

## STUDYING THE EFFECT OF BIOCHAR ON SOIL PHOSPHORUS AVAILABILITY AND REDUCING CADMIUM POLLUTION

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**ABSTRACT:** This research examined the impacts of calcium super phosphate, mono ammonium phosphate (MAP), and biochar on wheat during the 2022 and 2023 growing seasons. The study was conducted at the Agricultural Research Station farm in Sakha, Egypt, to evaluate the effects of these amendments, both individually and in combination, on clay soil properties, phosphorus availability, and the mitigation of cadmium contamination. A field study was arranged using a completely randomized block design with three replications. Bulk density values were significantly decreased by applying the used materials except calcium super phosphate and MAP fertilizers; meanwhile, total porosity and organic matter content were significantly increased. All soil treatments decreased pH and electrical conductivity. Cation exchange capacity was increased by applying all treatments. All soil treatments caused a marked improvement in soil available phosphorus. Meanwhile, the available nitrogen significantly improved except for calcium super phosphate and MAP fertilizers. The application of the evaluated materials caused a pronounced increment in straw yield, grain yield, thousand-grain weight, plant height, nitrogen use efficiency, harvest index ratio, relative increase, and nutritional wheat grain composition, N and P uptake in grains of wheat plants. It was clearly observed that cadmium concentration in fertilizer-treated soil was slightly higher than in the soil amended with biochar. Also, bioconcentrations of cadmium were low except for inorganic MAP fertilizer treatment in wheat plants.

**Keywords:** Phosphorus; unconventional fertilizers; biochar; cadmium.

## INTRODUCTION

Agricultural soils need adequate supplies of essential macro- and micronutrients to support optimal plant growth and development. Improper use of inorganic fertilizers in the environment can lead to accumulation of potentially toxic heavy metals in the agricultural soils, thereby causing soil degradation to become a pressing environmental challenge with serious implications for the global ecosystem (Hossain *et al.*, 2022). Despite their occurrence at low levels, these potentially toxic elements can accumulate and disrupt ecological balance (Palansooriya *et al.*, 2020). As phosphate fertilizers are manufactured from phosphate rocks (Sahu *et al.*, 2019) that contain toxic heavy metals, such as Cd, Pb, and Cu (Kumar *et al.*, 2021), such metals are highly toxic in soil, degradation-resistant, and easily accumulate in the environment (Habib *et*

*al.*, 2022). Despite the widespread use of chemical fertilizers negatively impacting the environment and crop productivity, phosphorus may also be fixed within the soil, leading to a decrease in its bioavailability to plants. Inadequate or unbalanced application of chemical fertilizers leads to a reduction in both the quantitative and qualitative yield of wheat (Sharma *et al.*, 2020). Among heavy metals, cadmium shows greater solubility and mobility, which enhances its potential for leaching and bioaccumulation. Lowering soil pH facilitates the release of cadmium from its fixed fractions into more soluble and mobile forms, thereby increasing its potential for plant uptake (Mondal *et al.*, 2020), and may be transmitted from plants to humans along the food chain, posing potential health risks (Wei *et al.*, 2020). Effective agricultural planning requires the optimal and balanced management of soil nutrients to

improve phosphorus availability using alternative or unconventional methods and reducing pollution with heavy metals. Monoammonium phosphate (MAP), a highly water-soluble fertilizer, serves as an effective means of supplying phosphorus to crops and mitigating potential cadmium toxicity. Owing to the absence of toxic elements such as chlorine, sodium, and heavy metals, it is considered safe for use across various plant species.

To overcome the deleterious effects of heavy metals, the incorporation of biochar into soil represents a practical strategy (Yuan *et al.*, 2019). Biochar (BC), an organic soil amendment, has proven effective in immobilizing heavy metals in soil because of its high adsorption capacity (Haider *et al.*, 2022), and reduces cadmium (Cd) transport. The potential of biochar in cadmium immobilization arises from its alkaline characteristics, high porosity, and the presence of reactive surface functional groups, and high cation exchange capacity (Medynska-Juraszek and Cwiela-Piasecka, 2020). Biochar contributes to plant growth enhancement through the supply of essential nutrients that improve soil fertility and nutrient availability. In recent years, biochar has emerged as a potential solution for improving nutrient management in agricultural systems, crop production, and soil improvement.

In this context, the present study aims to evaluate the impact of biochar as an organic amendment on different phosphorus fertilizer forms, soil properties, cadmium transport, and wheat growth and productivity.

## MATERIALS AND METHODS

### Study area and soil physicochemical properties

The field experiment was implemented at the Agricultural Research Station Farm, located in Kafr El-Sheikh Governorate, Egypt (30° 56' N latitude and 31° 05' E longitude) for two winter growing seasons, 2022/2023 and 2023/2024, to study the effect of different phosphorus fertilizer

forms, such as calcium super phosphate, unconventional mineral fertilizer. i.e., MAP in the presence of biochar as an organic amendment on the physicochemical properties of clay soil, the phosphorus suitability, and reducing pollution with cadmium (Cd). The baseline physicochemical parameters of the investigated soil before planting were determined, and the obtained data are illustrated in Table 1. These properties were studied according to the method described by Page *et al.* (1982).

### Design of the experiment

The experimental layout followed a completely randomized block design with three replications. The treatments were categorized as follows:

1. Without any additions, control.
2. At a rate of 15 kg P<sub>2</sub>O<sub>5</sub> fed<sup>-1</sup>, calcium superphosphate (15.5% P<sub>2</sub>O<sub>5</sub>).
3. MAP at a rate of 25 kg fed<sup>-1</sup>, 61% P<sub>2</sub>O<sub>5</sub> + 12% N.
4. Treatment with BC at a rate of 2 t fed<sup>-1</sup>.
5. The BC + P treatment.
6. Treatment with BC and MAP.

The BC used in the experiment was produced by a local company through the pyrolysis of citrus tree wood. BC granules were uniformly mixed with the soil during the tillage process. Some chemical analyses of BC are shown in Table 2. These determinations were conducted according to Lehmann and Joseph (2015).

- BC granules addition at the rate of 2 t fed<sup>-1</sup> and thoroughly incorporated into the topsoil (0-25 cm depth) during tillage, before cultivation, except control.
- MAP is commonly used as an unconventional P fertilizer applied to wheat. It was added with the first irrigation at the rate of 25 kg/fed.
- Calcium superphosphate (15.5% P<sub>2</sub>O<sub>5</sub>) was used as a traditional P form (P<sub>2</sub>O<sub>5</sub>) at the rate of 15 kg fed<sup>-1</sup> mixed during soil tillage.

**Table 1. Average values of the main physical and chemical characteristics of the experimental soil prior to cultivation in the two successive growing seasons.**

| Characteristic                                        | Soil depths (cm) |       |       |
|-------------------------------------------------------|------------------|-------|-------|
|                                                       | 0-20             | 20-40 | 40-60 |
| <b>Particle size distribution (%)</b>                 |                  |       |       |
| Coarse Sand                                           | 6.4              | 4.5   | 4.0   |
| Fine sand                                             | 14.1             | 15.4  | 16.3  |
| Silt                                                  | 35.2             | 34.6  | 36.0  |
| Clay                                                  | 44.3             | 45.5  | 43.7  |
| Texture class                                         | Silt Clay        |       |       |
| Bulk density (g/cm <sup>3</sup> )                     | 1.26             | 1.28  | 1.29  |
| <b>Soil Chemical Analysis</b>                         |                  |       |       |
| pH (1:2.5 soil: water suspension)                     | 7.73             | 7.78  | 7.70  |
| OM (%)                                                | 1.20             | 1.11  | 0.9   |
| EC (dS/m) soil paste extracted                        | 3.82             | 4.30  | 4.45  |
| CEC (cmol/kg)                                         | 43.0             | -     | -     |
| <b>Soluble cations (meq/L)</b>                        |                  |       |       |
| Ca <sup>++</sup>                                      | 9.1              | 9.0   | 9.2   |
| Mg <sup>++</sup>                                      | 6.3              | 7.1   | 7.5   |
| Na <sup>+</sup>                                       | 21.6             | 25.4  | 27.2  |
| K <sup>+</sup>                                        | 1.2              | 1.5   | 0.6   |
| <b>Soluble anions (meq/L)</b>                         |                  |       |       |
| CO <sub>3</sub> <sup>--</sup>                         | -                | -     | -     |
| HCO <sub>3</sub> <sup>-</sup>                         | 0.3              | 0.4   | 0.5   |
| Cl <sup>-</sup>                                       | 26.9             | 29.5  | 35.0  |
| SO <sub>4</sub> <sup>--</sup>                         | 11.0             | 13.1  | 9.0   |
| <b>Available macro nutrients (mg kg<sup>-1</sup>)</b> |                  |       |       |
| Available nitrogen                                    | 23               | 18.3  | 16.3  |
| Available phosphorus                                  | 9.1              | 7.8   | 5.6   |
| Available potassium                                   | 119.4            | 155.6 | 111.3 |
| <b>Soluble heavy metal (mg kg<sup>-1</sup>)</b>       |                  |       |       |
| Cadmium (Cd)                                          | 0.01             | -     | -     |

EC: electrical conductivity; OM: organic matter; CEC: cation exchange capacity

**Table 2: The main characteristics of BC used in the experiment**

| Parameters | pH (1:10) | EC dS/m (1:10) | OC % | CEC cmol/kg | N %  | P %  | K %  | Ca % | Mg % | C/N   |
|------------|-----------|----------------|------|-------------|------|------|------|------|------|-------|
| Values     | 8.09      | 0.52           | 46.1 | 30.31       | 1.32 | 0.95 | 1.41 | 1.50 | 2.70 | 34.92 |

### Culture practices

In the two growth seasons, wheat grains (*Triticum aestivum* L.) variety Sakha 95 was

used as a tested plant and was obtained from the Department of Wheat Research, Agricultural Research Station, Sakha, Kafr El-Sheikh. Date of

planting was 15<sup>th</sup>, 20<sup>th</sup> November in 2022 and 2023, respectively, by using 142.8 kg ha<sup>-1</sup> (60 kg fed<sup>-1</sup>) grain rate. NPK was applied to the soil in the following amounts: Nitrogen fertilizer was applied as urea (46.5% N) at rate of 75 Kg fed<sup>-1</sup>, in equal two doses, the first dose was at Mohayah irrigation (21 days after sowing); while the second addition was at the second irrigation was scheduled directly following the mohayah irrigation event (20 days after the first application). The amount of nitrogen in MAP (12%) was calculated from the nitrogen applied. Potassium was applied as potassium sulphate (48% K<sub>2</sub>O) at a rate of 24 kg K<sub>2</sub>O fed<sup>-1</sup>. Phosphorus was applied as in the previous treatments. Through the two growing seasons, other agricultural practices were added in the amounts advised by the Egyptian Ministry of Agriculture.

### Initial soil sampling

Soil samples were collected from three depths (0–20, 20–40, and 40–60 cm) prior to wheat sowing. The samples were air-dried, gently ground, and passed through a 2 mm sieve for the initial determination of soil physicochemical properties.

### Determination of soil physical and chemical properties

At harvest, soil samples were collected from each plot during the first and second growing seasons from two depths (0–20 and 20–40 cm). The collected samples were air-dried and analyzed for selected chemical properties, i.e., soil pH, which was determined according to the method described by McLean (1982), and soil EC was measured in the saturated soil extract using an EC meter and expressed as dS m<sup>-1</sup>, according to the procedure described by Page *et al.* (1982). The CEC, expressed as cmol kg<sup>-1</sup>, was determined using the sodium acetate (NaOAc) method following Kim *et al.* (1996). OM content was determined following the method of Bhattacharyya *et al.* (2015). Available N was estimated according to Matsumoto *et al.* (2000), and available P and K were determined following the procedures described by Tian *et al.*

(2021). Undisturbed soil samples were also used to evaluate some physical properties, i.e., Soil bulk density (g cm<sup>-3</sup>) and total porosity (%), which were determined according to standard methods described by Campbell (1994). All measurements were made in triplicate.

## Heavy Metals Analysis

### Samples digestion

One gram of soil was placed separately in a 100 mL beaker, and 15 mL of a tri-acid mixture consisting of HNO<sub>3</sub> (70%), HClO<sub>4</sub> (65%), and H<sub>2</sub> SO<sub>4</sub> (70%) in a ratio of 5:1:1 was added. The mixture was digested at 80°C until the solution became clear, indicating complete digestion. The digested solution was then filtered, diluted to 50 mL with distilled water, and analyzed for total Cd concentration according to the procedure described by Ogunfowokan *et al.* (2013). Available Cd in soil samples was also extracted by 0.05 M Diethylene Triamine Penta Acetic acid (DTPA), according to Lindsay and Norvall (1978).

### Crop growth and yield measurements

A one-square-meter area was selected from each replicate to measure the plant height (cm), yield, and its components were determined, including 1000-grain weight (g), grain yield (kg fed<sup>-1</sup>), and straw yield (kg fed<sup>-1</sup>). Grains and straw contents of N and P were determined using the Kjeldahl method and spectrophotometric analysis, respectively, according to the procedure described by Walinga *et al.* (2013), where each sample was digested using a mixture of sulfuric acid (H<sub>2</sub> SO<sub>4</sub>) and perchloric acid (HClO<sub>4</sub>) in a 1:1 ratio. N, P, and Cd were determined in the digested plant materials. The digested soil and plant samples were analyzed for their Cd concentration using inductively coupled plasma–optical emission spectrometry (ICP–OES; iCAP™ 7000 Plus Series, Thermo Scientific™, USA). Relative increase in yield (RI) was calculated as follows:

$$RI = (\text{yield in treatment} - \text{yield in control}) / (\text{yield in control}) \times 100.$$

### Harvest index ratio (HI)

Harvest index ratio for grain was determined as follows:

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Biological yield (grain + straw)}} \times 100$$

Sharma and Mittra (1988).

$$\text{Efficiency \%} = \frac{C_0 - C_1}{C_0} \times 100$$

Tanhan *et al.* (2007).

Where,  $C_0$ =initial concentration,  
 $C_1$ = final concentration

**Bio concentration factor (BF):** calculated by the following equation:

BF = total content of metal in plants/ total content of metal in soil (Brooks, 1998).

N content (kg/fed) of wheat grain = Grain yield (kg/fed)  $\times$  N% of wheat grain /100

P content (kg/fed) of wheat grain = Grain yield kg/fed  $\times$  P% of wheat grain /100

### Statistical Analysis

The data obtained from the two growing seasons were statistically analyzed using analysis of variance (ANOVA) according to the procedure described by Gomez and Gomez (1984) with the IRRISTAT software. Differences among treatment means were tested using the least significant difference (LSD) test at a probability level of  $P \leq 0.05$ .

## RESULTS AND DISCUSSION

### 1. Soil physical characteristics

#### 1.1. Soil bulk density and total porosity

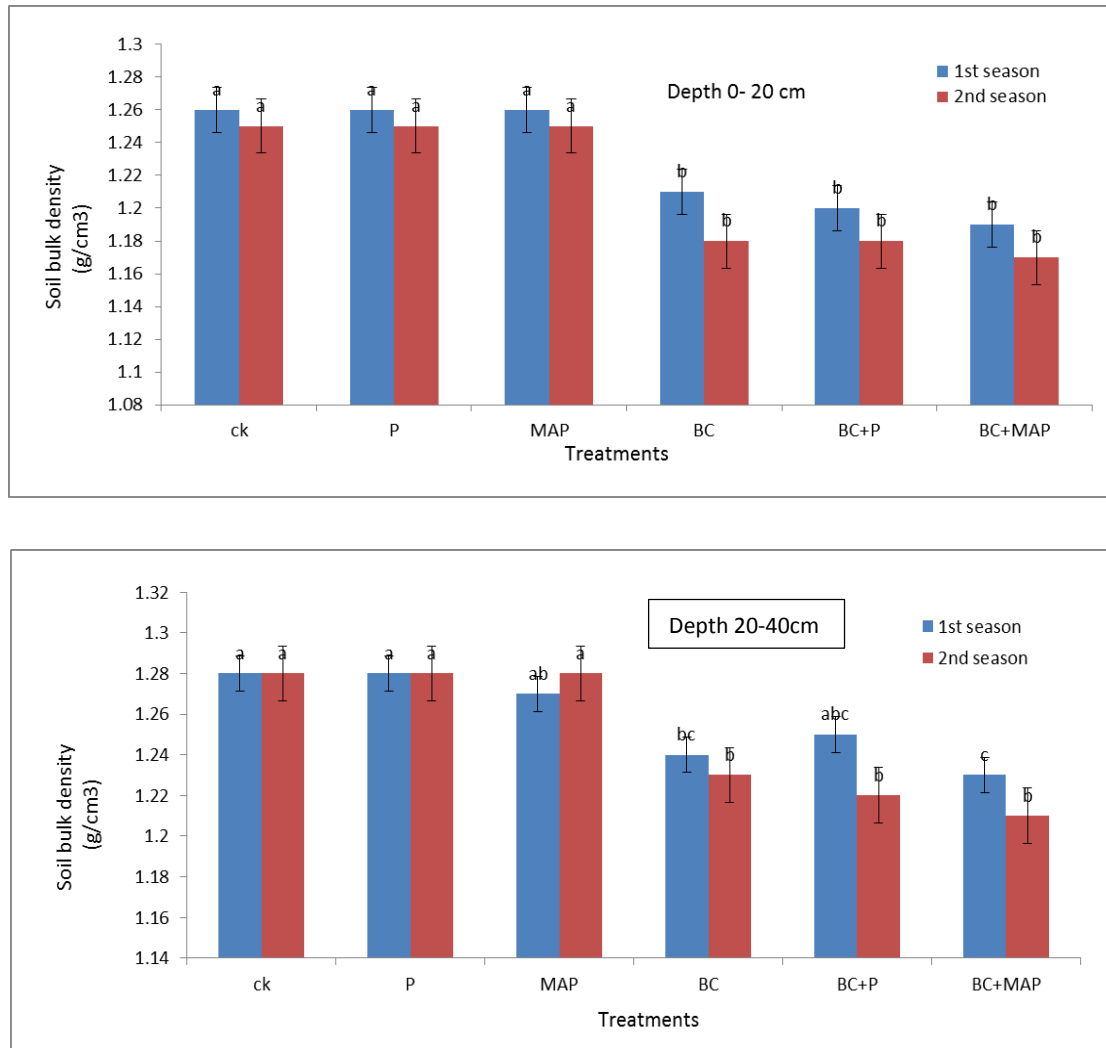
Soil bulk density (SBD) is a key parameter used as an indicator of soil structure status and serves as one of the criteria for assessing physical soil degradation. Results in Figs. 1 and 2 illustrated the effect of different soil treatments (calcium superphosphate, MAP, and BC) applied separately or together on bulk density and total porosity of both seasons. It was detected that bulk density data recorded for both soil layers was significantly lowered due to the application of the materials used, except calcium superphosphate and MAP fertilizers after

harvesting wheat, compared to untreated plots (Fig. 1). BC treatment was more beneficial than the recommended calcium superphosphate and MAP fertilizers in reducing bulk density values. Moreover, the effect was more pronounced in the surface soil layer (0–20 cm) compared to the subsurface layer (20–40 cm). The lowest bulk density was recorded under the treatment of biochar combined with MAP in both seasons. BC decreased the bulk density in the clay soil; an increase in soil organic carbon leads to an improvement in soil aggregate stability to aggregate, enhancing both macro- and micropores, which in turn increases soil porosity and decreases bulk density. Also, application of phosphorus fertilizers with biochar may increase root diffusion and increase root channels (Busscher *et al.*, 2010). These results were in agreement with Afaf *et al.* (2023). Lusiba *et al.* (2016) showed that the application of  $10 \text{ t ha}^{-1}$  of biochar combined with  $90 \text{ kg ha}^{-1}$  of phosphorus fertilizer reduced the bulk density of the clay soil. For example, during the first season, within the 0–20 cm soil layer, the reduction percentage of bulk density caused by biochar + calcium superphosphate and BC + MAP treatments was 4.76 and 5.56 %, respectively, compared to untreated plots.

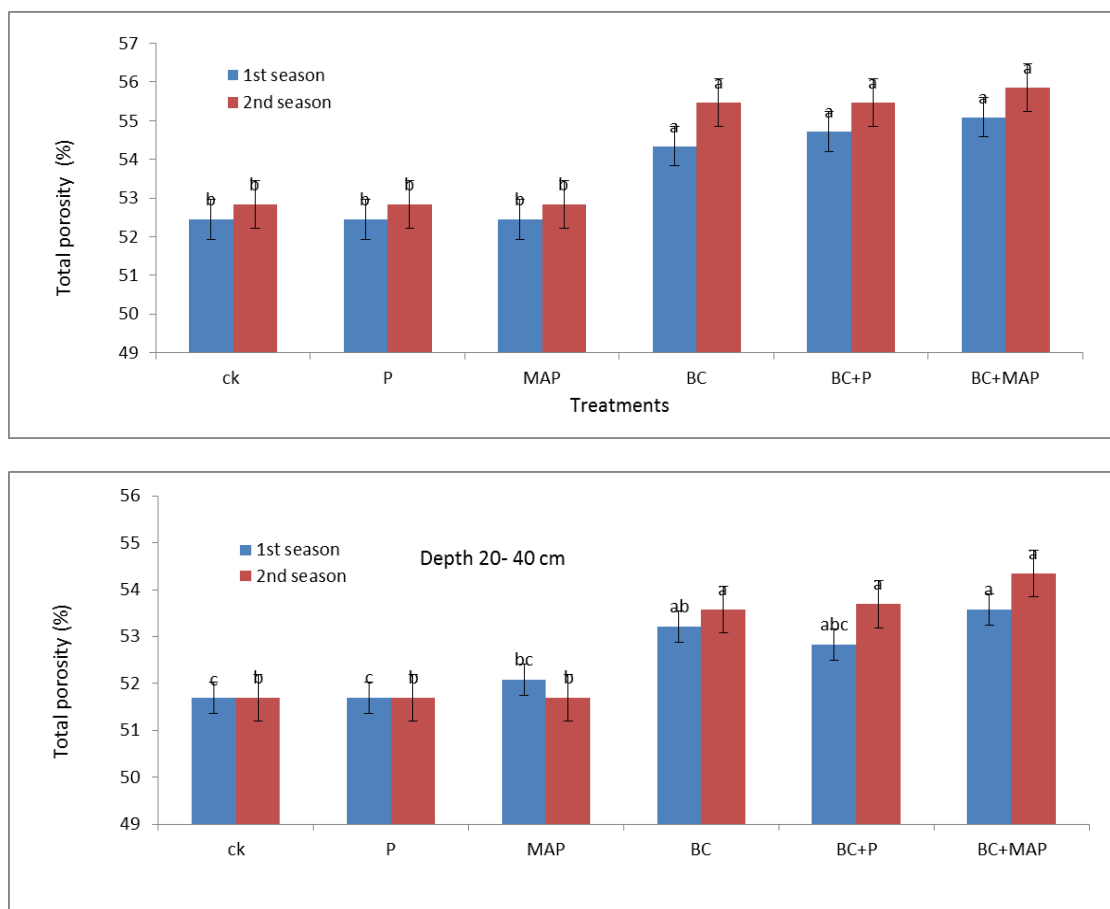
Soil porosity (SP) values take almost the opposite trend to that encountered with bulk density. Data showed that the values of total porosity were significantly increased especially in the topsoil (0–20 cm depth) through the individual application of different soil treatments or as duality treatment except calcium superphosphate and MAP fertilizers of both seasons compared to chick treatment Fig. 2. Results showed that BC treatment was superior to calcium superphosphate and MAP one in increasing total porosity values of both seasons. Meanwhile, there is no obvious difference between total porosity values in 20–40 cm soil depth at the 2<sup>nd</sup> season under application of calcium superphosphate and MAP fertilizers treatment, as well as the duality treatment. The use of MAP and calcium superphosphate

fertilizers could have an indirect impact on bulk density and porosity via modifications in soil aggregation associated with root activity (Bronick and Lal, 2005). Similar results were obtained with Xuan *et al* (2023), who said that the porosity was improved by adding organic

amendments. According to the above results, the BC + MAP treatment in 0- 20 cm depth, particularly in the second season, was the most effective treatment for improving soil physical properties.



**Fig. 1. Effect of calcium superphosphate, MAP fertilizers, BC, and the combined effect of both factors on soil bulk density (g/cm³) during the two consecutive seasons following the wheat harvest.**



**Fig. 2. Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on total porosity (%) during the two growing seasons after wheat harvest.**

## 2. Chemical attributes of the soil

### 2.1. Soil electrical conductivity (EC)

According to the data illustrated in Table 3, the application of different study treatments either alone or together significantly reduced soil EC measured in the two soil layers (0–20 and 20–40 cm) after two growing seasons compared to the control, which reduction due to BC amendment. It could be observed that soil EC values can be arranged in a descending order as 20–40 cm > 0–20 cm depth of both seasons, and this reduction in soil EC values in the 2<sup>nd</sup> season was more effective than the 1<sup>st</sup> one. Interestingly, the lowest EC value was obtained by BC treatment alone in the top soil in the 2<sup>nd</sup> season. Meanwhile, application of BC + calcium superphosphate treatment of the same character had the highest value in both study seasons in comparison with the other applied treatments.

For instance, in a 0–20 cm soil layer, at 1<sup>st</sup> season, the decrease in EC value treated with BC treatment was 7.85 %. Additionally, MAP, BC, and their combined treatment resulted in a decrease in soil EC represented by 3.40, 7.85, and 10.47%, respectively, over the untreated plots. Similar results were obtained by Mahmoud *et al.* (2017), who demonstrated that the salinity amelioration is due to the rise in water diffusion rate caused by the BC addition. BC and P fertilizer supply soil supplemented with cations  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and other cations. These cations replace the exchangeable  $\text{Na}^+$  from the soil matrix and form new stable aggregates (Sun *et al.*, 2016). These processes increase hydraulic conductivity, thereby facilitating water movement downward and enhancing salt leaching, which might be the reason for the rise of EC in soil depths.

## 2.2. Soil pH

Table 3 illustrates the influence of various soil treatments (calcium superphosphate, MAP, and BC) applied separately or alternatively on soil pH in two depths (0- 20, 20- 40 cm) during harvest for the two growing seasons. It could be noticed that soil pH values were significantly decreased by applying the materials used in comparison with the untreated plots. This decrease was more pronounced in the topsoil than in the subsurface. However, soil pH values under BC treatment in the 2<sup>nd</sup> season were clearly less than calcium superphosphate and MAP fertilizers. Meanwhile, the highest values of this trait were obtained under the chick treatment. This could be as a result of the release of carboxylic groups from the biochar (Brodowski *et al.*, 2006). Moreover, the release of electrons and organic acids during OM decomposition present in soil and BC interferes

with reducing pH and thus increasing the solubility of many nutrients. For instance, the decrement percentage in soil pH values was 0.39, 3.62, and 2.46% as a result of applied of calcium superphosphate, BC, and their duality treatment, respectively, in the 0- 20 cm soil layer at 1<sup>st</sup> season. Also, MAP, BC, and their combined treatment reduced soil pH values by 1.29, 3.62, and 4.14%, respectively, at the same level compared to control plots. Similar results were consistent with the findings reported by Mete *et al.* (2015) who stated that the same results where application of BC with NPK fertilizer decreased the pH in an alkaline soil. Rahim *et al.* (2010) reported that phosphorus fertilizer additions decreased pH in comparison with the control soil. Yamato *et al.* (2006) concluded that pH reduction after the application of superphosphate was the result of the release of H<sup>+</sup> ions during the dissolution process.

**Table 3: An assessment was carried out to determine the effect of calcium superphosphate, MAP, and BC, individually and in combination, on soil EC (dS/m), pH, and OM % during two consecutive seasons after wheat harvesting.**

| 2022/2023                   |           |         |            |         |        |         |
|-----------------------------|-----------|---------|------------|---------|--------|---------|
| Treatments                  | EC (dS/m) |         | pH (1:2.5) |         | OM%    |         |
|                             | 0-20cm    | 20-40cm | 0-20cm     | 20-40cm | 0-20cm | 20-40cm |
| Control                     | 3.82ab    | 4.40a   | 7.73a      | 7.78a   | 1.24d  | 1.11c   |
| Calcium superphosphate      | 3.76ab    | 3.93bc  | 7.70a      | 7.78a   | 1.24d  | 1.11c   |
| MAP                         | 3.69ab    | 3.81c   | 7.63ab     | 7.7ab   | 1.24d  | 1.12bc  |
| BC                          | 3.52b     | 3.70c   | 7.45b      | 7.66bc  | 1.51b  | 1.35ab  |
| BC + Calcium superphosphate | 4.12a     | 4.3ab   | 7.54ab     | 7.6cd   | 1.40c  | 1.23abc |
| BC + MAP                    | 3.42b     | 3.60c   | 7.41b      | 7.54d   | 1.65a  | 1.41a   |
| LSD at 0.05                 | 0.40      | 0.42    | 0.22       | 0.08    | 0.09   | 0.22    |
| F. test                     | *         | **      | *          | **      | **     | *       |
| 2023/2024                   |           |         |            |         |        |         |
| Control                     | 3.80a     | 4.30a   | 7.74a      | 7.79a   | 1.25b  | 1.12b   |
| Calcium superphosphate      | 3.60b     | 3.98abc | 7.73a      | 7.79a   | 1.25b  | 1.12b   |
| MAP                         | 3.56b     | 3.78bcd | 7.60b      | 7.65abc | 1.26b  | 1.13b   |
| BC                          | 2.99c     | 3.63cd  | 7.40d      | 7.68ab  | 1.64a  | 1.41a   |
| BC + Calcium superphosphate | 3.78a     | 4.2ab   | 7.50c      | 7.59bc  | 1.56a  | 1.32ab  |
| BC + MAP                    | 3.08c     | 3.41d   | 7.40d      | 7.50c   | 1.78a  | 1.51a   |
| LSD at 0.05                 | 0.17      | 0.42    | 0.06       | 0.15    | 0.23   | 0.22    |
| F. test                     | **        | **      | **         | **      | **     | **      |

## 2.3. Soil organic matter

Results showed a marked and significant increment in soil OM by applying different

treatments singly or as alternatively except calcium superphosphate and MAP fertilizers over to control, especially at (0- 20cm depth)

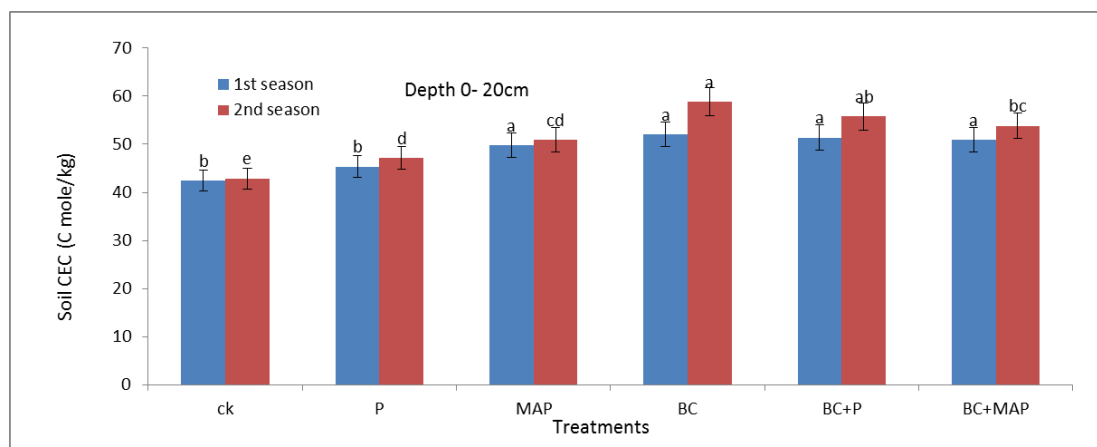


Table 3. This increment was more obvious in the 2<sup>nd</sup> season than in the 1<sup>st</sup> one. Moreover, BC treatments were superior to calcium superphosphate and MAP in promoting soil organic matter. These findings are consistent with those reported by Baiamonte *et al.* (2019) and Fu *et al.* (2019), who demonstrated that the incorporation of BC into soil enhances its organic carbon content and alters its physicochemical properties (including soil pore distribution and aggregate stability). Such improvements are closely related to the soil's capacity to retain water and conserve fertilizers (Ouyang and Zhang, 2013). Additionally, Lehmann *et al.* (2015) observed that BC is a highly stable material that can persist in the soil for hundreds of years when used as a carbon-rich amendment. Likewise, Abel *et al.* (2013) reported that incorporating BC into the soil enhances its organic carbon content. Also, it could be noticed that the BC + MAP treatment seemed to be the best one for increasing organic matter content in both soil layers during the two seasons, as compared to the other treatments. For instance, in the 0–20 cm soil layer during the second season, MAP, BC, and their duality treatment increased organic matter content by 0.8, 31.2, and 42.4%, respectively, relative to the control.

#### 2.4. Soil cation exchange capacity (CEC)

Data illustrated in Fig. 3 investigated the effect of calcium superphosphate, MAP, and BC treatments on soil CEC. It was clear that soil CEC in 0–20 cm depth was greatly improved by

applying the tested materials alone or as duality treatments of both seasons compared to untreated plots. Moreover, BC treatment was more pronounced in enhancing this character than calcium superphosphate and MAP one especially in the second season. In contrast, the lowest values of soil CEC were found with the control treatment. For instance, the increment percentage in soil CEC at the 2<sup>nd</sup> season in 0–20 cm depth was 18.49, 36.72, and 25.19 % as a result of application of MAP, biochar, and their duality treatment, respectively. Also, calcium superphosphate, BC, and their duality treatment increased the same character by 9.53, 36.72, and 29.63%, respectively, at the same season relative to corresponding control plots. However, the soil CEC under all treatments, values recorded in the second season, were noticeably higher than those obtained in the first season. This indicates that the CEC of biochar develops over time due to the oxidation of its surface functional groups upon exposure to oxygen and moisture (Lehmann and Joseph, 2015). Thus, the ability of biochar to retain nutrients can be attributed to its high specific surface area and porosity, as well as to its high functional groups loading (Lehmann and Joseph, 2003). Additionally, an increment of CEC due to high organic carbon and CEC of biochar (Gundale and DeLuca, 2006). Similar results were in agreement with the findings reported by Zhang *et al.* (2020). Lusiba *et al.* (2016) stated that the application of phosphorus fertilizer increased CEC. The same trend was detected for the MAP fertilizer.



**Fig. 3. Effect of calcium superphosphate and MAP fertilizers, BC, and their interaction on soil CEC (cmole/kg) during the two growing seasons after wheat harvest**

## 2.5. Soil available nutrient content

The obtained results listed in Table 4 indicated that all the used materials applied separately or as duality treatment markedly increased the available P content in two soil depths after wheat harvesting compared to untreated plots. The results showed that biochar treatment was more efficient in enhancing soil available P content than calcium superphosphate and MAP one especially in the 2<sup>nd</sup> season. These increments were more pronounced in the topsoil than in the subsurface. This finding was consistent with DeLuca *et al.* (2009), who stated that BC addition increased available P concentration; this increment could be attributed to the direct release of soluble P present in the biochar itself. It has been estimated that more than 80% of soil phosphorus becomes immobile and unavailable for plant uptake; however, BC can modify the balance between P adsorption and desorption, thereby influencing its dynamics in the soil (Gao *et al.*, 2016). In addition, BC facilitates the mineralization of organic phosphorus into its inorganic form. These findings are consistent with those reported by Farooque *et al.* (2020), who observed that biochar application significantly increased the availability of soil phosphorus.

The soil available P content was higher in the 1<sup>st</sup> season by applying calcium super phosphate fertilizer alone than 2<sup>nd</sup> one. Phosphorus tends to be fixed. This results in nutrient deficiencies in

the majority of crops. Naderi and Danesh (2013) found that approximately 80–90% of the applied phosphorus is lost when supplied in mineral fertilizer form. For instance, in the surface soil layer (0–20 cm), the rate of increase of available P content and pretreated with BC + MAP and BC + calcium superphosphate treatments were 61.52 and 54.04%, respectively, in the 2<sup>nd</sup> season compared to control plots. This might be due to biochar could reduce the leaching losses of applied P fertilizers, thereby decreasing the risk of phosphate pollution in water bodies (Kumari *et al.*, 2014). In addition, biochar possesses a strong ability to retain soil nutrients (Yamato *et al.*, 2006). Phosphorus efficiency of use can be improved through improving soil quality by using biochar (Gunes *et al.*, 214).

Concerning the soil content of available N, the data presented in Table 4 illustrated that the use of different soil amendments, each singly or together, significantly improved the available N content in the two soil depths of both seasons, except calcium superphosphate fertilizer. Moreover, applying MAP fertilizer was better than BC treatment alone in increasing soil available N content after two growing seasons in comparison with control plots. This increase was more pronounced in the topsoil (0–20 cm) than in the subsurface one (20–40 cm). For instance, in the 0–20 cm soil layer, the percentage increase of available N content was 152.17% and 166.67% as a result of the application of BC+

MAP treatment at the 1st and 2nd seasons, respectively, compared to the control. These increments are due to the decrease in pH with MAP application and an increase in microbial activity. In contrast, P fertilizer application did not increase available N concentration. This finding aligns with Gunes *et al.* (2014), who reported that the concentrations of available N significant increased with the combination of BC and P fertilizers in alkaline soil compared to the control. Also, this increment is likely attributed

to the capacity of BC to reversibly retain nutrients (Singh *et al.*, 2010) and its potential to function as a slow-release fertilizer (Alling *et al.*, 2014). Nigussie *et al.* (2012) demonstrated that the applied of BC at different application rates of 5 and 10 t ha<sup>-1</sup> significantly increased available N content. Thus, it can be mentioned that the combined application of the tested materials achieved the best results for increasing the available N content compared to other treatments.

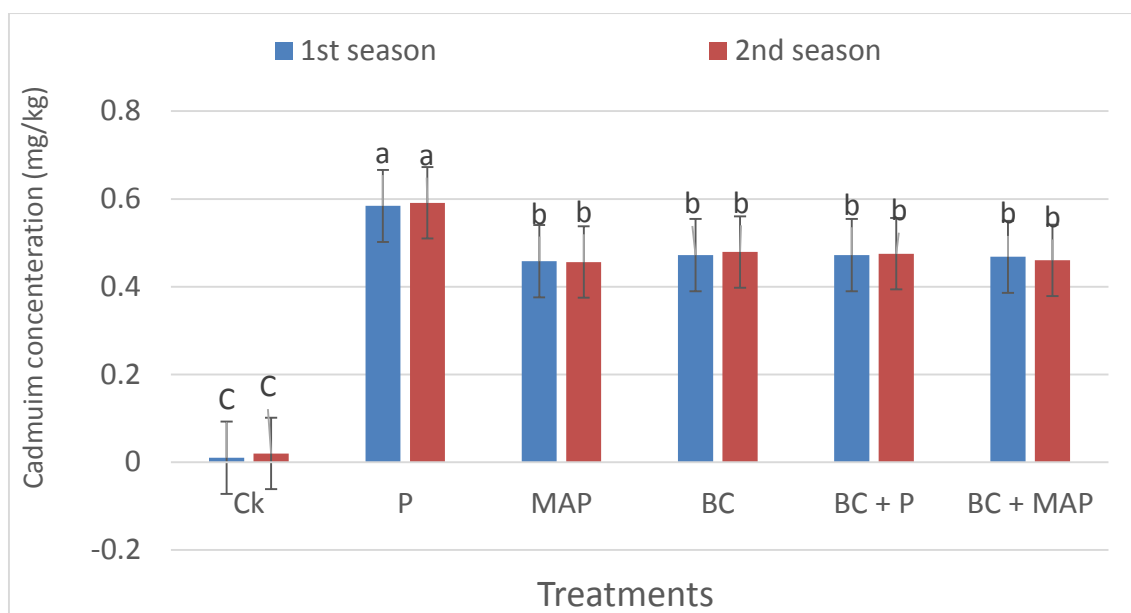
**Table 4: Effect of calcium superphosphate and MAP fertilizers, BC, and their interaction on soil available P level (mg/kg) and soil available N (mg/kg) during the two growing seasons after wheat harvest.**

| Treatments                  | 2022/2023 |         |           |         | 2023/2024 |         |           |         |
|-----------------------------|-----------|---------|-----------|---------|-----------|---------|-----------|---------|
|                             | P (mg/kg) |         | N (mg/kg) |         | P (mg/kg) |         | N (mg/kg) |         |
|                             | 0-20cm    | 20-40cm | 0-20cm    | 20-40cm | 0-20cm    | 20-40cm | 0-20cm    | 20-40cm |
| Control                     | 9.10b     | 7.80    | 23.0e     | 18.3d   | 9.90c     | 8.10    | 23.1e     | 18.0d   |
| Calcium superphosphate      | 11.2ab    | 8.90    | 23.0e     | 18.5d   | 11.0bc    | 8.85    | 23.1e     | 18.0d   |
| MAP                         | 12.6ab    | 9.55    | 35.9c     | 29.8bc  | 12.9abc   | 9.80    | 38.5c     | 31.7bc  |
| BC                          | 13.8a     | 9.98    | 30.1d     | 25.3c   | 14.6ab    | 10.2    | 30.8d     | 26.9c   |
| BC + calcium superphosphate | 14.67a    | 10.09   | 42.9b     | 32.1b   | 15.25ab   | 10.9    | 46.2b     | 34.9b   |
| BC + MAP                    | 15.2a     | 10.80   | 58.0a     | 40.1a   | 15.99a    | 11.3    | 61.6a     | 43.4a   |
| LSD at 0.05                 | 3.77      | -       | 5.76      | 5.14    | 4.23      | -       | 4.98      | 6.03    |
| F. test                     | *         | Ns      | **        | **      | *         | Ns      | **        | **      |

### 3. Concentration of cadmium in soil

Fig. 4 indicates the effect of different soil treatments (calcium super phosphate, mono ammonium phosphate, and biochar) applied alone or together on soil cadmium concentration in the 0- 20 cm depth of both seasons at harvest time. Soil cadmium values were significantly increased by applying the used materials compared to untreated plots. It could be noticed that soil cadmium values can be decreased in the order of calcium superphosphate > BC > MAP treatments of both seasons. The physical properties of BC, including pore number, pore structure, and specific surface area, significantly

influence nutrient availability in soil (Xu *et al.*, 2022). Additionally, the capacity of biochar to buffer soil pH is closely linked to its cation exchange capacity (CEC) (Xu *et al.*, 2012). Salmanzadeh *et al.* (2016) reported that the application of chemical fertilizers may lead to cadmium (Cd) contamination in soil, resulting in higher Cd concentrations in soils treated with chemical fertilizers compared to those amended with organic materials. Fertilizers have long been used to improve soil fertility and crop yields (Zhang *et al.*, 2020); however, excessive fertilizer application can cause serious environmental pollution.



**Fig. 4. Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on available soil Cd concentration (mg/kg) during the two growing seasons after wheat harvest**

Prolonged use of NPK fertilizers can lead to a decline in soil fertility, reducing the stability of soil aggregates and depleting essential micronutrients. The application of mineral fertilizers may also introduce potentially harmful heavy metals into the soil-plant system. Additionally, phosphate rock-based fertilizers frequently contain trace elements, such as cadmium, that can be toxic (Kumar *et al.*, 2021). BC exhibits strong selective adsorption of heavy metals in soils with multiple metal contaminants (Wang *et al.*, 2017). It also contains appreciable amounts of K, Ca, and Mg ions, which supply exchangeable cations that enhance ion exchange and increase its competitive ability to immobilize heavy metals in the soil. BC contains many hydroxyls, carboxyl, and other functional groups that are favorable for complexation with heavy-metal ions. Comparable findings were reported by Adriano (2001), who observed that cadmium levels decreased as the soil CEC increased through the addition of organic matter, which also promoted greater growth of oat shoots. This was probably due to the inhibition of Cd availability, which in turn diminished the harmful effects of Cd on growth and human health.

#### 4. Yield and its components

Data in Table 5 declared the influence of different soil treatments (calcium superphosphate, MAP, and BC) applied separately or as alternatively on measured yield parameters, including wheat straw yield, grain yield, and thousand-grain weight in the growing 1<sup>st</sup> and 2<sup>nd</sup> seasons at harvest time. It was observed that the application of the tested materials caused a pronounced increment in straw yield, wheat grain yield, and 1,000-grain weight compared with the control value. Data showed that MAP fertilizer was more effective than calcium superphosphate and BC treatments in increasing straw and grain yield. Meanwhile, 1000-grain weight was higher in BC treatment than in calcium superphosphate and MAP fertilizers in the two seasons of the study. Similar observations were made by Albuquerque *et al.* (2014), who indicated that at mineral fertilizer and the incorporation of biochar resulted in an approximately 20–30% increase in sunflower yield compared with using mineral fertilizer alone. Consequently, BC application can be utilized to enhance wheat grain yield and decrease dependence on chemical fertilizers. The

observed increase in plant yield with BC application can be attributed to improvements in soil quality and enhanced nutrient availability for crops (Gaskin *et al.*, 2010). Likewise, the combined use of chemical fertilizers and BC likely contributed to higher wheat grain and straw yields by improving soil physical properties and increasing OM content (Mahmoud *et al.*, 2017). These beneficial effects have also been linked to biochar's low bulk density, high water-holding capacity, and enhanced nutrient retention (Chan and Xu, 2009). Additionally, Arif *et al.* (2017) reported that the joint application of BC and P fertilizers increased the 1,000-grain weight of wheat. Majeed *et al.* (2014) observed a significant increase in 1,000-

grain weight with increasing P applications. This increase is due to improved accumulation of photosynthesis that is affected by P fertilization. Rahim *et al.* (2010) observed that raising P fertilizer rates resulted in significant increases in grain yield, straw yield, and 1,000-grain weight. For example, calcium superphosphate, MAP, and BC treatments at 1st season gave 7.28, 10.46, and 8.87% increments in grain yield, respectively. Moreover, the increment percentage of 1000-grain weight was 6.38, 12.31, and 16.12% for the same treatments at the 1<sup>st</sup> season, respectively, compared to the control value. Results illustrated that BC + MAP appeared to be the most effective treatment for enhancing the yield parameters of wheat plants.

**Table 5: Effect of calcium superphosphate, mono MAP fertilizers, BC, and their interaction on Straw yield (kg/fed), Grain yield (kg/fed), 1000-grain weight (g), and plant height (cm) of wheat plants during the two growing seasons.**

| Treatments                  | Straw yield (kg/fed) |           | Grain yield (kg/fed) |           | 1000-grain weight (g) |           | plant height (cm) |           |
|-----------------------------|----------------------|-----------|----------------------|-----------|-----------------------|-----------|-------------------|-----------|
|                             | 2022/2023            | 2023/2024 | 2022/2023            | 2023/2024 | 2022/2023             | 2023/2024 | 2022/2023         | 2023/2024 |
| Control                     | 3471.7d              | 3510c     | 2725e                | 2820e     | 47.78e                | 47.85e    | 90.71f            | 90.70f    |
| Calcium superphosphate      | 3526.7c              | 3565bc    | 2923.3d              | 2963.3d   | 50.83d                | 51.86d    | 91.23e            | 91.49e    |
| MAP                         | 3660b                | 3753.3a   | 3010bc               | 3090bc    | 53.66c                | 53.75c    | 95.82d            | 95.94d    |
| BC                          | 3561.7c              | 3583.3b   | 2966.7cd             | 3060c     | 55.48b                | 56.07b    | 98.85c            | 99.37c    |
| BC + calcium superphosphate | 3538.3c              | 3583.3b   | 3036.7b              | 3146.7b   | 55.69b                | 55.87b    | 99.77b            | 101.2b    |
| BC + MAP                    | 3723.3a              | 3758.3a   | 3196.7a              | 3310a     | 56.73a                | 57.36a    | 103.3a            | 104.4a    |
| LSD at 0.05                 | 51.31                | 58.70     | 49.30                | 59.19     | 0.588                 | 0.307     | 0.488             | 0.393     |
| F. test                     | **                   | **        | **                   | **        | **                    | **        | **                | **        |

With respect to the impact of various soil treatments applied alone or together on plant height of wheat plants, Table 5 illustrates that plant height was significantly rose by using calcium superphosphate, MAP, BC, and their duality treatments compared to the control. The results illustrated that BC treatment was better than calcium superphosphate and MAP fertilizers in improving plant height, especially in the 2<sup>nd</sup> season. Similar results were in agreed with those obtained by Agegnehu *et al.* (2017), who found that the plant height of wheat increased with BC addition. This increase is due to BC's functions as

a soil conditioner, which promotes plant growth by providing nutrients more efficiently, and contributes to increased crop yields (Spokas *et al.*, 2012). Furthermore, the observed improvement in crop growth is likely related to enhanced P availability. P is essential for plant growth and development, as it supports early root formation, plays a key role in cell division, and is vital for energy transfer within the plant (Dotaniya *et al.*, 2014). Secondly, the observed increase in plant height may be attributed to the combined application of BC and calcium superphosphate fertilizers. BC enhances soil

fertility by improving both the physical and chemical properties of the soil and by increasing the availability of essential nutrients (Arif *et al.*, 2017); it improves the nutrient-holding capacity and the soil's ability to retain water and its cation exchange capacity (Liang *et al.*, 2006). For instance, calcium superphosphate, MAP, BC, BC + calcium superphosphate, and BC + MAP treatments in the 2<sup>nd</sup> season caused an increment in plant height of wheat plants represented by 0.87, 5.78, 9.56, 11.58, and 15.10%, respectively. This indicates the ability of BC to enhance P use efficiency, which may be the reason for increasing plant height. Thus, it can be mentioned that the BC + MAP achieved the best result for increasing the plant height of wheat plants compared to other treatments.

The application of different soil treatments, whether individually or in combination, resulted in a marked increase in N use efficiency (N-UE), harvest index (HI), and relative increase (RI) at harvest compared with the control values (Table 6). Concerning N-UE, the application of calcium superphosphate, MAP, and BC, either individually or in combination, significantly enhanced this parameter in both seasons (Table 6). The lowest N-UE values were observed in the control plots, whereas the greatest increases were achieved with the dual application of BC and MAP during the first season. The increment percentage of nitrogen use efficiency in grains in the 2<sup>nd</sup> season as affected by MAP, BC, and their duality treatment was 7.98, 9.57, and 9.39%, respectively, over to control. BC can help improve soil quality and increase P use efficiency (Gunes *et al.*, 214). More than 80% of applied phosphorus becomes immobile and unavailable for plant uptake due to processes such as adsorption, precipitation, or conversion to organic forms El-Dissoky *et al.* (2020). Biochar has emerged as a simple yet effective technology that provides multiple environmental benefits when incorporated into soil, including long-term carbon sequestration and enhanced P use efficiency (P-UE) (Woolf *et al.*, 2010). This improvement is attributed to BC's ability to

adsorb ammonia and nitrate, reduce nitrate leaching, and increase N fertilizer use efficiency (Spokas *et al.*, 2012).

The addition of MAP and calcium superphosphate to soil often results in low overall N and P use efficiency, as only the soluble fractions of these nutrients are available for plant uptake (Vassilev and Vassileva, 2003). To compensate, land managers and homeowners frequently apply inorganic N and P fertilizers in amounts exceeding plant requirements, which can lead to nutrient leaching and contamination of surface and groundwater.

Data indicated that the harvest index ratio (HI%) and relative increase (RI%) of wheat significantly improved with the application of various soil treatments (calcium superphosphate, MAP, and BC) in both seasons compared to the control, as shown in Table 6. It was observed that the duality treatment of MAP + BC recorded the highest harvest index ratio% of wheat at 1<sup>st</sup> and 2<sup>nd</sup> seasons (46.19 and 46.83%, respectively) as compared with the control. Likewise, this treatment achieved the highest value of relative increase (RI) from wheat (grains and straw) (17.31, 17.39, and 7.25, 7.08%, respectively) over the control treatment.

It was observed that biochar treatment gained the highest value of harvest index % and relative increase of grain wheat, while mono ammonium phosphate treatment was better than the calcium superphosphate and BC ones in relative increase of straw wheat, as compared with the control one. This finding agrees with Lorry *et al.* (2006), who reported that mineral fertilizers release nutrients rapidly during the early growth stages, whereas organic amendments provide a gradual nutrient release extending into later developmental stages. El-Dissoky *et al.* (2020) revealed that the application of green manures prior to barley sowing, combined with different rates of mineral P fertilizer, significantly influenced the relative increase percentage (RI%) and P-UE (expressed as kg yield per kg P applied).

**Table 6: Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on N-UE; harvest index ratio (HI) %, and relative increase (RI) % of wheat plants over the two growing seasons**

| Treatments                  | N-UE Grain          |                    | HI (%)             |                    | RI Grain %         |                    | RI Straw%         |                   |
|-----------------------------|---------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------------------|
|                             | 2022/2023           | 2023/2024          | 2022/2023          | 2023/2024          | 2022/2023          | 2023/2024          | 2022/2023         | 2023/2024         |
| Control                     | 36.33 <sup>e</sup>  | 37.6 <sup>e</sup>  | 43.98 <sup>c</sup> | 44.55 <sup>d</sup> | 0 <sup>e</sup>     | 0 <sup>e</sup>     | 0 <sup>a</sup>    | 0 <sup>c</sup>    |
| Calcium superphosphate      | 38.98 <sup>d</sup>  | 39.51 <sup>a</sup> | 45.15 <sup>b</sup> | 45.39 <sup>c</sup> | 7.28 <sup>d</sup>  | 5.09 <sup>d</sup>  | 1.58 <sup>b</sup> | 1.57 <sup>b</sup> |
| MAP                         | 39.56 <sup>cd</sup> | 40.6 <sup>c</sup>  | 43.32 <sup>b</sup> | 45.15 <sup>c</sup> | 8.87 <sup>cd</sup> | 8.52 <sup>c</sup>  | 5.43 <sup>b</sup> | 6.93 <sup>a</sup> |
| BC                          | 40.13 <sup>bc</sup> | 41.2 <sup>bc</sup> | 45.44 <sup>b</sup> | 46.06 <sup>b</sup> | 10.6 <sup>bc</sup> | 9.59 <sup>bc</sup> | 2.59 <sup>c</sup> | 2.28 <sup>b</sup> |
| BC + calcium superphosphate | 40.49 <sup>b</sup>  | 41.95 <sup>b</sup> | 46.17 <sup>a</sup> | 46.76 <sup>a</sup> | 11.44 <sup>b</sup> | 11.59 <sup>b</sup> | 1.92 <sup>c</sup> | 2.09 <sup>b</sup> |
| BC + MAP                    | 42.62 <sup>a</sup>  | 41.13 <sup>a</sup> | 46.19 <sup>a</sup> | 46.83 <sup>a</sup> | 17.31 <sup>a</sup> | 17.39 <sup>a</sup> | 7.25 <sup>a</sup> | 7.08 <sup>a</sup> |
| LSD at 0.05                 | 0.66                | 0.79               | 0.37               | 0.51               | 2.02               | 2.84               | 1.48              | 1.51              |
| F. test                     | ***                 | ***                | ***                | ***                | ***                | ***                | ***               | ***               |

N-UE: Nitrogen use efficiency; HI: Harvest index ratio; RI: Relative Increase

## 5. Nutritional wheat grain composition (%)

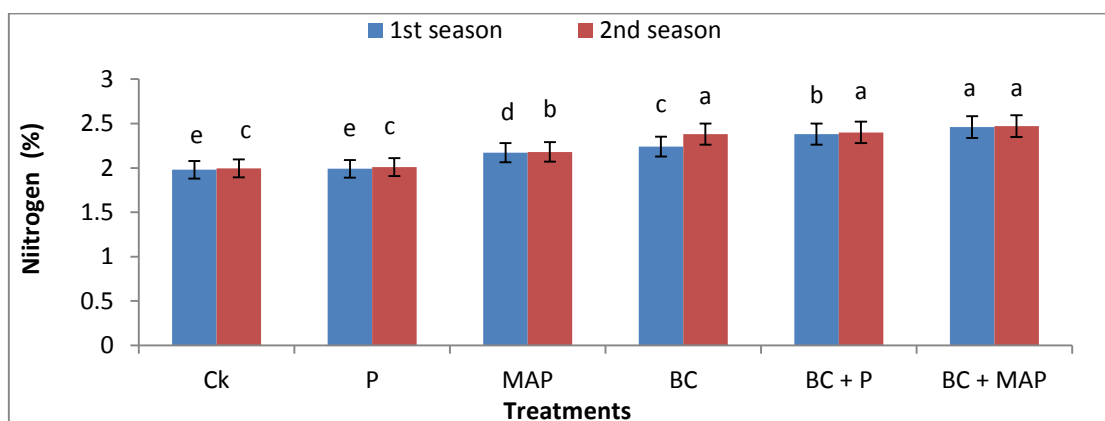
A significant increment was detected in nitrogen content of grains when soil was treated with different treatments singly or as an alternative to two growing seasons (Fig. 5). The results showed that BC treatment is superior to MAP fertilizer in improving nitrogen in grains, especially at 2<sup>nd</sup> season. Meanwhile, there is no obvious difference in N values between the calcium superphosphate fertilizer and the control. This result agrees with Barnes *et al.* (2014), who reported that BC application significantly increased N concentration in the yielded grain. Asai *et al.* (2009) indicate that nutrient availability is greater when biochar is applied together with inorganic fertilizers than when either is applied individually. Ali *et al.* (2015) indicated that wheat grain yields at 80 kg N ha<sup>-1</sup> with rice straw BC was higher than that at the sole use of 120 kg N ha<sup>-1</sup> on non-amended plots.

Concerning the P percentage of wheat grains, data in Fig. 6 revealed that application of calcium superphosphate, MAP, and BC treatments alone or together significantly increased phosphorus % in wheat grains. For instance, calcium superphosphate, MAP, BC, and BC + MAP treatments at the 2<sup>nd</sup> season gave an increment of P% in grains represented by 7.5,

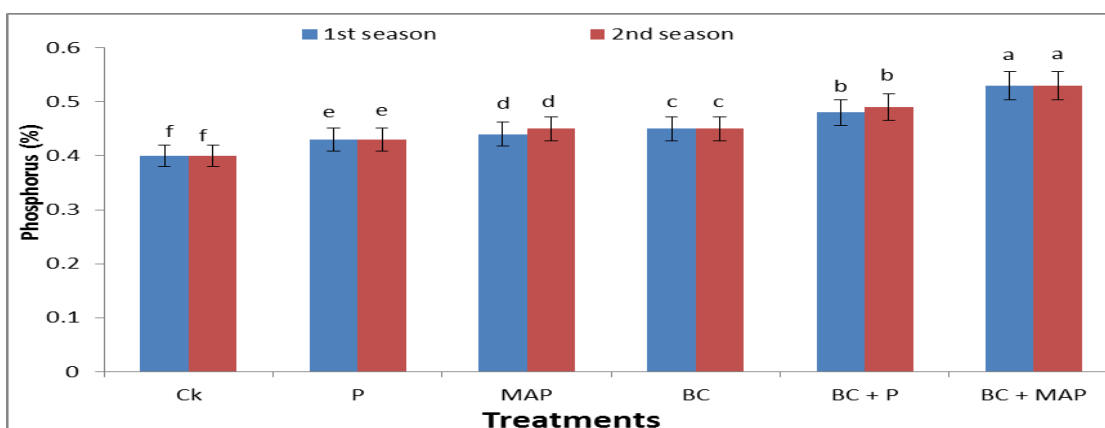
12.5, 12.5, and 32.5%, respectively, relative to the control. P availability to crops is influenced by soil phosphorus content, fertilizer management, and environmental conditions that affect P availability and root growth. Achieving optimum crop yield requires an adequate supply of phosphorus, either from the soil or through fertilizer additions. When early-season P availability is low, fertilization can enhance P nutrition and improve yield potential. Sustainable P management practices should be implemented in both conventional and MAP-based agricultural systems (Grant *et al.*, 2010). Rahim *et al.* (2010) reported that the phosphorus concentration in wheat grain increased significantly with higher P application rates. This improvement can be attributed to the immediate availability of phosphorus from chemical fertilizers and the additive effects of biochar, which, under optimal soil pH, enhances P availability (Nigussie *et al.*, 2012). Additionally, biochar can immobilize P-complexing metallic ions, reducing phosphorus fixation, and it can modify the equilibrium between P adsorption and desorption, thereby influencing soil P dynamics (Gao *et al.*, 2016). Incorporating a P source, such as MAP, into BC has been shown to increase soil P levels, likely due to BC's capacity to enhance nutrient availability to plants (Liu *et al.*, 2010). The observed increase in soil P (Table 5) is also

attributed to the phosphorus retained within biochar during pyrolysis, which remains in a plant-available form (Morales *et al.*, 2013).

It could be mentioned that application of BC + MAP treatment, especially at the 2<sup>nd</sup> season, appeared to be the most effective treatment for enhancing N and P % in the yielded grains of wheat plants than other treatments.



**Fig 5: Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on N in grains of wheat plants over the two growing seasons.**



**Fig 6: Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on P content in wheat grains during the two growing seasons."**

## 6. Nutrition Content of Wheat Grains (kg/fed)

### 6.1. N content

The result presented in Fig. 7 revealed the effect of calcium super phosphate, mono ammonium phosphate, and BC treatments on N content of wheat grains. Results showed that all treatments markedly increased N content in grains of both seasons compared to the control. N content of grain wheat showed a significant increase with the addition of calcium

superphosphate and MAP fertilizers from 58.18 and 65.28 kg fed<sup>-1</sup> to 49.41 and 67.21 kg fed<sup>-1</sup> in the 1<sup>st</sup> and 2<sup>nd</sup> seasons, respectively. This result agrees with Haileselassie *et al.* (2014), who indicated that total N uptake of wheat rose with higher phosphorus fertilizer rates. Also, Gunes *et al.* (2014) found that biochar with P application significantly increased N uptake in wheat plants. Calcium superphosphate fertilization or the addition of organic amendments to soil provides nutrients that are available to plants only for a limited period, as they can be lost over time



through plant uptake, chemical conversion to insoluble forms, or adsorption onto mineral and organic soil surfaces. Similarly, Major *et al.* (2010) found that the BC addition has a positive effect on N uptake when used as a soil amendment. The positive BC effect on N content

is due to the high availability of nitrogen of biochar itself and the yield of wheat, as well as reduced gaseous N losses and diminished N leaching (Brockhoff *et al.*, 2010).

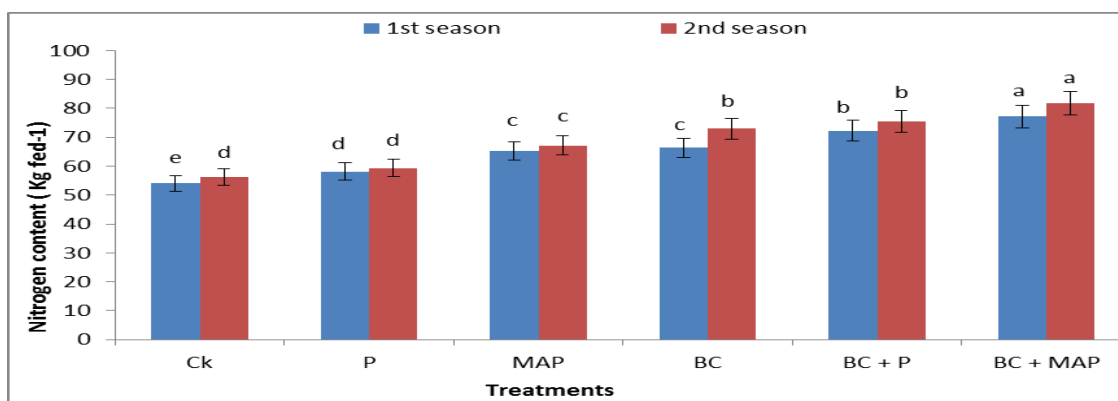


Fig 7: Impact of calcium superphosphate fertilizer, MAP, and BC, as well as their combined application, on N levels in wheat grains (kg fed<sup>-1</sup>) during the winter seasons.

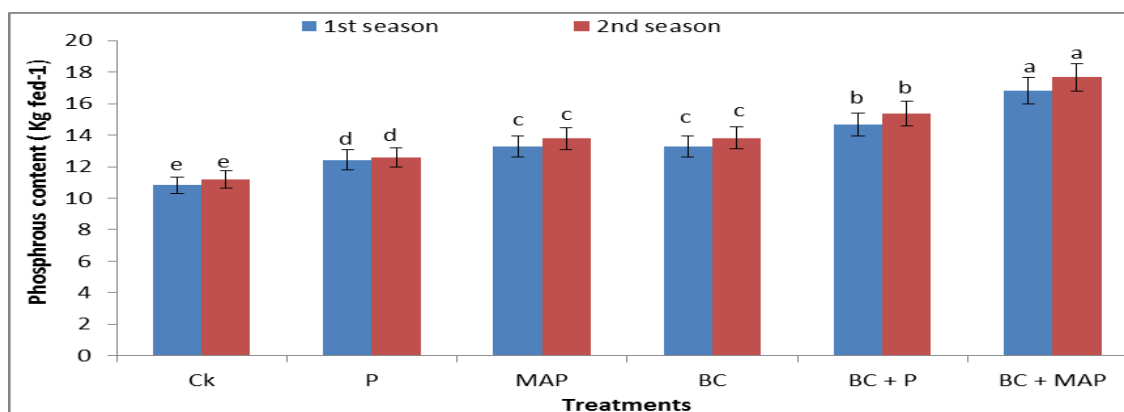


Fig 8: Effect of calcium superphosphate, MAP fertilizers, BC and their interaction on P content of wheat grains (kg fed<sup>-1</sup>) during the winter seasons.

## 6.2. Phosphorus (P) content

The results shown in Fig. 8 illustrate the effect of different soil treatments (calcium superphosphate, MAP, and BC), applied either alone or as duality treatments on P content in wheat grains at harvest time. Results indicated a notable and progressive rise in P content in wheat grains of two growing seasons relative to control plots. Additionally, the combined application of BC and MAP appeared to be the most effective treatment for enhancing

phosphorus content compared with the other tested treatments. For instance, the increment percentages of P content were 37.27 and 57.91% as a result of application of biochar + calcium superphosphate and BC + MAP treatments at the 2<sup>nd</sup> season, respectively. Similarly, Lehmann *et al.* (2003) found that P uptake increased when charcoal was added to the soil. This increase could be due to higher P content of BC, as well as the observed increase in plant growth and P content can be attributed to BC's ability to enhance soil P retention and provide a more

available supply of P to growing plants (Madiba *et al.*, 2016). Moreover, Haileselassie *et al.* (2014) indicated that total phosphorus uptake by wheat increased as the rate of P application increased and showed that this increase may be due to consistent with the soil P content and the yield response of wheat to P application. Madiba *et al.* (2016) investigated that BC applied with P fertilization increases available P uptake. This increase is due to BC increasing P use efficiency regarding P uptake by various crops. Rahim *et al.* (2010) observed that P uptake in wheat crop increased significantly with the increase of inorganic P application rates.

## 7. Bioconcentration factor of cadmium in the grains of the wheat plant

The bioconcentration factor (BCF) values in the wheat are presented in Fig. 9. The BCF values for Cd were lower than 1 except inorganic MAP fertilizer treatment (1.28 and 1.18 mg/kg). Meanwhile, the lowest concentration of Cd (0.56 and 0.48) was found in BC + calcium superphosphate treatment in the 1<sup>st</sup> and 2<sup>nd</sup> seasons, respectively. This indicates that bioconcentrations of Cd were low except for monoammonium phosphate fertilizer treatment in wheat plants. The mobility index of heavy metal (Cd) in plants treated with only calcium superphosphate and MAP fertilizers was higher than that for fertilizers mixed with BC Fig.9. This means that the application of heavy metal

with fertilizers has increased. The combined addition of organic-amended and monoammonium phosphate fertilizer increased the growth of roots and shoots of wheat plants. Increasing the growth of the wheat root system enabled the plants to access more contaminated soil, thereby enhancing their efficiency in extracting Cd.

Concentration of Cd was lower in soils amended with biochar compared to the control (Fig. 9). In contrast, nutrient use efficiency (NUE) for heavy metals was higher in plants grown in organically amended soils than in the control (Table 9). Moreover, BC amendment reduced the concentration of heavy metals Fig. 9. Hameeda *et al.* (2019) observed that biochar-based organic fertilizers, which enhance plant biomass production and WUE, also improve NUE for heavy metal absorption. Furthermore, wood-derived BC has been shown to reduce heavy metal concentrations in plants grown in soils with high heavy metal contamination. Although wood-derived biochar itself contains low nutrient levels, when combined with nutrient-rich organic fertilizers, it can adsorb nutrients from the fertilizer and supply them to plants as a slow-release source. This not only improves nutrient availability but also helps reduce heavy metal uptake in plants. (Xu *et al.*, 2016).

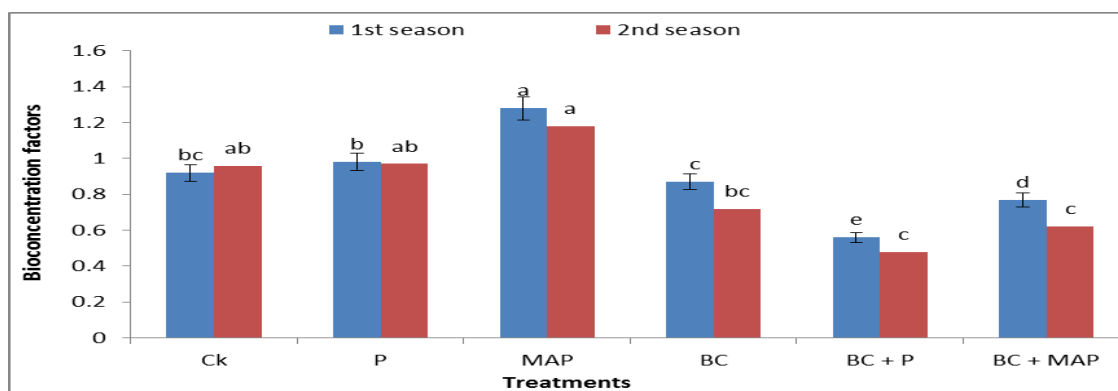


Fig 9: Effect of calcium superphosphate, MAP fertilizers, BC, and their interaction on bioconcentration factor of cadmium in wheat plant.

MAP application has been reported to enhance the growth and yield of various crops without causing negative environmental effects (Rady, 2011). Applying fertilizers in combination with organic amendments to farmland offers an economical and environmentally sustainable approach to boost crop production while reducing the bioavailability of heavy metals (Younis *et al.*, 2015). BC possesses favorable properties such as a stable carbon fraction, high surface area, porosity, and diverse functional groups, which contribute to nutrient retention and make it an effective fertilizer enhancer (Nardis *et al.*, 2020). BC-based N fertilizers are promising for sustainable agricultural development, mitigating N losses and increasing soil C stocks (Puga *et al.*, 2019). BC enriched with P sources was shown to greatly improve C stability and showed increased plant P-UE in highly weathered soils (Carneiro *et al.*, 2021). These properties make biochar a promising carrier for nitrogen, enhancing the efficiency of N-P fertilizers and potentially improving N-UE in crops.

## CONCLUSION

The application of chemical fertilizers contributed to the gradual accumulation of cadmium in the soil. The results of the present study indicated that cadmium concentrations remained within national standards. Moreover, cadmium levels in soils treated with chemical fertilizers were slightly higher than those in soils amended with biochar, as the bioconcentration factor of cadmium in BC+P treatment was the lowest. The results investigated that the interaction effect of different soil treatments (calcium super phosphate, monoammonium phosphate, and biochar) had a positive effect in enhancing the soil physio-chemical properties via (bulk density, total porosity, EC, organic matter, pH, and cation exchange capacity) in addition for improving soil available nitrogen and phosphorus and this reflected an increase in wheat yield. Consequently, this combined application may be considered as a good strategy to the suitability of phosphorus in soil and reducing pollution with heavy metal on straw

yield, grain yield, 1000-grain weight, plant height, nitrogen use efficiency, harvest index ratio, relative increase, and nutritional wheat grain composition, N and P content in grains of wheat plants.

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## دراسة تأثير الفحم الحيوي على إتاحة الفوسفور في التربة وتقليل التلوث بالكاديوم.

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### الملخص العربي

أجريت تجربة حقلية خلال موسمي ٢٠٢٣ و ٢٠٢٤ على محصول القمح في مزرعة محطة البحوث الزراعية بسخا، محافظة كفر الشيخ، مصر، بهدف دراسة تأثير كلٍّ من سوبر فوسفات الكالسيوم، فوسفات أحادي الأمونيوم، والفحم الحيوي كمُحسِّن عضوي، وكذلك تأثير المعاملات المزوجة منها، على خصائص التربة الطينية، مدى تيسر الفوسفور، وتقليل التلوث بعنصر الكاديوم. تُقَدَّت التجربة باستخدام تصميم القطاعات العشوائية الكاملة بثلاث مكررات.

أظهرت النتائج أن الكثافة الظاهرية للتربة انخفضت مع تطبيق المواد المستخدمة باستثناء سوبر فوسفات الكالسيوم وفوسفات أحادي الأمونيوم، في حين زادت المسامية الكلية ومحتوى المادة العضوية بشكل ملحوظ. كما أدت جميع المعاملات إلى خفض قيم الأس الهيدروجيني (pH) والتوصيل الكهربائي (EC)، بينما ازدادت السعة التبادلية الكاتيونية (CEC) مع جميع المعاملات.

أظهرت أحدثت جميع المعاملات تحسناً ملحوظاً في المحتوى الميسر من الفوسفور في التربة، كما زاد المحتوى الميسر من النيتروجين بشكل معنوي باستثناء معاملة السوبر فوسفات الكالسيوم وفوسفات أحادي الأمونيوم. ومن الملاحظ أن تطبيق المعاملات أدى إلى زيادة واضحة في محصول القش والحبوب، ووزن الألف حبة، وارتفاع النبات، وكفاءة استخدام النيتروجين، ونسبة دليل الحصاد، والزيادة النسبية، وكذلك محتوى الحبوب من العناصر وامتصاص النيتروجين والفوسفور. كما لوحظ بوضوح أن تركيز الكاديوم في التربة المعاملة بالأسمدة المعدنية كان أعلى قليلاً من التربة المعاملة بالفحم الحيوي. كذلك، كانت تراكيز الكاديوم في نباتات القمح منخفضة باستثناء معاملة فوسفات أحادي الأمونيوم غير العضوية.