Tikrit Journal for Agricultural Sciences
ISSN:1813-1646 (Print); 2664-0597 (Online)
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq

TJAS
Tikrit Journal for
Agricultural Sciences

DOI: https://doi.org/10.25130/tjas.25.1.6

# Relationship between biochar addition, clay minerals, potassium forms and soil properties in some gypsiferous soils in Iraq

**Hudhaifa Maan Al-Hamandi [1], Yasir Hmood Ijresh AL Janabi [2], Ahmed Maath Ahmed [3], Mijbil Mohammad Aljumaily [4], Mohammed Ali Al-Obaidi [5]**

[1,2,3,4] *Department of Soil Science and Water Rescores, College of Agriculture, Tikrit University, Tikrit, Iraq*
[5] *Department of Soil Science and Water Rescores, College of Agriculture and Forestry, Mosul University, Nineveh, Iraq*

**Correspondence email*: **hudhaifaalhamandi@tu.edu.iq**

**KEY WORDS:**
gypsiferous soil; potassium forms; before adding biochar; after adding biochar; correlation coefficient, biochar production

Received: 01/04/2024
**Revision:** 30/09/2024
**Proofreading:** 26/12/2024
**Accepted**: 20/01/2025
**Available** online: 31/03/2025

**ABSTRACT**

The application of biochar has aroused great interest. Still, our understanding of the behavior of biochar with soil properties and its relationship with potassium forms on soil health in gypsum soils is limited. Biochar is a carbon-rich product that is used as a means to improve soil properties. Twelve soil samples have been collected from some gypsiferous soils in Iraq to determine the different forms of potassium and their relation with clay mineralogy and other soil properties. Collect soil samples were put in small plastic pots and adding biochar at a rate of 5 gm. Kg$^{-1}$ for each soil to evaluate the effect of biochar on potassium forms. The X-ray diffraction showed that smectite was the dominant mineral in the studied soils followed by Illite, Kaolinite, Palygoriskite and Chlorite clay fractions. Results showed that biochar application improved all potassium forms and soil chemical characteristics. Biochar addition increased all potassium forms, from (0.011-0.041) to (0.031-0.075) (Cmolec Kg$^{-1}$), from (0.05-0.19) to (0.08-0.22) (Cmolec Kg$^{-1}$) and from (0.15-0. 41) to (0.25-0.61) (Cmolec Kg$^{-1}$) for soluble, exchangeable and non-exchangeable potassium before and after adding biochar respectively. Whereas increased soil cation exchange capacity from (4.8-11) to (9.8-18) Cmolckg$^{-1}$ and organic matter from (3.5-13) to (7.9-19) gm. Kg$^{-1}$. It was found that the correlation coefficient between potassium forms for all soils after adding biochar was high and positive except for the pH.

# العلاقة بين إضافة الفحم الحيوي والمعادن الطينية وأشكال البوتاسيوم وخصائص التربة في بعض الترب الجبسية في العراق

حذيفة معن الحمندي, ياسر حمود عجرش الجنابي, احمد معاذ احمد , مجبل محمد الجميلي, محمد علي جمال العبيدي
[1,2,3,4]قسم علوم التربة والموارد المائية ، كلية الزراعة ،جامعة تكريت ، العراق
[5]قسم علوم التربة والموارد المائية ، كلية الزراعة والغابات ،جامعة الموصل ، العراق

## الخلاصة

لقد أثار تطبيق الفحم الحيوي اهتماماً كبيراً، ومع ذلك فإن فهمنا لسلوك الفحم الحيوي مع خصائص التربة وعلاقته بأشكال البوتاسيوم على صحة التربة في التربة الجبسية كان محدود. الفحم الحيوي هو منتج غني بالكربون يستخدم كوسيلة لتحسين خصائص التربة. تم جمع اثني عشر عينة تربة من بعض الترب الجبسية في العراق لتحديد أشكال البوتاسيوم المختلفة وعلاقتها بمعادن الطين وخصائص التربة الأخرى. تم جمع عينات التربة ووضعها في أواني بلاستيكية صغيرة وإضافة الفحم الحيوي بمعدل 5 غم.كغم$^{-1}$ لكل تربة لتقييم تأثير الفحم الحيوي على أشكال البوتاسيوم. أظهر حيود الأشعة السينية أن السمكتيت كان المعدن السائد في الترب المدروسة يليه الإليت والكاولينيت والباليجورسكيت والكلوريت. أظهرت النتائج أن تطبيق الفحم الحيوي أدى إلى تحسين جميع أشكال البوتاسيوم والخصائص الكيميائية للتربة. أدت إضافة الفحم الحيوي إلى زيادة جميع أشكال البوتاسيوم من (0.041-0.011) إلى (0.075-0.031) سنتي مول كغم$^{-1}$ ومن (0.19-0.05) إلى (0.22-0.08) سنتي مول كغم$^{-1}$ ومن (0.41-0.15) إلى (0.61-0.25) سنتي مول كغم$^{-1}$ للبوتاسيوم القابل للذوبان والتبادلي وغير القابل للتبادل قبل وبعد إضافة الفحم الحيوي على التوالي. في حين زادت السعة التبادلية الكاتيونية في التربة من(11-4.8) إلى (18-9.8) سنتي مول كغم$^{-1}$ وايضا ازدادت المادة العضوية من (13-3.5) إلى (19-7.9) غم. كغم$^{-1}$. وقد وجد أن معامل الارتباط بين أشكال البوتاسيوم لجميع الترب بعد إضافة الفحم الحيوي كان مرتفعًا وإيجابيًا باستثناء الرقم الهيدروجيني.

**الكلمات الافتتاحية:** التربة الجبسية؛ أشكال البوتاسيوم؛ قبل إضافة الفحم الحيوي؛ بعد إضافة الفحم الحيوي؛ معامل الارتباط؛ انتاج الفحم الحيوي.

## INTROUCTION

Gypsum soils are an interesting complex system, gypsum soils are generally arid to semiarid and constitute about 12 % of Iraq's area(Khairo,2024; Ismaeal *et al.*, 2024). Competition between the calcium element on the one hand and the potassium element, on the other hand, occurs on the surfaces of the exchange complex gypsum soils which depends on the ion's charge, concentration, and size, which causes the potassium ion to be displaced from the exchange complex ion exchange reactions and these ions are exposed to being washed out of the root zone(Qadir and Al-Obaidi,2024). A high percentage of gypsum in the soil reduces its ability to retain positive ions. Thus the soil’s ability to exchange positive ions decreases as the gypsum content in the soil increases(Tirado-Corbalá *et al.*, 2019).

Potassium (K) is one of the essential elements required for plants(Alsajri *et al.*, 2024). In most soils, the total K reserves are generally large, but only a small portion of them are immediately or slowly available for plant uptake(Alsultan and AL-Obaidi,2022). The potassium content of soils varies depending on the soil texture, soil pH, and soil mineralogical composition(Liu *et al.*, 2020).The relations between potassium forms and soil properties can be used to predict potassium availability in soil, potassium cycling, and potassium supplying power of soils(Elbaalawy *et al.*,2016). Soils differ in tendencies to fix applied potassium in forms unavailable to plants and each soil has its fixing capacity for Potassium which must be satisfied before a change in soil solution occurs(Al-Jumaily *et al.*, 2022).

Biochar is a product resulting from the decomposition of organic materials and is rich in carbon. It is important in agriculture, where it is used to improve soil quality (Khdir and Rahman,2024). The use of biochar is one of these technologies that may be the key to producing soil rich in nutrients, and has a positive effect that improving soil health(Yadav *et al.*, 2023). Biochar increases soil fertility by improving soil physical and chemical properties, enhancing microbial actives related to nutrient availability and actively contributing to modifying gas exchange in the soil ecosystem. Furthermore, it was hypothesized that the biochar application rate affects the biochar surface oxidation rate, nature, and mineralization of functional groups when added to soils. The study aims to compare biochars' effect on potassium forms in some Iraq gypsiferous soils by improving some soil properties and relating them with potassium availability.

## MATERIAL AND METHODS

### Study area and samples collection

A representative of twelve surface soil samples (0-30 cm) has been collected from different locations in Salahuddin Province central Iraq with different gypsum content, as shown in table (1) and figure (1). The study area belongs to the climate of arid and semi-arid zones and is classified as typic Torrifluvents as claimed by soil survey Staff (1999),(Mahmoud and Ismaeal,2024). Soil samples were dried, crushed, and passed through 2 mm sieve, physical and chemical analyses were carried out. Soil analysis was measured including Ec and pH was determined with soil water extraction of 1:2.5 according to (Rhoades, 1996; Mahmoud and Ismail,2024) and (Thomas, 1996) using a conductivity meter (YK2001CT) Lutron Taiwan and pH meter (HI 9017, Hanna Instruments Inc USA) respectively. All potassium forms were estimated by flame photometer. Tables (2,3) show studied soil properties and potassium forms before and after biochar adding. X-ray diffraction was performed to determine mineralogy analysis. X-ray diffract data and clay fraction quantitative mineralogical composition were obtained using a Philips X-ray diffract meter according to Abdullah *et al.*, (2019). The probability levels of 0.01 and 0.05 were compared using a paired t-test (Hoshmand ,2017).

Table 1. Coordinates of the soil sampling locations in the study areas using GPS.

| Sample number | Soil locations | Latitude (N) | Longitude (E) |
|---|---|---|---|
| 1 | Shirqat 1 | 35º32’25.84” | 43º13’50.38” |
| 2 | Shirqat 2 | 35º32’23.27” | 43º15’07.41” |
| 3 | Makhool | 35º08’20.13” | 43º27’44.04” |
| 4 | Makhool 2 | 34º57’23.43” | 43º26’02.88” |
| 5 | Baje 1 | 34º55’46.52” | 43º31’22.54” |
| 6 | Baje 2 | 34º50’19.44” | 43º32’51.23” |
| 7 | Tikrit 1 | 34º46’28.55” | 43º43’49.66” |
| 8 | Tikrit 2 | 34º43’29.39” | 43º39’17.16” |
| 9 | Dour 1 | 34º31’07.55” | 43º51’30.46” |
| 10 | Dour 2 | 34º29’17.65” | 43º49’19.91” |
| 11 | Tuz 1 | 34º40’51.09” | 44º24’59.48” |
| 12 | Tuz 2 | 34º53’20.66” | 44º28’21.34” |

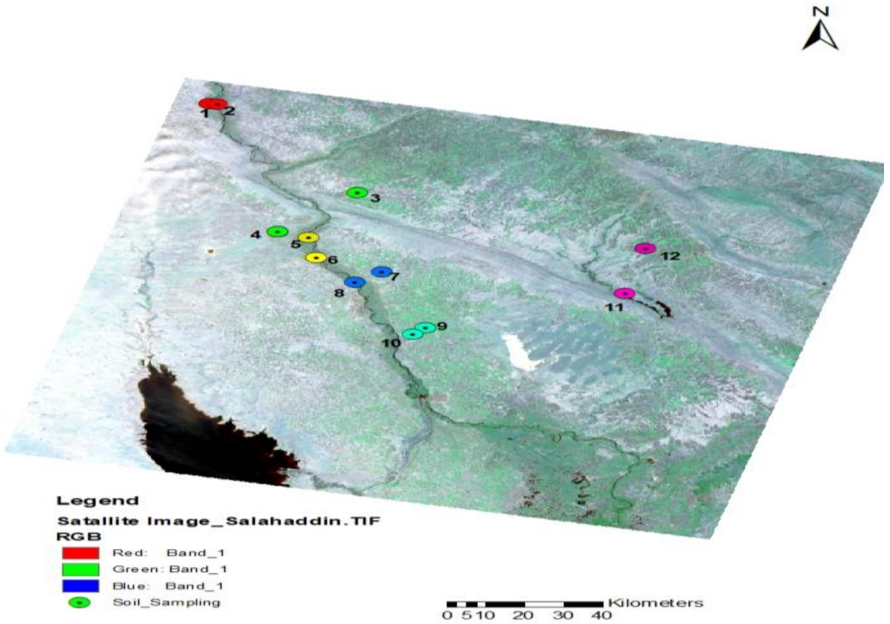

**Figure 1. Soil sampling locations in Salahaddin, Iraq.**

## Biochar production and incubation

A feedstock has been brought from a cornfield for the production of biochar. A rotein processes were made, air dried, ground, and passed through 2 mm Sieve. The production of corn biochar was carried out by using a slow pyrolysis procedure. Ready raw feedstock material was heated to 400°C for 2h using thermal furnaces in an oxygen-limited environment. We wrapped raw feedstocks in aluminum foil to minimize free oxygen during thermal heating. Then we put a stainless cylinder into a muffle furnace with gradually heating to the point temperature. The properties of prepared biochar at 400 C were E.C2.93 $ds.m^{-1}$, pH 8.6, cation exchange capacity

16.52 C.molc $kg^{-1}$, Organic carbon 412gm.$kg^{-1}$, P 0.72 gm. $Kg^{-1}$, N 15.00 gm.$kg^{-1}$, and K 1.82 gm.$kg^{-1}$. The previous methods described according to (Khadem *et al.,* 2017; Song *et al.,* 2019 ).An incubation experiment was carried out to study the biochar effects on the differences in potassium forms of gypsiferous soils. Twelve presentative gypsiferous soil samples were collected from different gypsiferous regions. 5 gm of prepared biochar was added to 995 gm of gypsiferous soils with a different gypsum content and mixed well in a 1 kg plastic pot. The plastic pots were incubated for 8 weeks at 25C and moistened with distilled water as required. Gypsiferous biochar-amended soils and control soil were sampled to assess their properties according to the previous methods Naeem *et al.,* (2017). Table 2 shows some biochar chemical properties.

## Different soil potassium forms

We determined the quantity of K forms in each sample as mentioned by Knudsen *et al.,* (1982). Water-soluble K was assessed by shaking a 5gm soil sample with 25 ml distilled water for 1 hour centrifuged and filtered. Exchangeable K was measured by shaking 10 gm of soil sample in 25 ml of $NH_4OAC$ at pH 7, centrifuged, and filtrated. The differences between extractable-$NH_4O$ AC and water-soluble K represent exchangeable K.2.5 gm of soil sample boiled in 25 ml of ($HNO_3$ 1M). Solution for 10 minutes to determine nitric acid extractable K. Non-exchangeable K was determined by the differences between nitric acid extractable K and $NH_4$- exchangeable K. Total k was obtained by digestion of 1 gm of Soil sample in the acid mixture (6 M HCl + 48% FH). The subtracting of $HNO_3$ extractable K from total K represents mineral K. The results of each K form represent the mean of three replicate determinations.

## RESULTS AND DISSCUSION

The effects of biochar addition on the changes in soil chemical properties

Biochar addition significantly increases affects all soil chemical properties, soil fertility and crop growth. According to table (2), biochar exhibited an increase in pH when compared with the control soil. The pH values for the studied soil before adding biochar ranged between 7.3 -7.7, while the pH values after adding biochar ranged between 7.4 -7.9. Our results are consistent with other studies. Several researchers mentioned that biochar application to the soils led to an increase in the soil pH (Lehmann *et al.,* 2006 ; Sun *et al.,* 2022 ). This is likely because the base ions affect biochar in oxide form and soluble carbonates (Tan et al., 2017). Yuan et al., (2011) revealed a rise in the pH of the soil when compared to the control and this was anticipated given the high pH values (10.2) of biochar because pyrolysis produces carbonates, basic oxides, and organic carboxylates. Figure (2a) shows the different pH values before and after biochar adding.

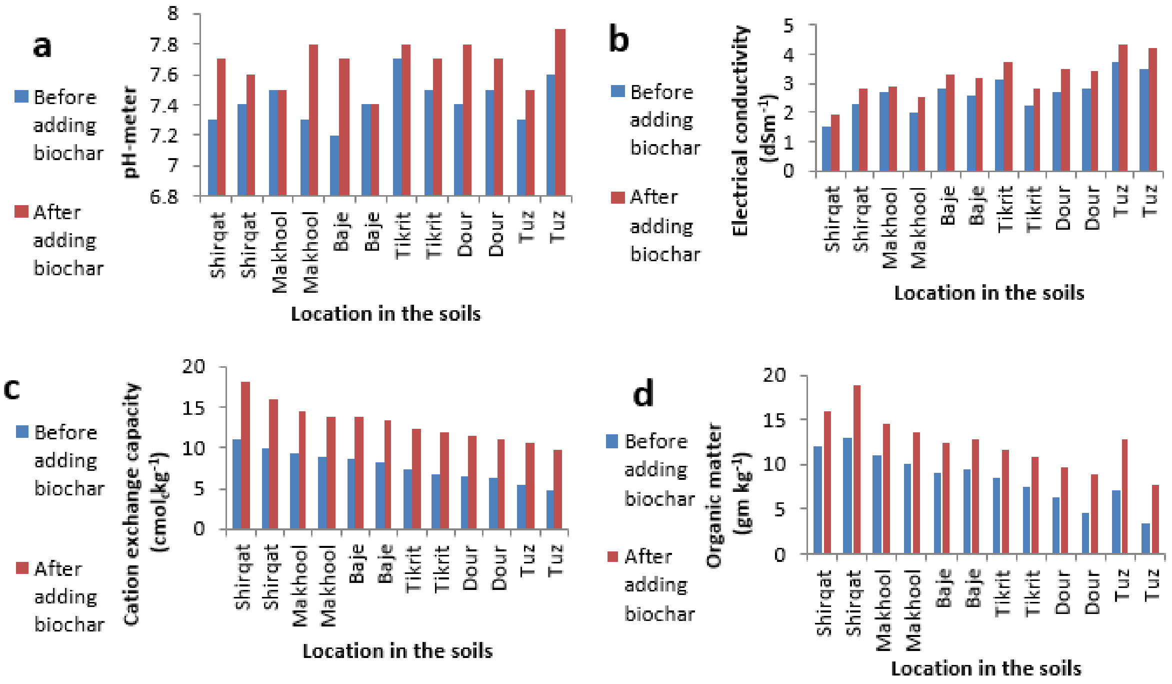

Figure 2 shows the effect before and after adding biochar to the study soil on both (a) pH values (b) Electrical conductivity values (c)Cation exchange capacity values (d) Organic matter values.

The ash is the residual of biochar and significantly increases soil electrical conductivity (E.C) because of basic soluble water cations content (Song *et al.*, 2018; Khadem *et al.*, 2021). EC values of the studied soils before adding biochar ranged between 1.5 -3.7 dS/m, while the EC values after adding biochar ranged between 1.9 - 4.3 dS/m. Our results indicated that the soil EC value significantly increases because addition of biochar. Karimi *et al.*, (2020) also reported that biochar increased EC by 0.05 dS/m. In addition, some researchers joined the increase in EC values with the addition of biochar to the greater alkaline cations like K+ (Beheshti *et al.,* 2018). Our study results are in agreement with the results of Song *et al.*, (2018) the results ranged from (2.86-4.75 dS/m) who mentioned that different types of biochar application could increase soil EC figure(2b).

Pursuant to the findings of the experiment, biochar application has a significantly positive effect on C.E.C values. C.E.C values of the studied soils before adding biochar ranged between

4.8-11cmol$_c$.kg$^{-1}$, while the C.E.C values after adding biochar ranged between 9.8-18cmol$_c$.kg$^{-1}$ figure (2c). C.E.C is an important indicator of soil's ability to cation exchange, nutrient elements storage, and soil quality (Solly *et al.,* 2020). So the higher values of C. E.C point to high nutrient element adsorption capacity which is necessary for plant growth (Antonangelo *et al.,* 2024). Biochar surfaces are rich with functional groups such as –OH and -COOH which react with soluble metals in soil solution resulting in soluble metal complexes with electrostatic bonds (Blenis *et al.,* 2023). Besides the surface of functional groups, biochar has the ability to release the low molecular weight of organic acid compounds which might contribute to the increase of soil C.E.C after the addition of biochar. The stronger and higher adsorption capacity of biochar against nutrient elements improves soil C.E.C to slow-release fertilizer storage and reduces nutrient loss via leaching (Kapoor *et al.,* 2022). The mechanism effect of biochar on C.E.C has been discussed extensively by many others (Hagner *et al.,* 2016; Shaaban *et al.,* 2018). Tan *et al.,* (2017) mentioned that the addition of biochar to the soil with the ratio of 1:100 resulted in an increase in C.E.C value by 0.92 cmolc.kg$^{-1}$ and increased continuously as biochar addition increased too. However, the biochar effect on C.E.C is almost related to biochar origin materials, the condition of biochar production, and soil characteristics.(Kuryntseva *et al.,* 2023 ). Our study results are consistent with those mentioned by other researchers, (Yuan *et al.,* 2011; Laghari *et al.,* 2015)

According to our study results, biochar application showed an influential factor on soil organic matter content. Because biochar consists of several aromatic and aliphatic organic compounds that contribute directly by increasing soil organic carbon (Lyu *et al.,* 2018; Faloye *et al.,* 2019). Additionally, soil organic carbon stability will be increased and its degradation will be prevented by the porosity of the biochar structure (Liu *et al.,* 2019).The surface morphology structure of biochar facilitates the adsorption of soil organic carbon onto its outer surfaces and this mechanism could be inhabiting the deterioration of soil organic carbon and indirectly increase Soil organic matter content (Tan *et al.,* 2017, Yu *et al.,* 2019). Organic matter values of the studied soils before adding biochar ranged between 3.5 -13 gm kg$^{-1}$, while the organic matter values after adding biochar ranged between7.9 -19 gm kg$^{-1}$ figure (2d). These results are consistent with those of (Dong *et al.,* 2016; Gross *et al.,* 2021), biochar distribution increased the content of organic matter, confirming its potential as an efficient strategy for C storage. Because biochar raises the pH of the soil, it prevents soil carbon mineralization in neutral or alkaline soils (Liu *et al.,* 2019).

Table 2. physical and chemical characteristics of gypsiferous soils before and after adding biochar

| No. | Locations | PSD gm $kg^{-1}$ | | | | Before adding biochar | | | | | | After adding biochar | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Texture | pH | EC $dSm^{-1}$ | CEC $cmol_c kg^{-1}$ | O.M. | $CaSO_4$ | $CaCO_3$ | pH | EC $dSm^{-1}$ | CEC $cmol_c kg^{-1}$ | O.M. gm $kg^{-1}$ |
| | | | | | | | | | gm $kg^{-1}$ | | | | | | |
| 1 | Shirqat | 530 | 235 | 235 | SCL | 7.3 | 1.5 | 11 | 12 | 21 | 311 | 7.7 | 1.9* | 18* | 16* |
| 2 | Shirqat | 505 | 285 | 210 | L | 7.4 | 2.3 | 10 | 13 | 35 | 342 | 7.6 | 2.8* | 16* | 19* |
| 3 | Makhool | 497 | 315 | 188 | L | 7.5 | 2.7 | 9.2 | 11 | 51 | 253 | 7.5 | 2.9* | 14.5* | 14.7* |
| 4 | Makhool | 480 | 350 | 170 | L | 7.3 | 2.0 | 8.9 | 10 | 65 | 284 | 7.8 | 2.5* | 13.91* | 13.6* |
| 5 | Baje | 499 | 351 | 150 | L | 7.2 | 2.8 | 8.7 | 9 | 87 | 363 | 7.7 | 3.3* | 13.8* | 12.5* |
| 6 | Baje | 603 | 255 | 142 | SL | 7.4 | 2.6 | 8.3 | 9.5 | 115 | 314 | 7.4 | 3.2* | 13.3* | 12.8* |
| 7 | Tikrit | 510 | 355 | 135 | L | 7.7 | 3.1 | 7.4 | 8.5 | 132 | 213 | 7.8 | 3.7* | 12.4* | 11.7* |
| 8 | Tikrit | 533 | 342 | 125 | SL | 7.5 | 2.2 | 6.8 | 7.5 | 161 | 252 | 7.7 | 2.8* | 11.8* | 10.9* |
| 9 | Dour | 528 | 357 | 115 | SL | 7.4 | 2.7 | 6.6 | 6.3 | 176 | 313 | 7.8 | 3.5* | 11.5* | 9.8* |
| 10 | Dour | 586 | 307 | 107 | SL | 7.5 | 2.8 | 6.2 | 4.5 | 187 | 332 | 7.7 | 3.4* | 11.1* | 8.9* |
| 11 | Tuz | 604 | 301 | 95 | SL | 7.3 | 3.7 | 5.5 | 7.2 | 209 | 296 | 7.5 | 4.3* | 10.5* | 12.8* |
| 12 | Tuz | 634 | 276 | 90 | SL | 7.6 | 3.5 | 4.8 | 3.5 | 226 | 212 | 7.9 | 4.2* | 9.8* | 7.9* |

Note. * means a significant difference between before and after adding biochar for EC, CEC, and O.M

There are four types of potassium found in soil: total, soluble, exchangeable, and non-exchangeable. Only a small percentage of the total potassium is made up of exchangeable and non-exchangeable potassium levels. (Elbaalawy *et al.,* 2016). There are equilibrium and kinetic reactions between the four forms of soil potassium that affect the level of soil solution potassium table 3 shows potassium forms in studied soil before and after adding biochar.

Table 3. Potassium forms in studied soil samples used before and after adding biochar.

| No. | Locations | before adding biochar<br>K-forms ($Cmole_c$ $Kg^{-1}$) | | | after adding biochar<br>K-forms ($Cmole_c$ $Kg^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | Soluble | Exch | Non- Exch | Soluble | Exch | Non- Exch |
| 1 | Shirqat | 0.041 | 0.19 | 0.41 | 0.075 | 0.22 | 0.61 |
| 2 | Shirqat | 0.037 | 0.18 | 0.37 | 0.070 | 0.21 | 0.57 |
| 3 | Makhool | 0.035 | 0.17 | 0.35 | 0.065 | 0.20 | 0.48 |
| 4 | Makhool | 0.032 | 0.15 | 0.30 | 0.062 | 0.18 | 0.44 |
| 5 | Baje | 0.028 | 0.14 | 0.28 | 0.058 | 0.17 | 0.38 |
| 6 | Baje | 0.026 | 0.11 | 0.26 | 0.056 | 0.15 | 0.36 |
| 7 | Tikrit | 0.022 | 0.10 | 0.24 | 0.048 | 0.13 | 0.34 |
| 8 | Tikrit | 0.019 | 0.09 | 0.23 | 0.045 | 0.12 | 0.33 |
| 9 | Dour | 0.017 | 0.09 | 0.22 | 0.041 | 0.11 | 0.32 |
| 10 | Dour | 0.015 | 0.09 | 0.19 | 0.035 | 0.10 | 0.29 |
| 11 | Tuz | 0.013 | 0.07 | 0.17 | 0.033 | 0.09 | 0.27 |
| 12 | Tuz | 0.011 | 0.05 | 0.15 | 0.031 | 0.08 | 0. 25 |

## Soil Solution Potassium

Soil solution potassium is the form of potassium that is directly taken up by plants and microbes and also is the form most subject to leaching in soils (Meena *et al.,* 2016). Levels of soil solution potassium are generally low unless a recent amendment of potassium has been made to the soil (Rawat *et al.,* 2016). Potassium that is soluble in water is the potassium that is present in the liquid phase at all times and will rise in the soil solution when field conditions are met. (Yahaya *et al.,* 2023).Potassium and other soluble ions are the primary sites of chemical reactivity in soils, the natural medium for plant growth, and the chemical fraction that is instantly exposed to the environment condition (Hasanuzzaman *et al.,* 2018). The soluble soil potassium significantly increased with the addition of biochar (Table 3). The addition of biochar to this soil caused the potassium soluble value to rise from ranging between 0.041 and 0.011 Cmolec Kg$^{-1}$ before adding biochar and between 0.75 and 0.031 Cmolec Kg$^{-1}$ after adding biochar. These results are consistent with what they found by Abu Zied Amin (2016), when 60 Mg ha$^{-1}$ of biochar was added to the calcareous sandy soil, the amount of soluble potassium increased from 100.4 mg kg$^{-1}$ for the control treatment to 232.7 mg kg$^{-1}$. Even with low levels of biochar added, the soluble potassium in the soil rose noticeably with each subsequent Dobermann *et al.,* (1998) mentioned that water soluble potassium in indian soils range form (4 -125 mg kg$^{-1}$) because biochar contains free nutrient cations like potassium and does not volatilize after burning during the biochar synthesis process, this suggests that biochar can improve the accessible soil nutritional status of potassium. It was also discovered that adding biochar to soil greatly increased the availability of basic cations like potassium (Farrar *et al.,* 2021; Bao *et al.,* 2024). Exchangeable potassium is defined as the fraction that occupies sites in the soil colloidal complex (Das *et al.,* 2021). Unlike the pH-dependent negative sites on clays, non-specific adsorption sites occur at the planar and edge positions of clay minerals as well as at the negative charges produced by the carboxylic and phenolic groups of humus colloids (Strawn, 2021). The dissociation of $H^+$ from weak acid groups causes the negative charges on the humus colloids and the edges of the amorphous clay minerals to grow as pH rises, despite the exchange sites on clay particles created via isomorphic substitution having a relatively constant number (Alemayehu and Teshome, 2021). This is known as exchangeable potassium, and it is quickly restored by the release of potassium stored on the cation exchange sites of clay minerals and organic matter ($K^+$) (Yadav and Sidhu, 2016). Potassium deposits can also be "fixed" or trapped in 2:1 clay minerals between the plate-like units. By means of weathering, these stocks replenish exchangeable potassium (Barré *et al.,* 2008). When biochar was added, the exchangeable potassium values for the soils under study ranged from 0.08 to 0.22 Cmolec Kg$^{-1}$, while the values of exchangeable potassium before adding biochar ranged from 0.05 to 0.19 Cmolec Kg$^{-1}$ Ayman and Fawzy (2023) reported an increase in exchangeable potassium up to 367 mg kg$^{-1}$ for sandy soils and 415 mg kg$^{-1}$ for calcareous soils after adding 2% olive stone biochar. Also, Abu Zied Amin (2016) obtained an increase in exchangeable potassium for about 28% by using 20 Mg.ha$^{-1}$ of corn cop biochar in calcareous soils and Zhang *et al.,* (2021) obtained increase in soil exchangeable potassium by 30% in yellow-brown soil when they used 2% peanut shell biochar.

Non-exchangeable or fixed potassium differs from mineral potassium in that it is not bonded within the crystal structures of soil mineral particles (Kubo *et al.,* 2018). It is held between adjacent tetrahedral layers of octahedral micas, vermiculites, and intergrade clay minerals such as chlorite and vermiculite (Paola *et al.,* 2016). Potassium becomes fixed because the binding forces between potassium and the clay surfaces are greater than the hydration forces between individual potassium ions (Gurav *et al.,* 2019). Potassium release is a gradual, diffusion-controlled process as a result of the partial collapse of the crystal structures and the variable degrees of physical trapping of the potassium ions (Mouhamad *et al.,* 2016).

The largest quantities of soil potassium are contained deep within crystalline, precipitated materials and this insoluble potassium is classed as inert potassium (Sharma *et al.,* 2024). The size and rate of release of the exchangeable potassium fraction, plus the fixed fraction, determines the long-term need for potassium fertilisers (Islam *et al.,* 2017).

The values of non-exchangeable potassium ranged between 0.15 and 0.41 Cmolec $Kg^{-1}$, before adding biochar where as the non- exchangeable potassium values for studied soils ranged between 0.25 and 0.61 Cmolec $Kg^{-1}$after adding biochar . Najafi-Ghiri *et al.,* (2022) mentioned that cow manure biochar increased non-exchangeable potassium to 2.09 fold compared to control soil content . Also, (Lu *et al.*, 2020) pointed that the addition of 25 gm $Kg^{-1}$ of biochar increased non-exchangeable potassium about 141.9 mg $Kg^{-1}$ in Entisol soil. The increase in the non-exchangeable portion of potassium in the study soils is due to the dominance of 2:1 bilayer clay minerals such as smectite and illite table (4), which are characterized by their high ability to isomorphic substitution, this ultimately leaves a negative charge, leading to the adsorption of more positive cations, including potassium (Missana *et al.,* 2009). Iraqi soils are characterized by their varying content of different clay minerals, and this is due to the source material of those soils, the conditions of their formation, and the climate (Al-Hazaa, 2018). Mawlood (2018) noted that the semctite group of minerals is the dominant component of clay in many Iraqi soils, and its percentage decreases with depth and with the increase in the size of the clay grains. Illite is the second component in terms of percentage, and its distribution is opposite to that of semctite. Chlorite is the third component in all clay separations, it was observed that chlorite increased in the coarse clay with increasing depth. In another study on some selected soils in different regions of Iraq, Abdullah *et al.*, (2019) indicated that the most important dominant clay minerals are palygorskite, illite, chlorite, and vermiculite, in addition to the presence of calcite and quartz. He also confirmed that the mineral montmorillonite is dominant in the northeastern regions of Iraq, table (4) shows dominant clay minerals in soils.

**Table 4. Potassium Clay minerals in Studied soils.**

| No. | Locations | Minerals content% | | | | |
|---|---|---|---|---|---|---|
| | | Semctite | Illite | Kaolinite | Palygoriskite | Chlorite |
| 1 | Shirqat | ++++ | +++ | +++ | ++ | + |
| 2 | Shirqat | +++ | +++ | +++ | ++ | ++ |
| 3 | Makhool | +++ | +++ | +++ | +++ | + |
| 4 | Makhool | +++ | ++++ | ++ | + | + |
| 5 | Baje | +++ | +++ | ++ | + | ++ |
| 6 | Baje | +++ | ++ | ++ | ++ | ++ |
| 7 | Tikrit | +++ | +++ | +++ | ++ | ++ |
| 8 | Tikrit | +++ | ++ | +++ | ++ | ++ |
| 9 | Dour | ++++ | +++ | ++ | +++ | + |
| 10 | Dour | ++++ | ++++ | +++ | ++ | + |
| 11 | Tuz | +++ | ++ | + | + | ++ |
| 12 | Tuz | +++ | ++ | + | + | + |

**Note. +4= Dominant (50-90%),+ 3= Major (20-50%), +2= Minor (5-20%), +1= Trace (<5%)**

Clay minerals found in arid and semi-arid areas are (smectite, illite, kaolinite, palygorskite and chlorite) (AL-Bayati and AL-Obaydi, 2019). Generally believed that micaceous minerals such as chlorite and illite were largely inherited from their parent rocks. (Abbaslou *et al.,* 2013). Due to the high concentration of Mg and Si in the calcareous environment, smectite makes up the majority of the clay minerals in the studied soil. These elements' mobility may create ideal circumstances for smectite formation by transformation at the soil surface (Khormali and Abtahi, 2003). The relative abundance of clay mineral fractions of study soil regions is shown in table 4.Semctite, illite, kaolinite, palygoriskite, and chlorite were the principal minerals found. were discovered in nearly every surface horizon; this may be the result of little precipitation (Hameed *et al.,* 2018). Trivial convert in the abundance of these minerals were found because of their inherited origin in calcareous soils (Owliaie *et al.,* 2006). The incidence of smectite in soils is due to its succession from the surrounding smectite-bearing cretaceous rocks (Mckinley *et al.,* 1999). Illite and chlorite plenty in soils is also largely related to their existence in parent rocks (Hashemi *et al.,* 2003). The reduction of downpours in this region led to the low comparative abundance of montmorillonite and its low dynamic transportation in the soil profile (Enjavinezhad *et al.,* 2024). Although preceding studies proclaimed the dominant minerals in study soils were chlorite, illite, and kaolinite with the inherited origin (Salari *et al.,* 2019). Several studies communicate an increase in the amount of illite on the soil surface due to factors such as the formation of illite on the soil surface due to biotite and muscovite weathering (Bétard *et al.,* 2009). This study demonstrated that the studied soils have higher concentrations of K-bearing minerals including illite and semctite.

Table (5) shows the correlation coefficients between potassium forms and soil properties. Most potassium forms and soil properties showed a high correlation with each other, except The reduction of correlation coefficient of pH has a very low correlation coefficient with all potassium forms and potassium dynamic parameters, ranged between (0.138-0-276). Many researchers reported that biochar application increases soil pH due to base ions existing in biochar as oxide forms (Lehmann *et al.,* 2006; Sun *et al.,* 2022).

Table 5. Correlation coefficients between potassium forms and some thermodynamic potassium parameters and soil properties.

| | Soluble | Exch | Non-Exch | pH | EC | CEC | O.M | Clay |
|---|---|---|---|---|---|---|---|---|
| Soluble | ____ | 0.9929** | 0.8985** | 0.2718 | 0.8257** | 0.9710** | 0.8566** | 0.9756** |
| Exch | | ____ | 0.9026** | 0.2767 | 0.8062** | 0.9660** | 0.8648** | 0.9806** |
| Non-Exch | | | ____ | 0.2632 | 0.8314** | 0.9693** | 0.8587** | 0.9783** |

**(*)and (** )significant at 0.01 ,0.05 probability level, respectively.**

The high correlation coefficient values between potassium images and clay minerals are due to the ability of clay minerals to adsorb potassium added by biochar to be a source for later potassium supply (Zhang *et al.,* 2020). Biochar is also an important source of organic matter containing potassium and increasing humic compounds that are characterized by their wide surfaces contain high negative charges and can chelate potassium due to the high cation exchange capacity of the soil after adding biochar (Gęca *et al.,* 2022). Also, organic matter contains high concentrations of basic cations such as (calcium, magnesium, and potassium) and their oxides, which causes an increase in the electrical conductivity values of the soil solution (Wu *et al.*, 2021). There was no positive relationship between potassium images in the study soils and pH values because the study soils were originally basic soils and contained lime and gypsum, so there was no significant change in pH values figure (3)( Xia *et al.*, 2024).

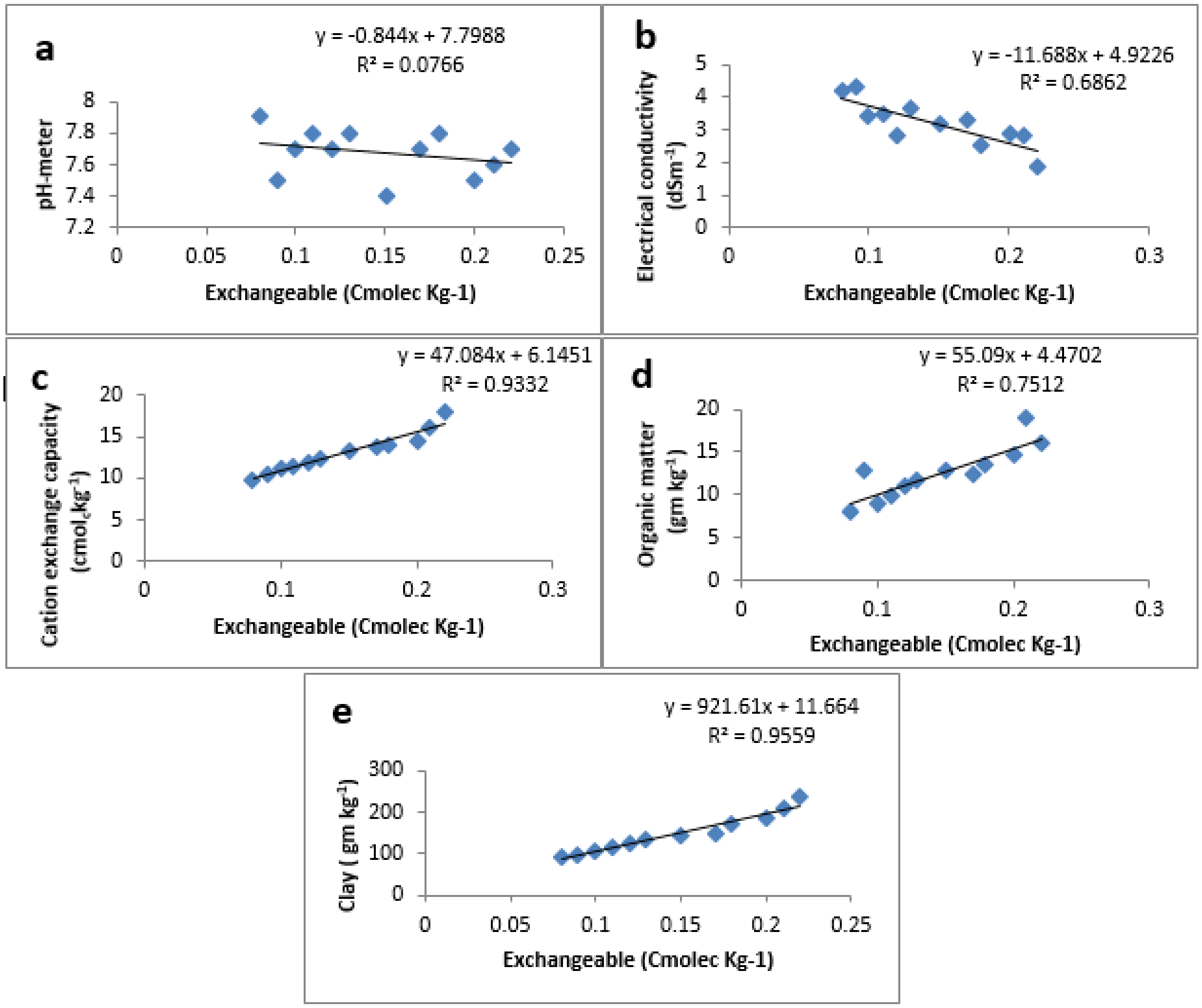

Figure 3 the linear relationship between the exchange potassium values of the study soils soil on both (a) pH values (b) Electrical conductivity values (c)Cation exchange capacity values (d) Organic matter values (e) Clay values.

## CONCLUSIONS

Gypsiferous soils in Iraq are poorly in nutrition elements because of nutrient leaching due to gypsum content. Biochars is a good and cheap production that may change soil K distribution, pool, and dynamics depending on its pyrolysis. Adding biochar to the soils improved some soil properties such as C.E.C and organic matter content. This research shows that biochar increases soil potassium capacity and enhances potassium release conditions by increasing the distribution of soluble and exchangeable potassium forms. All potassium forms recorded high correlation coefficient values with each other except pH showed a low correlation coefficients.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

## ACKNOWLEDGMENTS

The authors thank the department of soil science and water resources, college of agriculture, Tikrit University and college of agriculture and forestry, University of Mosul for providing the laboratory equipment and scientific support to conduct this research.

## REFRANCES

Abbaslou, H., Abtahi, A., Peinado, F. J. M., Owliaie, H., and Khormali, F. 2013. Mineralogy and characteristics of soils developed on Persian Gulf and Oman sea basin, southern Iran: implications for soil evolution in relation to sedimentary parent material. *Soil science*, *178*(10), 568-584. DOI: 10.1097/SS.0000000000000022

Abdullah, A. S., Esmail, A. O., and Ali, O. O. 2019. Mineralogical properties of oak forest soils in Iraqi Kurdistan region. *Iraqi Journal of Agricultural Sciences*, *50*(6). https://doi.org/10.36103/ijas.v50i6.838

Abu Zied Amin, A. E. E. 2016. Impact of corn cob biochar on potassium status and wheat growth in a calcareous sandy soil. *Communications in Soil Science and Plant Analysis*, *47*(17), 2026-2033. https://doi.org/10.1080/00103624.2016.1225081

Al-Bayati, M., and Al-Obaydi, B. 2023. Study of the mineral analysis of some gypsiferous soils in Salah al-Din and Najaf governorates using X-ray diffraction powder technique. *Tikrit Journal for Agricultural Sciences*, *23*(2), 10-24. https://doi.org/10.25130/tjas.23.2.2

Alemayehu, B., and Teshome, H. 2021. Soil colloids, types and their properties: A review. *Open Journal of Bioinformatics and Biostatistics*, *5*(1), 008-013. DOI: https://dx.doi.org/10.17352/ojbb.000010

Al-Hazaa, S. H. 2018. Clay mineral typing in the shale units of the Kaista and Ora formations of north Iraq: implications for depositional environments. *Iraqi Journal of Agricultural Sciences*, *49*(4). https://doi.org/10.36103/ijas.v49i4.68

Al-Jumaily, M. M., Al-Hamandi, H. M., Al-Obaidi, M. A., and Al-Zidan, R. R. 2022. Quantity-intensity ratio of potassium in gypsiferous soils in Iraq. *Pesquisa Agropecuária Tropical*, *52*, e71620. https://doi.org/10.1590/1983-40632022v5271620

Alsajri, F. A., Farhan, M., and Hilai, N. 2024. Evaluating the Efficiency of Potassium Fertilizer Sources and Levels on Sesame Growth and Yield in Two Different Gypsum Soils. *Tikrit Journal for Agricultural Sciences*, *24*(1), 156–169. https://doi.org/10.25130/tjas.24.1.13

Alsultan, N. M. A., and AL-Obaidi, M. A. J. 2022. Potassium Buffering Potential in Some Burne Soils of North Iraq. *Tikrit Journal for Agricultural Sciences*, *22*(4), 81-95. https://doi.org/10.25130/tjas.22.4.11

Antonangelo, J. A., Culman, S., and Zhang, H. 2024. Comparative analysis and prediction of cation exchange capacity via summation: influence of biochar type and nutrient ratios. *Frontiers in Soil Science*, *4*, 1371777. https://doi.org/10.3389/fsoil.2024.1371777

Ayman, M., and Fawzy, Z. F. 2023, July. Enhancing the Availability of Potassium in New Egyptian Soils using Biochar Produced from Olive Stone Waste. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1213, No. 1, p. 012025). IOP Publishing. DOI 10.1088/1755-1315/1213/1/012025

Bao, Z., Dai, W., Su, X., Liu, Z., An, Z., Sun, Q., ... and Meng, J. 2024. Long-term biochar application promoted soil aggregate-associated potassium availability and maize potassium uptake. *GCB Bioenergy*, *16*(4), e13134. https://doi.org/10.1111/gcbb.13134

Barré, P., Velde, B., Fontaine, C., Catel, N., and Abbadie, L. 2008. Which 2: 1 clay minerals are involved in the soil potassium reservoir? Insights from potassium addition or removal experiments on three temperate grassland soil clay assemblages. *Geoderma*, *146*(1-2), 216-223. https://doi.org/10.1016/j.geoderma.2008.05.022

Beheshti, M., Etesami, H., and Alikhani, H. A. 2018. Effect of different biochars amendment on soil biological indicators in a calcareous soil. *Environmental Science and Pollution Research*, *25*, 14752-14761. https://doi.org/10.1007/s11356-018-1682-2

Bétard, F., Caner, L., Gunnell, Y., and Bourgeon, G. 2009. Illite neoformation in plagioclase during weathering: evidence from semi-arid Northeast Brazil. *Geoderma*, *152*(1-2), 53-62. https://doi.org/10.1016/j.geoderma.2009.05.016

Blenis, N., Hue, N., Maaz, T. M., and Kantar, M. 2023. Biochar production, modification, and its uses in soil remediation: A review. *Sustainability*, *15*(4), 3442. https://doi.org/10.3390/su15043442

Das, D., Dwivedi, B. S., Datta, S. P., Datta, S. C., Meena, M. C., Dwivedi, A. K., ... and Jaggi, S. 2021. Long-term differences in nutrient management under intensive cultivation alter potassium supplying ability of soils. *Geoderma*, *393*, 114983. https://doi.org/10.1016/j.geoderma.2021.114983

Dobermann, A., Cassman, K. G., Mamaril, C. P., and Sheehy, J. E. 1998. Management of phosphorus, potassium, and sulfur in intensive, irrigated lowland rice. *Field Crops Research*, *56*(1-2), 113-138. https://doi.org/10.1016/S0378-4290(97)00124-X

Dong, X., Guan, T., Li, G., Lin, Q., and Zhao, X. 2016. Long-term effects of biochar amount on the content and composition of organic matter in soil aggregates under field conditions. *Journal of soils and sediments*, *16*, 1481-1497. https://doi.org/10.1007/s11368-015-1338-5

Elbaalawy, A. M., Benbi, D. K., and Benipal, D. S. 2016. Potassium forms in relation to clay mineralogy and other soil properties in different agro-ecological sub-regions of northern India. *Agricultural Research Journal*, *53*(2). DOI No. 10.5958/2395-146X.2016.00038.7

Enjavinezhad, S. M., Baghernejad, M., Abtahi, S. A., Ghasemi-Fasaei, R., and Zarei, M. 2024. Effects of topography, climate, mineralogy and physicochemical properties on potassium forms in various soils of Fars province, southern Iran. *Physics and Chemistry of the Earth, Parts A/B/C*, *133*, 103539. https://doi.org/10.1016/j.pce.2023.103539

Faloye, O. T., Alatise, M. O., Ajayi, A. E., and Ewulo, B. S. 2019. Effects of biochar and inorganic fertiliser applications on growth, yield and water use efficiency of maize under deficit irrigation. *Agricultural Water Management*, *217*, 165-178. https://doi.org/10.1016/j.agwat.2019.02.044

Farrar, M. B., Wallace, H. M., Xu, C. Y., Joseph, S., Dunn, P. K., Nguyen, T. T. N., and Bai, S. H. 2021. Biochar co-applied with organic amendments increased soil-plant potassium and root biomass but not crop yield. *Journal of Soils and Sediments*, *21*, 784-798. https://doi.org/10.1007/s11368-020-02846-2

Gęca, M., Wiśniewska, M., and Nowicki, P. 2022. Biochars and activated carbons as adsorbents of inorganic and organic compounds from multicomponent systems–A review. *Advances in Colloid and Interface Science*, *305*, 102687. https://doi.org/10.1016/j.cis.2022.102687

Gross, A., Bromm, T., and Glaser, B. 2021. Soil organic carbon sequestration after biochar application: a global meta-analysis. *Agronomy*, *11*(12), 2474. https://doi.org/10.3390/agronomy11122474

Gurav, P. P., Ray, S. K., Choudhari, P. L., Shirale, A. O., Meena, B. P., Biswas, A. K., and Patra, A. K. 2019. Potassium in shrink–swell soils of India. *Current Science*, *117*(4), 587-596. https://www.jstor.org/stable/27138308

Hagner, M., Kemppainen, R., Jauhiainen, L., Tiilikkala, K., and Setälä, H. 2016. The effects of birch (Betula spp.) biochar and pyrolysis temperature on soil properties and plant growth. *Soil and tillage Research*, *163*, 224-234. https://doi.org/10.1016/j.still.2016.06.006

Hameed, A., Raja, P., Ali, M., Upreti, N., Kumar, N., Tripathi, J. K., and Srivastava, P. 2018. Micromorphology, clay mineralogy, and geochemistry of calcic-soils from western Thar Desert: Implications for origin of palygorskite and southwestern monsoonal fluctuations over the last 30 ka. *Catena*, *163*, 378-398. https://doi.org/10.1016/j.catena.2017.12.034

Hasanuzzaman, M., Bhuyan, M. B., Nahar, K., Hossain, M. S., Mahmud, J. A., Hossen, M. S., ... and Fujita, M. 2018. Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, *8*(3), 31. https://doi.org/10.3390/agronomy8030031

Hashemi, S. S., Baghernejad, M., and NAJAFI, G. M. 2013. Clay mineralogy of gypsiferous soils under different soil moisture regimes in Fars province, Iran. http://jast.modares.ac.ir/article-23-10581-en.html

Hoshmand, R. 2017. Statistical methods for environmental and agricultural sciences.2$^{nd}$ ed. Pub. Location CRC Press P: 384

Islam, A., Karim, A. S., Solaiman, A. R. M., Islam, M. S., and Saleque, M. A. 2017. Eight-year long potassium fertilization effects on quantity/intensity relationship of soil potassium under double rice cropping. *Soil and Tillage Research*, *169*, 99-117. https://doi.org/10.1016/j.still.2017.02.002

Ismaeal, A. S., farhan, M. J. F., and Khalaf, A. A. 2024. Wheat Crop Management and growth stage monitoring in some gypsiferous soil units using remote sensing. *Tikrit Journal for Agricultural Sciences*, *24*(2), 131–160. https://doi.org/10.25130/tjas.24.2.11

Kapoor, A., Sharma, R., Kumar, A., and Sepehya, S. 2022. Biochar as a means to improve soil fertility and crop productivity: a review. *Journal of Plant Nutrition*, *45*(15), 2380-2388.https://doi.org/10.1080/01904167.2022.2027980

Karimi, A., Moezzi, A., Chorom, M., and Enayatizamir, N. 2020. Application of biochar changed the status of nutrients and biological activity in a calcareous soil. *Journal of Soil Science and Plant Nutrition*, *20*, 450-459. https://doi.org/10.1007/s42729-019-00129-5

Khadem, A., and Raiesi, F. 2017. Responses of microbial performance and community to corn biochar in calcareous sandy and clayey soils. *Applied Soil Ecology*, *114*, 16-27. https://doi.org/10.1016/j.apsoil.2017.02.018

Khadem, A., Raiesi, F., Besharati, H., and Khalaj, M. A. 2021. The effects of biochar on soil nutrients status, microbial activity and carbon sequestration potential in two calcareous soils. *Biochar*, *3*(1), 105-116. https://doi.org/10.1007/s42773-020-00076-w

Khairo, A. 2024. Effect of deficit irrigation and partial rootzone drying on the water consumptive use, growth and yield of faba bean (vicia faba L.) in a gypsiferous soil. *Tikrit Journal for Agricultural Sciences*, *24*(2), 54-71. https://doi.org/10.25130/tjas.24.2.5

Khdir, S., and Rahman, K. 2024. Combined Effect of Biochar and Mycorrhizal Fungi on Wheat (Triticum aestivum L.) Growth and Performance in Calcareous Soil. *Tikrit Journal for Agricultural Sciences*, *24*(1), 9–21. https://doi.org/10.25130/tjas.24.1.2

Khormali, F., and Abtahi, A. 2003. Origin and distribution of clay minerals in calcareous arid and semi-arid soils of Fars Province, southern Iran. *Clay minerals*, *38*(4), 511-527. https://doi.org/10.1180/0009855023740112

Knudsen, D., Peterson, G. A., and Pratt, P. F. 1982. Lithium, sodium, and potassium. *Methods of soil analysis: part 2 chemical and microbiological properties*, *9*, 225-246. https://doi.org/10.2134/agronmonogr9.2.2ed.c13

Kubo, K., Hirayama, T., Fujimura, S., Eguchi, T., Nihei, N., Hamamoto, S., ... and Shinano, T. 2018. Potassium behavior and clay mineral composition in the soil with low effectiveness of potassium application. *Soil science and plant nutrition*, *64*(2), 265-271.https://doi.org/10.1080/00380768.2017.1419830

Kuryntseva, P., Karamova, K., Galitskaya, P., Selivanovskaya, S., and Evtugyn, G. 2023. Biochar Functions in Soil Depending on Feedstock and Pyrolyzation Properties with Particular Emphasis on Biological Properties. *Agriculture*, *13*(10), 2003. https://doi.org/10.3390/agriculture13102003

Laghari, M., Mirjat, M. S., Hu, Z., Fazal, S., Xiao, B., Hu, M., ... and Guo, D. 2015. Effects of biochar application rate on sandy desert soil properties and sorghum growth. *Catena*, *135*, 313-320. https://doi.org/10.1016/j.catena.2015.08.013

Lehmann, J., Gaunt, J., and Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems–a review. *Mitigation and adaptation strategies for global change*, *11*, 403-427. https://doi.org/10.1007/s11027-005-9006-5

Liu, C., Wang, H., Li, P., Xian, Q., and Tang, X. 2019. Biochar's impact on dissolved organic matter (DOM) export from a cropland soil during natural rainfalls. *Science of the total environment*, *650*, 1988-1995. https://doi.org/10.1016/j.scitotenv.2018.09.356

Liu, K. L., Han, T. F., Huang, J., Asad, S., Li, D. M., Yu, X. C., and Zhang, H. M. 2020. Links between potassium of soil aggregates and pH levels in acidic soils under long-term fertilization regimes. *Soil and Tillage Research*, *197*, 104480. https://doi.org/10.1016/j.still.2019.104480

Liu, X., Mao, P., Li, L., and Ma, J. 2019. Impact of biochar application on yield-scaled greenhouse gas intensity: a meta-analysis. *Science of the Total Environment*, *656*, 969-976. https://doi.org/10.1016/j.scitotenv.2018.11.396

Lu, L., Yu, W., Wang, Y., Zhang, K., Zhu, X., Zhang, Y., ... and Chen, B. 2020. Application of biochar-based materials in environmental remediation: from multi-level structures to specific devices. *Biochar*, *2*, 1-31. https://doi.org/10.1007/s42773-020-00041-7

Lyu, H., Gao, B., He, F., Zimmerman, A. R., Ding, C., Huang, H., and Tang, J. 2018. Effects of ball milling on the physicochemical and sorptive properties of biochar: experimental observations and governing mechanisms. *Environmental Pollution*, *233*, 54-63. https://doi.org/10.1016/j.envpol.2017.10.037

Mahmoud, H. I., and Ismaeal, A. S. 2024, July. Pedogenic and Spatial Distribution of Gypsum Content in Soil Series units in Al-Dur District in Salah Al-Din Governorate. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1371, No. 8, p. 082051). IOP Publishing. https:// doi.org/ 10.1088/1755-1315/1371/8/082051

Mahmoud, H. I., and Ismail, A. S. 2024, July. Preparing a Map of the Spatial Variation of Ready Phosphorus in the Units of Gypsum Soil Series in Al-Dur District/Salah Al-Din Governorate. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1371, No. 8, p. 082052). IOP Publishing. https:// doi.org/ 10.1088/1755-1315/1371/8/082052

Mawlood, S. (2018). A comparative mineralogical study of some soils formed under varying climatic conditions from northern Iraq. *Mesopotamia Journal of Agriculture*, *46*(2), 72-81. 10.33899/MAGRJ.2018.161445

McKinley, J. M., Worden, R. H., and Ruffell, A. H. 1999. Smectite in sandstones: a review of the controls on occurrence and behaviour during diagenesis. *Clay mineral cements in sandstones*, 109-128. https://doi.org/10.1002/9781444304336.ch5

Meena, V. S., Bahadur, I., Maurya, B. R., Kumar, A., Meena, R. K., Meena, S. K., and Verma, J. P. 2016. Potassium-solubilizing microorganism in evergreen agriculture: an overview. *Potassium solubilizing microorganisms for sustainable agriculture*, 1-20. https://doi.org/10.1007/978-81-322-2776-2_1

Missana, T., Alonso, U., and García-Gutiérrez, M. 2009. Experimental study and modelling of selenite sorption onto illite and smectite clays. *Journal of Colloid and Interface Science*, *334*(2), 132-138. https://doi.org/10.1016/j.jcis.2009.02.059

Mouhamad, R., Alsaede, A., and Iqbal, M. 2016. Behavior of potassium in soil: a mini review. *Chemistry International*, *2*(1), 58-69. DOI: 10.13140/RG.2.1.4830.7041

Naeem, M. A., Khalid, M., Aon, M., Abbas, G., Tahir, M., Amjad, M., ... and Akhtar, S. S. 2017. Effect of wheat and rice straw biochar produced at different temperatures on maize growth and nutrient dynamics of a calcareous soil. *Archives of Agronomy and Soil Science*, *63*(14), 2048-2061.https://doi.org/10.1080/03650340.2017.1325468

Najafi-Ghiri, M., Boostani, H. R., and Hardie, A. G. 2022. Investigation of biochars application on potassium forms and dynamics in a calcareous soil under different moisture conditions. *Archives of Agronomy and Soil Science*, *68*(3), 325-339.https://doi.org/10.1080/03650340.2020.1834083

Owliaie, H. R., Abtahi, A., and Heck, R. J. 2006. Pedogenesis and clay mineralogical investigation of soils formed on gypsiferous and calcareous materials, on a transect, southwestern Iran. *Geoderma*, *134*(1-2), 62-81. https://doi.org/10.1016/j.geoderma.2005.08.015

Paola, A., Pierre, B., Vincenza, C., and Bruce, V. 2016. Short term clay mineral release and re-capture of potassium in a Zea mays field experiment. *Geoderma*, *264*, 54-60. https://doi.org/10.1016/j.geoderma.2015.10.005

Qadir, K., and Al-Obaidi, M. A. 2024. Using the kinetic approach for the adsorption of base ions (Ca, Mg, Na, K) by the calm flow method in some soils in the northern of Iraq. *Tikrit Journal for Agricultural Sciences*, *24*(1), 180-192. https://doi.org/10.25130/tjas.24.1.15

Rawat, J., Sanwal, P., and Saxena, J. 2016. Potassium and its role in sustainable agriculture. In *Potassium solubilizing microorganisms for sustainable agriculture* (pp. 235-253). New Delhi: Springer India. https://doi.org/10.1007/978-81-322-2776-2_17

Rhoades, J. D. 1996. Salinity: Electrical conductivity and total dissolved solids. Methods of soil analysis: Part 3 Chemical methods, 5, 417-435. https://doi.org/10.2136/sssabookser5.3.c14

Salari, K. R., Delavar, M. A., Esfandiari, M., and Pazira, E. 2019. Morphological, physical, and clay mineralogy of calcareous and gypsiferous soils in North of Lorestan, Iran. *Canadian Journal of Soil Science*, *99*(4), 485-494. https://doi.org/10.1139/cjss-2018-0141

Shaaban, M., Van Zwieten, L., Bashir, S., Younas, A., Núñez-Delgado, A., Chhajro, M. A., ... and Hu, R. 2018. A concise review of biochar application to agricultural soils to improve soil conditions and fight pollution. *Journal of environmental management*, *228*, 429-440. https://doi.org/10.1016/j.jenvman.2018.09.006

Sharma, R., Sindhu, S. S., and Glick, B. R. 2024. Potassium Solubilizing Microorganisms as Potential Biofertilizer: A Sustainable Climate-Resilient Approach to Improve Soil Fertility and Crop Production in Agriculture. *Journal of Plant Growth Regulation*, 1-33. https://doi.org/10.1007/s00344-024-11297-9

Soil Survey Staff. 1999. Soil taxonomy: a basic system of soil classification for making and interpreting soil survey.2nd ed. (Agricultural Handbook 436. Natural Resource Conservation Service USDA, Washington, US Government Printing Office. pp. 869).

Solly, E. F., Weber, V., Zimmermann, S., Walthert, L., Hagedorn, F., and Schmidt, M. W. 2020. A critical evaluation of the relationship between the effective cation exchange capacity and soil organic carbon content in Swiss forest soils. *Frontiers in Forests and Global Change*, *3*, 98. https://doi.org/10.3389/ffgc.2020.00098

Song, D., Tang, J., Xi, X., Zhang, S., Liang, G., Zhou, W., and Wang, X. 2018. Responses of soil nutrients and microbial activities to additions of maize straw biochar and chemical fertilization in a calcareous soil. *European Journal of Soil Biology*, *84*, 1-10. https://doi.org/10.1016/j.ejsobi.2017.11.003

Song, D., Xi, X., Zheng, Q., Liang, G., Zhou, W., and Wang, X. 2019. Soil nutrient and microbial activity responses to two years after maize straw biochar application in a calcareous soil. *Ecotoxicology and environmental safety*, *180*, 348-356. https://doi.org/10.1016/j.ecoenv.2019.04.073

Strawn, D. G. 2021. Sorption mechanisms of chemicals in soils. *Soil Systems*, *5*(1), 13. https://doi.org/10.3390/soilsystems5010013

Sun, Z., Hu, Y., Shi, L., Li, G., Pang, Z. H. E., Liu, S., ... and Jia, B. 2022. Effects of biochar on soil chemical properties: A global meta-analysis of agricultural soil. *Plant, Soil and Environment*, *68*(6), 272-289. https://doi.org/10.17221/522/2021-PSE

Tan, Z., Lin, C. S., Ji, X., and Rainey, T. J. 2017. Returning biochar to fields: A review. *Applied Soil Ecology*, *116*, 1-11. https://doi.org/10.1016/j.apsoil.2017.03.017

Thomas, G. W. 1996. Soil pH and soil acidity. *Methods of soil analysis: part 3 chemical methods*, *5*, 475-490. https://doi.org/10.2136/sssabookser5.3.c16

Tirado-Corbalá, R., Slater, B. K., Dick, W. A., Bigham, J., and Muñoz-Muñoz, M. 2019. Gypsum amendment effects on micromorphology and aggregation in no-till Mollisols and Alfisols from western Ohio, USA. *Geoderma Regional*, *16*, e00217. https://doi.org/10.25130/tjas.24.1.2

Wu, W., Yan, B., Zhong, L., Zhang, R., Guo, X., Cui, X., and Chen, G. 2021. Combustion ash addition promotes the production of K-enriched biochar and K release characteristics. *Journal of Cleaner Production*, *311*, 127557. https://doi.org/10.1016/j.jclepro.2021.127557

Xia, H., Wang, J., Riaz, M., Babar, S., Li, Y., Wang, X., Jiang, C. 2024. Co-application of biochar and potassium fertilizer improves soil potassium availability and microbial utilization of organic carbon: A four-year study. *Journal of Cleaner Production*, *469*, 143211. https://doi.org/10.1016/j.jclepro.2024.143211

Yadav, B. K., and Sidhu, A. S. 2016. Dynamics of potassium and their bioavailability for plant nutrition. *Potassium solubilizing microorganisms for sustainable agriculture*, 187-201. https://doi.org/10.1007/978-81-322-2776-2_14

Yadav, S. P. S., Bhandari, S., Bhatta, D., Poudel, A., Bhattarai, S., Yadav, P., ... and Oli, B. 2023. Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research*, *11*, 100498. https://doi.org/10.1016/j.jafr.2023.100498

Yahaya, S. M., Mahmud, A. A., Abdullahi, M., and Haruna, A. 2023. Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: a review. *Pedosphere*, *33*(3), 385-406. https://doi.org/10.1016/j.pedsph.2022.07.012

Yu, H., Zou, W., Chen, J., Chen, H., Yu, Z., Huang, J., ... and Gao, B. 2019. Biochar amendment improves crop production in problem soils: A review. *Journal of environmental management*, *232*, 8-21. https://doi.org/10.1016/j.jenvman.2018.10.117

Yuan, J. H., Xu, R. K., and Zhang, H. 2011. The forms of alkalis in the biochar produced from crop residues at different temperatures. *Bioresource technology*, *102*(3), 3488-3497. https://doi.org/10.1016/j.biortech.2010.11.018

Zhang, M., Riaz, M., Liu, B., Xia, H., El-Desouki, Z., and Jiang, C. 2020. Two-year study of biochar: Achieving excellent capability of potassium supply via alter clay mineral composition and potassium-dissolving bacteria activity. *Science of the Total Environment*, *717*, 137286. https://doi.org/10.1016/j.scitotenv.2020.137286

Zhang, Y., Wang, J., and Feng, Y. 2021. The effects of biochar addition on soil physicochemical properties: A review. *Catena*, *202*, 105284. https://doi.org/10.1016/j.catena.2021.105284