest value of SOM (13.92 g kg^{-1}) was recorded at 3% of the BC, while the lowest value was observed with CK treatments. On the other hand, it was observed that the total calcium carbonate of the soil decreased as a result of the biochar treatments, whether compared to the control or the recommended superphosphate fertilizer.

3.2 Effects on nutrient availability and their uptake

Regarding macronutrients availability (N, P, K), the results indicated that the nutrients availability of amended soil significantly improved compared to the unamended soil (Figure 1a,c,e). Available N, P and K significantly increased with increasing the biochar application rate.

Table (3): Effect of biochar application on soil reaction (pH), electrical conductivity (EC), soil organic matter (SOM) and total calcium carbonate.

Treatments	pH	EC (dS m^{-1})	O.M (g kg^{-1})	$CaCO_3$ (g kg^{-1})
CK	8.48±0.04^{a}	0.49±0.01^{e}	3.73±0.04^{d}	108.40±3.17^{a}
CF	8.21±0.03^{b}	0.62±0.01^{d}	4.26±0.04^{d}	97.80±1.11^{b}
BC_1	7.61±0.05^{c}	1.04±0.06^{c}	9.38±0.30^{c}	78.63±2.15^{c}
BC_2	7.56±0.02^{c}	1.51±0.04^{b}	12.20±0.46^{b}	74.00±1.57^{d}
BC_3	7.13±0.02^{d}	1.97±0.05^{a}	13.92±0.30^{a}	71.47±0.65^{d}

CK= Control (no fertilizers applied), CF= Chemical fertilizer, BC_1= 1% biochar, BC_2= 2% biochar and BC_3= 3% biochar. Means denoted by the same letter indicate no significant difference according to Duncan's test at $p<0.05$.

The highest biochar rate (BC3) treatment recorded the highest values of available N (38.10 mg kg^{-1}), P (24.01 mg kg^{-1}) and K (111.67 mg kg^{-1}) in the soil, while the lowest available values of N, P and K were 12.00, 4.71 and 60.33 mg kg^{-1}, respectively, for CK treatment. The uptake of N, P and K nutrient improved by adding biochar compared to control. It was observed that the nutrient taken up by the Fennel plants significantly increased with increasing the rate of biochar (Figure 1b,d,f). The highest value of N uptake (8.34 g pot^{-1}) was recorded at the highest rate of biochar, while the lowest values of N uptake 0.60 and 1.55 g pot^{-1} were recorded with CK and CF treatments, respectively. The amount of P taken up by Fennel-Baladi plants also increased from 0.75 g pot^{-1} for control (CK) to 1.15 and 6.83 g pot^{-1}, respectively, for CF and BC_3 treatments. The amount of potassium absorbed by the fennel plants increased in all BC treatments compared to control. Maximum K value (9.53 g pot^{-1}) was observed in BC_3.

3.3 Effect of acidic biochar on plant growth

The growth parameters of Fennel-Baladi plants were influenced by addition of biochar and recommended fertilizers (Table 4). All treatments were higher than the control (CK). Fresh and dry weights, plant height, stem diameter and branch number of Fennel-Baladi plants significantly ($p<0.05$) increased by 62, 108.3, 37.07, 20.93, and 12.57%, respectively, for the CF treatment above the untreated soil. The best treatment was BC_3 since they gave the highest values of the growth parameters than the other treatments. The fresh, dry weight, plant height, stem diameter and branch number were significantly increased by 247, 275, 103, 56 and 63 %, respectively, for BC_3 treatment above the untreated (CK).

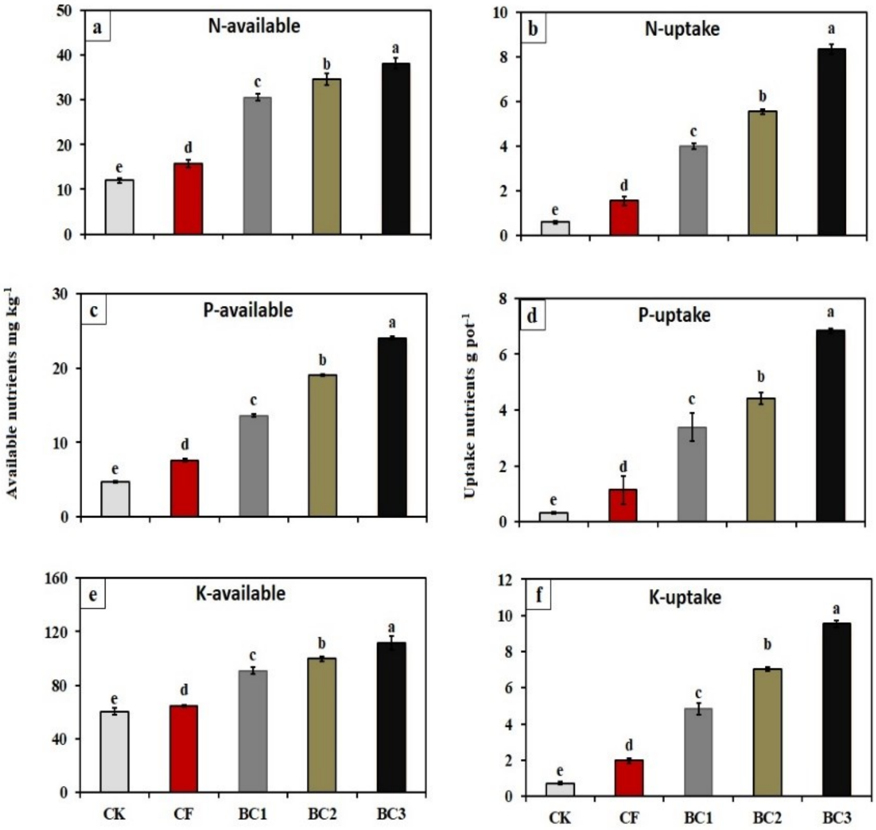

Figure (1): Effect of biochar application on available nitrogen (N, a), phosphorous (P, c) and potassium (K, e) and their uptake (b, d and f) in the shoots of Fennell plants. CK= control (no biochar applied), CF= recommended fertilizers dose, BC1, BC2 and BC3 fish waste biochar at rate of 1, 2, and 3%. Error bars are standard deviations of the means (n= 3). Different letters above the columns indicate significant ($p<0.05$).

3.4 Effect of biochar on plant roots

Data illustrated in Table (5) show the effect of chemical fertilizers and biochar on some root properties of Fennel-Baladi plants. Considerably improvement was observed in the root characteristics in the soil treated with biochar compared to the control and the increases were significantly pronounced with increasing the biochar rate. The fresh weight, dry weight, root length and root diameter of Fennel-Baladi plants were significantly ($p<0.05$) increased by 14.62, 50.36, 17.09 and 80%, respectively, for CF treatment than the untreated control, while it increased by 138.92, 337.96, 47.57 and 313.33%, respectively, for BC_3 treatment compared to the control.

Table (4): Effect of biochar application on the shoot vegetative characteristics of fennel plants.

Treatments	Fresh weight (g pot^{-1})	Dry weight (g pot^{-1})	Plant height (cm)	Stem diameter (cm)	Branches Number
CK	9.00±0.37^{e}	1.69±0.14^{e}	29.67±0.58^{d}	0.43±0.29^{d}	5.33±0.58^{b}
CF	14.58±0.17^{d}	3.52±0.26^{d}	40.67±1.53^{c}	0.52±0.29^{c}	6.00±0.00^{b}
BC_1	23.75±1.36^{c}	5.07±0.23^{c}	54.67±1.53^{b}	0.57±0.03^{b}	7.67±0.58^{a}
BC_2	28.13±0.42^{b}	5.51±0.15^{b}	59.67±1.53^{a}	0.63±0.03^{a}	8.33±0.58^{a}
BC_3	31.20±0.30^{a}	6.33±0.18^{a}	60.33±1.53^{a}	0.67±0.03^{a}	8.67±0.58^{a}

CK= Control (no fertilizers applied), CF= Chemical fertilizer, BC_1= 1% biochar, BC_2= 2% biochar and BC_3= 3% biochar. Means denoted by the same letter indicate no significant difference according to Duncan's test at p<0.05.

Table (5): Effect of biochar application on the vegetative characteristics of plant roots.

Treatments	Fresh weight (g pot^{-1})	Dry weight (g pot^{-1})	Root length (cm)	Root diameter (cm)
CK	4.65±0.21^{e}	1.37±0.02^{e}	27.33±0.58^{c}	0.15±0.00^{e}
CF	5.33±0.21^{d}	2.06±0.07^{d}	32.00±2.00^{b}	0.27±0.29^{d}
BC_1	9.05±0.08^{c}	4.41±0.08^{c}	33.33±0.58^{b}	0.43±0.03^{c}
BC_2	9.88±0.14^{b}	5.75±0.07^{b}	39.33±0.58^{a}	0.53±0.03^{b}
BC_3	11.11±0.19^{a}	6.00±0.08^{a}	40.33±0.58^{a}	0.62±0.03^{a}

CK= Control (no fertilizers applied), CF= Chemical fertilizer, BC_1= 1% biochar, BC_2= 2% biochar and BC_3= 3% biochar. Means denoted by the same letter indicate no significant difference according to Duncan's test at p<0.05.

3.5 Effect of biochar on photosynthetic pigments of Fennel-Baladi plant

Significant (P<0.05) increases of chlorophyll A and chlorophyll B were recorded as a result of CF and biochar additions (Table 6). The application of CF increased the chlorophyll (A and B) content of fennel leaves by 40.39, 1.02%, respectively, compared to the control (CK) treatment. Likewise, they increased by 191.64 and 15.41%, respectively, when the highest biochar rate (BC_3) was added, over the control. Although the increases in carotenoids are slight, the maximum value was observed with the control (CK) treatment, while the lowest value recorded for BC_3 treatment compared to the control.

Table (6): Effect of biochar application on chlorophyll and carotenoids content of leaves.

Treatments	Chlorophyll A (mgkg^{-1})	Chlorophyll B (mg kg^{-1})	Total Chlorophyll (mg kg^{-1})	Chlorophyll A / Chlorophyll B	Carotenoids (mg kg^{-1})	Chlorophyll / Carotenoids
CK	3.58±0.05^{e}	54.90±0.09^{e}	58.48±0.07^{e}	0.07±0.01^{d}	93.51±0.01^{a}	0.63±0.01^{e}
CF	5.04±0.05^{d}	55.45±0.18^{d}	60.49±0.23^{d}	0.09±0.00^{c}	93.46±0.01^{b}	0.65±0.01^{d}
BC_1	9.01±0.02^{c}	60.98±0.03^{c}	69.99±0.04^{c}	0.15±0.00^{b}	93.14±0.00^{c}	0.75±0.00^{c}
BC_2	9.54±0.09^{b}	62.73±0.09^{b}	72.27±0.06^{b}	0.15±0.00^{b}	93.05±0.00^{d}	0.78±0.00^{b}
BC_3	10.47±0.05^{a}	63.36±0.10^{a}	73.83±0.10^{a}	0.17±0.01^{a}	93.01±0.01^{e}	0.79±0.00^{a}

CK= Control (no fertilizers applied), CF= Chemical fertilizer, BC_1= 1% biochar, BC_2= 2% biochar and BC_3= 3% biochar. Means denoted by the same letter indicate no significant difference according to Duncan's test at p<0.05.

3.6 Nitrogen, phosphorus, and potassium use efficiencies

Figure (2) shows the effect of chemical fertilizers and biochar application rate on the NPK use efficiencies. The increases of use efficiencies were also related to biochar application rate increasing use efficiencies of nitrogen (NUE), phosphorous (PUE) and potassium (KUE) where the highest significant ($p<0.01$) use efficiencies increase was observed with the highest biochar rate compared to the control. The results showed that the application of superphosphate (CF) increased NUE from 3.52 to 7.33, PUE from 2.11 to 4.40 and KUE from 8.45 to 17.58 compared to the control. Application biochar at 3% rate (BC_3) recorded the highest value of NUE from 3.52 to 13.19, PUE from 2.11 to 7.92 and KUE from 8.45 to 31.67 compared to the control treatment.

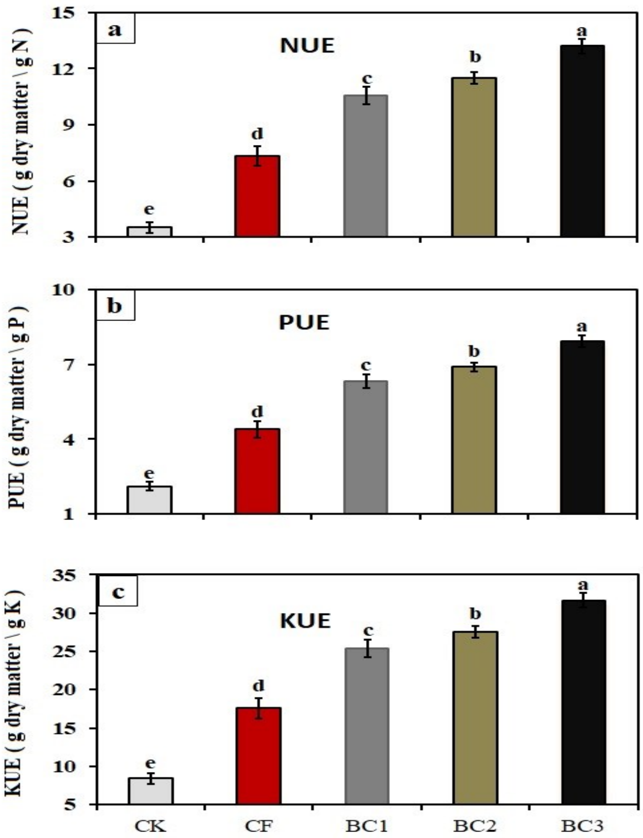

Figure (2): Effect of biochar application on the nitrogen, phosphorous and potassium use efficiencies.

4. Discussion

In our current study, significant improvement in soil chemical properties was detected as a result of the studied treatments. Gradual decrease in soil pH was observed with increasing l biochar level. It may be due to the release of H^+ protons from the exchange sites of acidified biochar and/or the formation of acidic functional groups which could contribute significantly in the alkalinity neutralization resulting in soil pH lowering. Similar results obtained by (Ippolito *et al*., 2016) where acidified biochar was found to be beneficial for lowering the pH of calcareous soils. The addition of biochar also caused an increase in the electrical conductivity values, especially at high levels of it, and this may be due to the higher content of total salts than other treatments, and that the amount added at the high level contains more salts. However, biochar contains base cations such as Ca^{+2}, K^{+} and Mg^{+2}, which may be the reason for raising the electrical conductivity values. These results matched those obtained by Gundale and DeLuca (2007), Chan *et al*. (2008), and Xu *et al*. (2016) who showed the release of poorly bound nutrients (cations and anions) from acidified biochar in soil solution, which available for plant uptake could increase EC value. An improvement in the soil organic matter (SOM) content as a result of the addition of biochar that can increase the soil's water holding capacity (WHC) and enhance the availability of nutrients such as N, P, and K (Yuan *et al*., 2016). In same regard, Agegnehu *et al*. (2015) indicated that the use of biochar increased soil organic matter (SOM) by 23.5% over untreated soil. In addition, Murad *et al*. (2022) confirmed that the addition of biochar at a rate of 4% increased the organic matter by 1.67% over the control treatment. The organic carbon in the biochar is more stable and resistant to degradation by soil microorganisms than other organic materials (Ding *et al*., 2020). Also, adding biochar to alkaline soils can improve soil alkalinity and enhance carbon sequestration, which may reduce carbon dioxide emissions and thus improve the organic matter contents of calcareous soils (Ahmed *et al*., 2021; Saranya *et al*., 2011). The availability increases of macronutrients such as nitrogen, potassium and phosphorous may be attributed to the fact that biochar is a rich source of nutrients (Glaser *et al*., 2002) and /or to its high absorption capacity and preventing nutrient loss, thus their slow release and retention, which helps in enhancing soil fertility (Gul *et al*., 2015). Also, the decrease in pH values in the soil as a result of biochar additions may have led to increase in the available nutrients. For example, when soil pH changes, it directly affects how much phosphorous is deposited, how much phosphorus reacts with Ca^{2+} and thus P becomes more soluble, and how much phosphorus is retained by anion exchange (Bashir *et al*., 2018; De Luca *et al*., 2015). Also, the pyrolysis process volatilizes C from the feedstock, which breaks the organic bond of P, thus increases the total contents of available N, P, and K (Chan, *et al*., 2008; Li *et al*., 2021). According to the increasing nutrients availability as a result of improvement soil properties such as neutralization of high alkalinity, the uptake of N, P and K by fennel plant increased with increasing the biochar added than other treatments. Similar findings were obtained by Wang *et al*. (2012) who reported that the tissue content of N, P, and K in maize, okra, and cassava were significantly increased with the biochar addition. Other studies confirmed that the applying of biochar at rate of 2% increased available N, P, and K by 24, 37, and 19%, respectively, was absorbed by hibiscus plants (Liu *et al*., 2021). A clear improvement in the vegetative growth characteristics of fennel plant, such as plant height and biomass production, as a result of the used treatments were obtained and the effect was more clear with highest biochar rate. This is probably due to the improvement of soil properties and the increments in nutrient availability and their use efficiencies, which made optimal conditions for the growth of fennel plant. These results were consistent with those observed by Ahmed *et al*. (2021), who verified that supplementation with phosphorus levels had a positive effect on maize plant height and dry weight via stimulating root growth, increasing cell division, building new tissues which was reflected as increase in yield. Bashir *et al*. (2021) also, found similar results about root growth stimulation by biochar addition, and an increase in root system ability to absorb more phosphorus and other nutrients, consequently, plant growth increased (Imran, 2015; Lehman *et al*., 2011). In alkaline soil, a significant ($P<0.05$) improvement in all plant measurement consequently in pigments as a result of improved soil properties due to BC and CF treatments. These findings are consistent with those of Feng *et al*. (2021), who found that application of biochar increased chlorophyll content in tomato leaves. The plant's photosynthetic capacity and productivity in peanut significantly increased soil organic matter, which aids in sustainable water and nutrient retention as well as increased nutrient use efficiency (Liu *et al*., 2021; Wang *et al*., 2021). The increase in the nutrient content of fennel was an indication of the ability of the soil to supply and thus increased the nutrient use efficiency (Ding *et al*., 2016). This is perhaps more plausible with the fact that biochar reduces nutrient loss by adsorbing them onto surfaces then releasing slowly, thus increase nutrient use efficiency (Alharbi *et al*., 2021; Liu *et al*. 2021; Randolph *et al*., 2017).

5. Conclusion

Common major problems of calcareous soil include low P availability, lower fertility and cation exchange capacity while the alkalinity is high. The acidification of biochar pyrolyzed at 600 °C plays an important role in influencing the soil chemical properties. So, it’s more suitable for application in alkaline soils. The application of fish wastes-derived biochar to calcareous sandy soil had a great role in decrease soil pH and calcium carbonate while increase soil organic matter. The availability of nitrogen, phosphorus and potassium was amelioration by applying acidic biochar. A clear improvement in the vegetative growth characteristics of fennel plant, such as plant height and biomass production were observed as a result of the used treatments. After BC and CF treatments, better growth parameters of the fennel plant caused improvement in photosynthesis which led to a significant increase ($P<0.05$) in chlorophyll (A and B). It became clear that acidification increased the importance of biochar additions in alkaline soils, and among all studied treatments, the higher levels (3%) were the superior one. Based on this study, the addition of acidified biochar at the studied levels might be an appropriate and safe management practice to improve the alkaline soil properties and the growth characteristics of fennel plants and reduce the use of chemical fertilizers.

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