Menoufia J. Soil Sci.,Vol. 5 December (2020): 235 -256 https://mjss.journals.ekb.eg/

IMPACT OF SULPHUR AND BIOCHAR APPLICATIONS ON SOIL PROPERTIES AND PRODUCTIONS OF WHEAT AND SOYBEAN YIELDS IN SOILS HAVING TEXTURE

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Received: Nov. 28 , 2020 Accepted: Dec. 19 , 2020

ABSTRACT: Lysimeter experiments were conducted during two consecutive seasons of winter 2017/2018 and summer season 2018 for wheat and soybean at EL-Gemmieza Agriculture Research Station, El Gharbiya Governorate to study the influence of sulphur and biochar on soil proprieties, productivity of wheat and soybean yields in soils have different texture classes. The experiments were lay out in a split plot (SP) design with three replicates. The main plots were occupied with three different types of soils (clay, calcareous and sandy soils), sub plots were devoted to soil amendments i.e T1: control, T2: sulphur (1.50 Mg ha^{-1}), T3: biochar (5 Mg ha^{-1}) and T4: sulphur (1.50 Mg ha^{-1}) + biochar (5 Mg ha^{-1}). Results indicated that application of sulphur or biochar and individually and in combination led to an increase in available N, P, K, cation exchange capacity, total porosity, organic matter, exchangeable Ca, Mg and K while EC, pH, bulk density and soil hydraulic conductivity high significantly decreased in sandy and calcareous soils. On the contrary, soil hydraulic conductivity high significantly increased by different treatments in the clay soil. Grain and straw yields as well as N, P and K concentration and uptake of wheat and soybean were high significantly increased by all application sulphur and biochar. Consequently the improvement of soil types on all properties can be arranged in the following order sandy soil < calcareous soil < clay soil. The combination application of biochar and sulphur (T4) lead to significant increase in yield of wheat and soybean (grain and straw).

Key words: Sandy soil, Calcareous soil, Clay soil, Wheat, Soybean, Sulphur, Biochar, Soil properties.

INTRODUCTION

In Egypt, wheat is considered as one of the most vital cereal crops in the human life because it is rich in mineral, gluten and fiber contents. The total production of wheat in Egypt was 8.4 million ton from a land area of 1.28 to 1.43 million hectare (FAO, 2011) and (Helmy and Shaban, 2013). At present, demand for soybeans is increasing because it is a major commercial crop that is grown around the world, and it is a major source of protein, oil, fiber, vitamins, minerals and nutrients. The seed of proteins contains 40-45% based on dry weight (Kaviani and Kharabian, 2008). Therefore, appropriate production technology as well as low-cost soybean production should be encouraged to improve soybean productivity. Because of rising prices for mineral fertilizers, low-cost organic adjustments are a convincing alternative to partial substitution.

Biochar is a porous and highly stable form of charcoal produced by slow down the pyramid movement of organic wastes such as crop residue. There is growing interest in their potential, especially as soil amendments and carbon sequestration. During the pyrolysis process, biomass is heated in a zero- or low-oxygen environment. The process generates three products; biochar, tar and syngas. The pyrolysis process retains carbon in the biomass in the form of biochar, instead of being converted to carbon dioxide as in regular combustion. (Verheijen *et al.,* 2010, Kookana *et al.,* 2011, and Xu *et al.,* 2011,). The biochar (B) integration can change the physical properties of soil such as structure, total density and pore size distribution, water holding capacity, with implications for soil aeration, soil workability and increasing soil C storage on a large scale as well as improve plant growth. Application of biochar at 5 and 10 ton fed^{-1} decreased soil bulk density (Bd), hydraulic conductivity(Hc), pH, EC, soluble Na, SAR and ESP values, while increased cation exchange capacity (CEC), organic matter, total nitrogen as well as available amounts of P, K. (Mousa, 2017).

Sulphur (S) is essential for the synthesis of proteins and vitamins and the containment of essential amino acids and vitamins, which is also associated with nitrogen metabolism. The good yield of wheat and soybean can be achieved by balanced and adequate supply of phosphate, sulphur and other deficient nutrients. The agricultural effectiveness of the reduced sulphur is directly related to the oxidation rate that provides the plant sulfate available after application. Elements sulphur are non-soluble hydrophobic particles based on the microbial colonization of their surface and the subsequent oxidation rates of sulphur are slow in cold and dry soils (Malhi *et al.,* 2005). In addition to providing sulfur as a nutrient, sulfur compounds are also used as soil conditioners, these compounds act as soil acidifiers neutralizing CaCO3 with acid, thus can reduce soil pH and improve the availability of elements. Soil compaction rates required for plant response depend on the amount of CaCO3 in the soil (El-Tarabily *et al.,* 2006). Calcareous soils are alkaline because of the presence of $CaCO_3$ which dominates the soil physical and chemical properties. Many soil factors affect uptake of nutrient crops from soil. Among these factors, high $CaCO_3$ and pH are often responsible for reducing the availability of crop nutrients (Kaya *et al.,* 2009). Relatively low calcareous sandy soil in OM with high soil pH has shown a significant decrease on nutrients availability that provide growth Plant. (Abdou, 2006). The pH of soil has an important role to play in the loss of nitrogen or fixation of most nutrients, so different nutrient management practices are needed to produce crops in different soil types. Calcareous soil contains total calcium carbonate and soil pH which significantly reduces the availability of macro and micronutrients (Brady and Weil, 2002).

Sandy soils in Egypt are characterized by poor fertility (low retention capacity for water and nutrients) and limited crop productivity. Searching for natural organic amendments to improve their fertilities is one of the vital tasks in the Egyptian agriculture system (Ali, 2018). Wahab *et al.,* (2010) found that a large area in the north of the Nile Delta was in great danger of physical and chemical degradation. Moreover, soil compaction, logging on water, alkaline, and salinity are very high in different land units. Therefore, the ameliorative impacts of biochar and sulphur on wheat and soybean yields and some soil properties were investigated under different soils.

MATERIALS AND METHODS

Sampling Location:

Three soil were used sandy, calcareous and clay soils. The sandy soil was collected from location of EL-

Bostan- Bahira Governorate, the calcareous soil was taken from Kilo 48 cairo –Alexandria desert road –Nubaria – Bahira Governorate, the clay soil was taken from EL-Gemmieza Agriculture Research Station, of the Agricultural Research Center (ARC), El Gharbiya Governorate. Three soils pot in thirty six lysimeters 2 meter in length, 1 meter in width and 2 meter in depth were used in this study.

Experimental design

Lysimeter experiments were conducted at EL-Gemmieza Agriculture Research Station, of the Agric., Res., Center (ARC), El Gharbiya Governorate, Egypt (Middle Delta region 30º 43- latitude and 31º 47- longitude) during two successive growing winter season of 2017/2018 and summer season of 2018. Thirty six lysimeters 2 meter in length, 1meter in width and 2 meter in depth. Lysimeters divided into three main groups, each group were filled with one of soil type namely: sandy, calcareous and clay soils. Each soil is considered as an independent experiment was designed as split plot (SP) with three replicates. The main groups were occupied by three soils (sandy, calcareous and clay soils). The lysimeters of each soil were deviled into four sub groups representing the studied treatments of sulphur (S) and biochar (B) which were T1: control (without any addition), T2: sulphur (1.50 Mg ha^{-1}), T3: biochar (5 Mg ha^{-1}) and T4: sulphur (1.50Mg ha^{-1}) + biochar (5 Mg ha^{-1}). S and B were thoroughly blended with the surface soil layer (0-30 cm) of the concerned plots before wheat planting.

The study started in winter growing season 2017/2018 with Wheat (*Triticum aestivum L Giza 168*) by using 120Kg ha^{-1} grains rate, grains were cultivated on 24^{th} November 2017. The recommended doses of mineral NPK fertilizers were applied as recommended by the Ministry of Agriculture, Egypt. Super phosphate (15.5% P_2O_5) was added as a single dose at rate of 230 kg ha^{-1} before cultivation and mixed in the same times with such surface layer. N fertilizer was used as ammonium nitrate (NH_4NO_3) (33.5%N) at rate of 540 kg ha^{-1} which added in three equal portions at heading stages and after 30 and 60 days of sowing. Potassium fertilizer was added at rate of 238 kg ha^{-1} as Potassium sulphate (K_2SO_4) (48% K_2O), where applied after 60 and 90 days of sowing. Wheat plants was harvested at in 19^{th} May 2018. The grains separated from straw and weighted separately. The second growing season of 2018 followed the first, 5 seeds of soybean *(Glycine max (L.) Merrill, Giza 111)* were sown in a small whole; the distance between the wholes was 15 cm. Soybean plants were thinned to 3 plants after their full germination. The other agricultural practices were done as the recommendation of Ministry of Agriculture. P was added at rate of 460 kg ha^{-1} before cultivation as superphosphate (15.5% P_2O_5). Nitrogen doses were added in equal three times at rate 450 Kg ha^{-1} as ammonium nitrate (NH_4NO_3) (33.5%N) after 30 and 60 days of sowing. Potassium fertilizer was added at rate 238 kg ha^{-1} was add as potassium sulphate (48% K_2O) after 40 and 60 days of sowing. Soybean Plants were harvested on the 17^{th} of September 2018 and the grains were separated from straw and weighted separately. After harvesting of either of wheat and soybean soil sample of each experimental unit was taken and analyzed for soil physical and chemical properties as well as its available N. P and K. Before planting, soil samples were collected at the depth of (0-30 cm) from three different soils. Samples were allowed to dry under shade, then ground and sieved to pass through a 2 mm sieve. Each sample was stored in prepared plastic bags for subsequent laboratory analysis. soil samples were analyzed for some chemical characteristics according to Land and Development Department

(2010) soil pH were determined in a 1:2.5 ratio (soil/water susp.), The total soluble salts (EC) were determined using electrical conductivity meter at 25°C in soil paste extract as dS m^{-1}, cation exchange capacity (CEC) were determined by using ammonium acetate. Organic matter (OM) were determined by using Walkley and Black method, the soil content of available N, P and K were extracted by KCl (2M), $NaHCO_3$ (0.5 M) and CH_3COONH_4 (1M), respectively. Available N, P and K were determined according to the method of AOAC. (1995). Exchangeable calcium, magnesium, sodium and potassium were determined in 1N ammonium acetate extraction at pH 7.0, where, Na and K were determined by flame photometry, while, Ca + Mg were determined by EDTA titration. The content of calcium carbonate was determined by using calcimeter according to (Balazs *et al.,* 2005). Particle size distribution was carried out by the Pipette method described by Sheldrick and Wang, (1993). Soil samples were taken from the three soils to determine the bulk density (Bd) according to Blake and Hartge, (1986), hydraulic conductivity (Hc) was measured by auger hole method according to Rowell, (1995). The main physical and chemical properties of the three soils are presented in Table (1). This material which supplied by El-Help company, Egypt. Sulphur was applied to improve the soils. The biochar treatment used in this experiment at two years was prepared from different types of citrus trees. Chemical and physical properties of the used biochar were determined and the obtained data are showed in Table (2). For trapping CO_2, vials containing 10 ml of 1 M Na OH were placed inside vessels filled with 100g of non and biochar treated soil samples having the moisture content at the field capacity. Then, the vessels were tightly closed and incubated under controlled conditions at 30°C. This temperature was chosen because the optimal temperature for the microbial activity ranges from 20 to 35°C. The CO_2 evolved during each incubation period was trapped in 1 M NaOH and the excess of NaOH was titrated with 0.1 M HCl after adding $BaCl_2$. Mineralized C was calculated as a cumulative CO_2^- evolution (g kg^{-1} soil) according to Leifeld *et al.,* (2002).

Table (1): chemical and physical properties of the experimental soils.

Soils	pH (1:2.5)	EC (ds m^{-1})	Soluble cations (meq L^{-1})				Soluble anaions (meq L^{-1})				OM (%)	$CaCO_3$ (%)
			Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	CO_3^{--}	HCO_3^-	SO_4^-		
Sandy	8.33	4.31	5.80	7.80	28.95	0.32	18.80	ND	7.95	16.12	0.25	4.80
Calcareous	8.21	2.90	6.80	4.90	17.89	0.39	12.80	ND	6.00	11.18	0.38	26.11
Clay	8.27	4.70	6.00	7.05	33.08	0.68	23.00	ND	8.75	15.06	0.69	3.10

Soils	Exchangeable cations (cmol Kg^{-1})				CEC (cmol Kg^{-1})	ESP	Particle size distribution				Texture	Bd (g cm^{-3})	Tp (%)	HC cm hr^{-1}
	Ca^{2+}	Mg^{2+}	Na^+	K^+			C-sand	F-sand	Silt	clay				
Sandy	1.70	2.20	2.15	0.40	65.65	32.33	50.75	40.05	5.20	4.00	sandy	1.62	38.87	19.27
Calcareous	7.00	4.40	4.00	0.70	16.80	23.81	20.45	22.80	30.71	26.04	sandy loam	1.49	43.77	10.01

Clay	11.13	14.90	14.85	1.40	43.27	34.32	7.90	11.75	35.18	45.17	clay	1.37	48.30	0.67

, CEC= Cation exchange capacity OM= Organic matter ESP= Exchangeable sodium percentage, Bd= bulk density, Tp= total porosity, Hc= Hydraulic conductivity

Table (2): Some characteristics of biochar used in this study.

properties	pH (1:10)	EC (1:10) dS m^{-1}	CEC (Cmol kg^{-1})	Bd (g cm^{-3})	Total N (%)	Total P (%)	Total K (%)	OC (%)	C/N ratio
Biochar	8.95	1.85	33.85	0.52	1.84	0.46	1.10	59.25	32.20

Sample of biochar was air-dried and ground, 1.0 gm weight of biochar and digested using mixture of H_2SO_4 and $HClO_4$ at mixed rate of 3:1 Then, the digest was diluted with distilled water to a volume of 100 ml. Aliquots from this digest was analyzed for physical and chemical properties according to Blake and Hartge (1986) and Cottenie *et al.* (1982). Plant samples (grain and straw) of both wheat and soybean were oven dried at 70 ˚C and ground A 0.5 g of oven-dried plant sample was digested using H_2SO_4 and $HClO_4$ mixture according to the method described by Chapman and Partt, (1961). In the final diluted digests of plant sample concentration N, P and K were determined according to methods described by (Cottenie *et al.,* 1982).

Statistical analysis:-

The data were analyzed statistically according to the contrast analysis (ANOVA) to assess the impact of amendments on soil characteristics and wheat and soybean yield, which is the least significant difference (LSD) at the probability level of 0.05 applied to make comparisons among treatment means (SAS, 2010).

RESULTS AND DISCUSSION

I. Effects the sulphur (S) and biochar (B) application on soil chemical properties

a: Soil pH and EC

Results given in Table (3) shows that soil pH and EC were significantly affected by integrated application of S and B. Results clearly indicated that combined addition of biochar and sulphur (T4) led to decrease of soil pH by 2.98, 3.89 and 2.50% after harvest of wheat, 5.31, 5.53 and 3.73% after harvest soybean whereas EC decreased by 23.70, 21.63 and 21.54% after harvest wheat 31.09, 33.59 and 34.98% as compared to control for sandy, calcareous and clay soils, respectively.

Reduction of soil pH at the end of experiments might be due to release of protons (H^+) from the exchange sites of biochar (B) and due to the spread of acid that produces soil microorganisms.The production of organic acid during the decomposition of OM present in soil and biochar may have contributed to a decrease in the pH of the soil. Shenbagavalli and Mahimairaja (2012) reported that biochar application at rates 1, 2, 3, 4 and 5% decreased soil pH in sandy clay loam soil by increasing periods 30, 60 and 90 day after application. Amini (2015) found that application amendments of biochar at 5 and 10%w/w and gypsum at rate 2%w/w reduction the values pH and EC in saline clay soil. Decline in soil pH and EC values due to chemical and biological reactions of each manure applied increase CO_2 concentrations Which can reduce pH toward a neutral point and release H^+ when dissolved in water, the released H^+ enhances $CaCO_3$ dissolution

and frees more calcium exchange for sodium exchange.These findings are in general agreement with the findings of Hasheminajd *et al., (*2012) and El-Gamal, (2015). Liu and Zhang (2012) found that biochar decrease the value soil pH in different alkaline soils. Mutowal *et al.,* (2013) and Motior *et al.,* (2011) found that

Table 3

the use of sulphur at rates of 0.00, 1.00, 5.00 and 10.00 t ha^{-1} reduced soil pH and EC. The plots sulphur treated reduce soil pH (7.5, 7.4 and 7.4 respectively) as compared to control as shown by (Jamal *et al.,* 2010).

b- Available nutrients, organic matter and CO_2 evolved in soils

The results shown in Table (3) appeared positive responses of N, P, K available, organic matter and CO_2 evolved with combined application of sulphur and biochar as compared to control treatments. The superior increases of nutrients availability were found with the treatments of biochar + sulphur, where the percent increases of these data nutrients in sandy soil 23.45, 215.48, 9.09, 136.67 and 49.50% and, were 22.05, 94.16, 11.05, 69.23, 54.61% in calcareous soil, where there were 13.73, 64.52, 16.71, 67.06 and 35.65% in clay soil for the content of available N, P, K, organic matter and CO_2 evolved respectively, as compared to control treatment after harvest wheat. Combined application sulphur and biochar give the greatest values of N, P, K available, organic matter and CO_2 evolved were increase percent by 30.68, 257.98, 9.80, 126.31 and 52.33% in sandy soil, were 26.10, 100.53, 9.16, 83.33 and 68.61% in calcareous soil, and were 17.88, 85.03, 14.73, 44.86 and 30.01% in clay soil with soil sample taken in harvest soybean N, P, K available, organic matter and CO_2 evolved, respectively, as compared to untreatment. These results attributed to application of sulphur and biochar which led to improve nutrients status in soils may be due to biochar and sulphur were major source of nutrients through internal soil transformations. Nutrients are released and retained through six processes, immobilization, mineralization, precipitation dissolution, desorption and adsorption. Application of biochar often increases soil N availability because of improved nutrient retention increase evolution of CO_2-C. Organic C is utilized for energy by decomposer microorganisms, its fate is to be assimilated into their tissues, released as metabolic products, or respired as carbon dioxide (CO_2). Energy organic C is used by decomposed microorganisms, their fate is absorbed into their tissues, released as metabolites, or exceeded as CO_2. In this respect, similar results were obtained by Major *et al.,* (2010a) and Prapagar *et al.,* (2012). Application of sulphue and biochar resulted in a clear change soil physical, biological and chemical properties (Buchkina *et al.,* 2019). Therefore, B application is a promising alternative to sequestration of more carbon compared to more traditional agricultural practices involving direct integration of biomass, (Bruun *et al.,* 2011). This results in immediate and rapid mineralization, and the release of carbon dioxide. Moreover, soil chemical properties, including OC and nutrients availability were markedly affected by biochar (B). Availability of N, P and K were markedly increased in biochar treatments as compared with untreatment (Ali, 2018).

Nabavinia *et al.,* (2015) found that application B at rate 2.5 t ha^{-1} increased total soil nitrogen, available P and K as compared to without treatment in loamy sand soil. The application of sulfur at rates 200, 300, 400 and 600 kg powdered S/fed, that is oxidized to SO_4^{-2} by soil microorganisms, expectedly lively lowers the pH value, and consequently increases the nutrients availability.

Deekshitha *et al., (*2017) indicated that application of sulphur in clay loam soil led to increased OM and available of NPK, while soil pH was decrease can be attributed to high availability of nutrients under decrease soil pH associated with use Sulphur application. The benefits that soybean can gain from organic amendments and Sulphur application may be related to the bioavailability of the substrate C as well as release of nutrients, however may not be obtained in terms of stabilizing N_2 in high-fertility soils.Also, the addition of biochar in clay loam plantation soil can increase the growth and yields of soybean, available P, K and OM (Yooyen *et al.,* 2015).

c-Cation exchange capacity (CEC), exchangeable cations and exchangeable sodium percentage (ESP)

Data in Table (4) shows the impact of B and S application individually and in together on CEC, ESP and exchangeable cations (Ca, Mg, Na and K). Results revealed that CEC and ESP values significant influence as a results of the used soil amendments applications. The greatest values of CEC, Ca, Mg and K after harvest of wheat with combined application of biochar and sulphur, which increased by 16.26, 45.45, 24.28 and 42.86 % in sandy soil, increased by 7.96, 14.87, 16.56 and 66.67% in calcareous soil and increased by 9.51, 34.66, 14.38 and 52.03% in clay soil respectively comparing with control treatment. Conversely, the values of exchangeable Na and ESP were decreased with biochar and sulphur application. However, biochar + sulphur mixture application led to decrease exchangeable Na and ESP by 26.47 and 36.43 % in sandy soil, decreased by 20.52 and 26.45% in calcareous soil and decreased by 18.56 and 25.63% in clay soil comparing with the control, respectively. Where the values of CEC, Ca, Mg and K after harvest soybean increased by 22.12, 57.95, 37.20 and 39.34% in sandy soil , 10.01, 24.61, 28.60 and 64.94% in calcareous soil and 9.02, 42.35, 18.01 and 47.10% in clay soil with the treatment of sulphur + biohar mixture, receptivity comparing with without application. On the other side, exchangeable Na and ESP slightly decrease by biochar, sulphur and sulphur + biohar mixture applied. Actually, it can be observed that, the decrease rate of exchangeable Na^+ and ESP were 33.33 and 45.12% in sandy soil, 44.50 and 49.60% in calcareous soil and decreased by 34.08 and 39.50% in clay soil which recorded with the treatment of sulphur + biohar mixture application less than those in the control treatment, respectively. Also, the increasing in soil CEC was due to organic manure addition and the increasing in the amount of active groups of biochar and sulphur. (Wakode *et al.,* 2011 and Dume *et al.,* 2016).

Due to the oxidation of sulphur biologically by sulphur oxidizing bacteria and the production of sulfuric acid, which is the source of hydrogen ions. Sulphuric acid leads to the dissolve of both of calcium and magnesium, which is substituting exchangeable sodium, thereby leads to lowering soil ESP. These results are parallel with those obtained by El-Maddah *et al.,* (2012). The use of biochar at rates (3.00, 6.00 and 9.00 Mg ha^{-1}) provides increases in elements calcium and magnesium and effective CEC of the soil after a soybean cropping (Dos Passos *et al.,* 2015). Kizito *et al.,* (2019) showed that biochar application at rates 0.5 and 1.50% to clay loam soil led to increased CEC and availability N, P, Ca, Mg and K. FAO (2014) showed that sulphur applied in calcareous soils where the oxidation of elemental sulphur by microorganism to H_2SO_4 and solubilizing $CaCO_3$ or forming $CaSO_4$ to supply the calcium ions which replace the adsorbed

sodium. Shenbagavalli and Mahimairaja (2012) found that, application biochar at rates 1, 2, 3, 4 and 5% increased soil CEC and OM in sandy clay loam soil by increasing periods 30, 60 and 90 days after application. In addition, slowing oxidation of the biochar increased the number of carboxylic groups, which in turn increased the CEC in soil. Abrishamkesh *et al.,* (2015) indicated that biochar application at rates 0.4, 0.8, 1.6,

Table 4

2.4, and 3.3% by weight to clay loam soil significantly increased soil OC, CEC and available K. The biochar (B) application improved soil fertility status, especially soil O.C., CEC, available P, exchangeable Ca, Mg and K in sandy loam soils. (Sukartono *et al.,* 2011). The increment of soil CEC as a result of biochar application caused by this discretion can be seen by analyzing of B, such as high porosity and surface area. High OC and CEC in soils amended by biochar. (Nigussie *et al.,* 2012).

II. Effects of sulphur and biochar applied on soil physical properties

Moreover, the influence of sulphur and biochar application individually and in combination on bulk density (Bd), total porosity (Tp) and hydraulic conductivity (Hc) in different soils were presented in Table (5). All treatments of Sulphur and biochar application significantly effect on Bd, Tp and (Hc) after harvest of wheat and soybean. The mean values of bulk density after harvest of wheat in sandy soil were decreased from1.60 to (1.57, 1.51and 1.47 g cm^{-3}), from 1.45 to (1.42, 1.38 and 1.34 g cm^{-3}) in calcareous soil and from 1.22 to (1.18, 1.15 and 1.11 g cm^{-3}) in clay soil, as compared with control of sulphur , biochar and sulphur+ biochar mixture application, respectively. On the other hand, the values of total porosity differed significant and increase from 39.62 to (40.75, 43.02 and 44.53%) in sandy soil and from 45.28 to (46.42, 47.92 and 49.43%) in calcareous soil, and from 53.96 to (55.47, 56.60 and 58.11%) in clay soil, as compared with control of sulphur, biochar and sulphur+ biochar mixture application, respectively. The values of hydraulic conductivity were decreased from 18.09 to (16.83, 14.85 and 13.67 cm h^{-1}) in sandy soil, decreased by 9.09 to (7.26, 7.76 and 7.25 cm h^{-1}) in calcareous soil and increased from 0.78 to (1.07, 1.36 and 1.70 cm h^{-1})in clay soil, as compared with control of sulphur , biochar and sulphur+ biochar mixture application, respectively. On the other hand, it is clear from the data that, the mean values of bulk density after harvest soybean decreased from 1.58 to (1.53, 1.48 and 1.44 g cm^{-3}) in sandy soil, decreased from 1.43 to (1.41, 1.34 and 1.31 g cm^{-3}) in calcareous soil and decreased from 1.22 to (1.18, 1.15 and 1.11 g cm^{-3}) in clay soil, as compared with control of sulphur, biochar and sulphur+ biochar mixture application, respectively. On the contrary, total porosity values in soils increase significant and reached to 40.38 to (42.26, 44.15 and 45.66%) in sandy soil, increase from 46.04 to (46.79, 49.43 and 50.57%) in calcareous soil, and increase from 54.34 to (56.23, 58.11 and 60.38%) in clay soil, as compared with control of sulphur , biochar and sulphur+ biochar mixture application, respectively. The values of hydraulic conductivity were significant influence due application of sulphur, biochar and sulphur+ biochar mixture when compared with control treatments. However, the response of hydraulic conductivity is comparatively observed with sulphur and biochar rates than that obtained under control treatment. The values decrease from 17.16 to (15.25, 13.36 and 11.29 cm h^{-1}) in sandy soil, decrease from 8.17 to (7.78, 7.15 and 6.08 cm h^{-1}), while in clay soil, the values increase from 0.96 to (1.43, 2.10 and 2.86 cm h^{-1}) as compared with control of

sulphur , biochar and sulphur+ biochar mixture application, respectively.

These results may be due to that stay long time of sulphur stimulate the microbial oxidation and led to the aggregating effect on soil particles, which create more aggregates leading to increase the apparent volume, consequently, then decrease bulk density. This increase of Tp may be due to that organic matter lead to synthesis of compound that bind soil particles and produced stable aggregates. physical properties would be improved, wherever, these aggregates help maintain a loose, open, and open state water, the more it can infiltrate and infiltrate the soil, requires constant supplies of CO_2 to enable it to encroach and grow, and greater poverty allows for better exchange of gases between soil and the atmosphere. These findings are consistent with the reported by El-Sodany *et al.,* (2012) and Hashemimajd *et al.,* (2012). Application of biochar significantly decreases Hc and Bd. It was also noted that, the increase biochar led to a significant reduction in the water-repellent soil. An increase in water retention was also observed at low matrix potential, where increased biochar were found to be able to hold more water when the soil was dry.(Verheijen *et al.,* (2010) and Barnes *et al.,* 2014). Ali, (2018) showed that incorporation of biochar at rates 0, 4.20, 8.40 and 16.80 g kg^{-1} caused significant improvements in the physical properties of the soil through decreasing Bd and increasing Td, water-holding capacity and volumetric water. Biochar is expected to increase the drainage of sandy soil slowly. (Atkinson *et al.,* 2010) and clay-rich soils to drain water more quickly (Major *et al.,* 2010b). However, the above results have not been consistent, and are likely to be the result of confounding factors such as biochar properties (e.g. raw materials, heat-projection temperatures), application rates, and soil characteristics.

Table (5): Influence of sulphur and biochar on some physical properties under different soils after harvesting of wheat and soybean yields.

Soils	Treatments	After harvesting of wheat			After harvesting of soybean		
		Bd (g cm^{-1})	Tp (%)	Hc (Cm hr^{-1})	Bd (g cm^{-1})	TP (%)	HC (Cm hr^{-1})
Sandy	T1	1.60	39.62	18.09	1.58	40.38	17.16
	T2	1.57	40.75	16.83	1.53	42.26	15.25
	T3	1.51	43.02	14.85	1.48	44.15	13.36
	T4	1.47	44.53	13.67	1.44	45.66	11.29
Mean		1.54	41.98	15.86	1.51	43.11	14.27
Calcareous	T1	1.45	45.28	9.09	1.43	46.04	8.17
	T2	1.42	46.42	7.26	1.41	46.79	7.78
	T3	1.38	47.92	7.79	1.34	49.43	7.15
	T4	1.34	49.43	7.25	1.31	50.57	6.08
Mean		1.40	47.26	7.85	1.37	48.21	7.29
Clay	T1	1.22	53.96	0.78	1.21	54.34	0.96
	T2	1.18	55.47	1.07	1.16	56.23	1.43
	T3	1.15	56.60	1.36	1.11	58.11	2.10

	T4	1.11	58.11	1.70	1.05	60.38	2.86
Mean		1.17	56.04	1.23	1.32	57.26	1.84
L.S.D. $_{0.05}$ S		0.02	0.85	0.34	0.01	0.39	0.33
L.S.D. $_{0.05}$ T		0.02	0.71	0.43	0.02	0.69	0.49
L.S.D. $_{0.05}$ S*T		ns	ns	0.31	ns	ns	0.57

Bd = bulk density, Tp= Total porosity and Hc= hydraulic conductivity

III. Effect of sulphur and biochar on wheat and soybean plants

a- Grain and straw yields of wheat and soybean

Grain and straw yields of both crops grown on three soils were affected significantly by the application sulphur and biochar individually and together as shown as in Tables (6 and 7). Where these application resulted in a significantly increase grain and straw of the plants. The highest yields of grains and straw were found with combined application sulphur and biochar. In addition, there demonstrating the beneficial impact of S and B on wheat and soybean yields. The substantially, analysis showed that adding sulphur + biochar mixture gave the highest values in wheat grain and straw.

Table (6): Influence of sulphur and biochar on wheat grain, straw yield (Mg ha^{-1}) and nutrients concentration (%) under different soils.

Soils	Treatments	Gain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	NPK concentration in grain (%)			NPK concentration in straw (%)		
				N	P	K	N	P	K
Sandy	T1	4.52	5.86	1.78	0.12	0.39	0.60	0.06	1.51
	T2	4.71	6.08	1.82	0.16	0.52	0.68	0.07	1.58
	T3	4.82	6.40	1.86	0.19	0.58	0.75	0.08	1.68
	T4	5.10	6.77	1.92	0.21	0.67	0.78	0.09	1.77
Mean		4.79	6.28	1.85	0.17	0.54	0.70	0.08	1.64
Calcareous	T1	4.95	7.03	1.88	0.14	0.48	0.68	0.07	1.58
	T2	5.57	7.91	1.98	0.17	0.72	0.77	0.08	1.72
	T3	5.27	7.51	2.10	0.19	0.77	0.82	0.10	1.78
	T4	6.18	7.78	2.17	0.22	0.82	0.93	0.11	1.87
Mean		5.49	7.56	2.03	0.18	0.70	0.80	0.09	1.74
Clay	T1	6.32	7.71	1.95	0.18	0.55	0.82	0.08	1.75
	T2	6.77	8.38	2.10	0.21	0.73	0.88	0.11	1.87
	T3	7.17	9.06	2.26	0.24	0.82	1.02	0.15	2.00
	T4	7.77	9.44	2.51	0.27	0.92	1.2	0.17	2.17

Mean	**7.01**	**8.65**	**2.21**	**0.23**	**0.76**	**0.98**	**0.13**	**1.95**
L.S.D. $_{0.05}$ S	**0.10**	**0.41**	**0.055**	**0.02**	**0.06**	**0.062**	**0.020**	**0.02**
L.S.D. $_{0.05}$ T	**0.16**	**0.27**	**0.072**	**0.02**	**0.066**	**0.057**	**0.08**	**0.04**
L.S.D. $_{0.05}$ S*T	**0.040**	**ns**	**0.067**	**ns**	**ns**	**ns**	**0.033**	**ns**

Table (7): Influence of sulphur and biochar on soybean grain, straw yield (Mg ha^{-1}) and nutrients concentration (%) under different soils.

Soils	**Treatments**	**Gain yield (Mg ha^{-1})**	**Straw yield (Mg ha^{-1})**	**NPK concentration in grain (%)**			**NPK concentration in straw (%)**		
				N	**P**	**K**	**N**	**P**	**K**
Sandy	**T1**	**1.22**	**1.79**	**3.81**	**0.25**	**0.67**	**1.70**	**0.15**	**1.67**
	T2	**1.55**	**1.99**	**4.01**	**0.29**	**0.82**	**1.85**	**0.19**	**1.73**
	T3	**1.83**	**2.63**	**4.27**	**0.32**	**1.02**	**2.06**	**0.22**	**1.87**
	T4	**2.11**	**2.90**	**4.75**	**0.37**	**1.15**	**2.23**	**0.26**	**2.00**
Mean		**1.68**	**2.33**	**4.21**	**0.31**	**0.92**	**1.96**	**0.21**	**1.82**
Calcareous	**T1**	**1.38**	**2.08**	**4.28**	**0.28**	**0.82**	**1.83**	**0.20**	**1.75**
	T2	**2.06**	**2.61**	**4.62**	**0.34**	**1.15**	**1.95**	**0.26**	**1.88**
	T3	**1.86**	**2.45**	**5.12**	**0.32**	**1.19**	**2.12**	**0.25**	**2.09**
	T4	**2.43**	**3.04**	**5.50**	**0.40**	**1.23**	**2.33**	**0.30**	**2.23**
Mean		**1.93**	**2.55**	**4.88**	**0.34**	**1.10**	**2.06**	**0.25**	**1.99**
Clay	**T1**	**1.77**	**2.44**	**5.06**	**0.32**	**1.02**	**2.08**	**0.22**	**1.80**
	T2	**1.96**	**2.78**	**5.35**	**0.35**	**1.17**	**2.33**	**0.28**	**2.02**
	T3	**2.61**	**3.32**	**5.72**	**0.41**	**1.28**	**2.39**	**0.32**	**2.28**
	T4	**3.12**	**4.13**	**6.15**	**0.46**	**1.37**	**2.51**	**0.34**	**2.43**
Mean		**2.37**	**3.17**	**5.57**	**0.39**	**1.21**	**2.33**	**0.29**	**2.13**
L.S.D. $_{0.05}$ S		**0.086**	**0.012**	**0.096**	**0.01**	**0.043**	**0.072**	**0.018**	**0.082**
L.S.D. $_{0.05}$ T		**0.077**	**0.14**	**0.18**	**0.02**	**0.052**	**0.061**	**0.022**	**0.066**
L.S.D. $_{0.05}$ S*T		**0.023**	**0.17**	**ns**	**ns**	**0.036**	**ns**	**0.012**	**0.038**

This increase recorded 12.83 and 15.53% in sandy soil, 24.85 and 10.67% in calcareous soil and 22.94 and 22.44% in clay soil as compared control, respectively (Table 6). The percent of increase in soybean grain and straw yield were 72.95 and 62.01% in sandy soil, 76.09 and 46.15% in calcareous soil, and 76.27 and 69.26% in clay soil (Table 7) due to combined application of sulphur and biochar than the without treatment, respectively. The synergistic effect of sulfur may be attributed to the use of high amounts of nutrients through its advanced root system and nodules that may have resulted in better growth and better soil yield. The influence of biochar on seeds dry weight of soybean is due to

its properties. This is because biochar is so well preserved with nutrients and increased, reduce loss of nutrient caused by erosion, improve water absorption, relieve soil density and enhance the growth of beneficial microorganisms. A study undertaken by Agboola and Moses (2015) found that the yield of soybean increased due to addition of rice husk biochar. Similarly, soil characteristics such as soil pH and the content of (N, Ca, Mg, K and Na) change due to the use of biochar in soil. Gebremedhin *et al.,* (2015). Ali (2018) revealed that B amended soils at rate 4 Mg ha^{-1} of Tigray region, north Ethiopia increases significantly yield of wheat. Thus, the presence of plant nutrients and charcoal in the biochar could have increased the production of wheat in B treatment soils. Applying B properties is therefore formal in order to increase soil fertility, water retention, and wheat productivity. Biochar enriched with sulfur, produced by exposure to H_2S generated from landfill biogas, can be used as a beneficial agricultural S fertilizer for promoting corn and soybean plant growth (Zhang *et al.,* 2017). Erdem *et al.,* (2016) found that sulphur application at rates 0.00, 25.00, 50.00 and 100.00 mg S kg^{-1} led to increased wheat yield most depend on soil characteristics, especially available sulfur levels in Eskisehir and Konya soils. Sulphur fertilization increased crop yields by 16.00% to 31.00% of crops studied in Brazil's NT soils.

Pias *et al.,* (2019) and Zhu *et al.,* (2018) showed that application biochar at rates 0, 0.15, 0.75 and 1.5%, w/v improve soybean seedling growth in sandy soil. The modification of biochar has resulted in a statistically significant increase in the root Shoot dry weight from soybeans. (Egamberdieva *et al.,* 2016). Suppadit *et al.,* (2012) showed that biochar application at rates of 0, 24.60, 49.20, 73.80, 98.40 and 123.00 g per pot a mixture has been served to soybean. Increased sulphur application led to a significant increase in soybean protein content. The positive response to additional sulphur is assigned to the low soil position available or because of the catalytic effect of sulphur used in the creation of chloroplast protein, which in turn increases the efficiency of photosynthesis, which translates into an increase in yield (Suman *et al.,* 2018). Additionally, Gebremedhin *et al.,* (2015) sohowed that biochar application significantly increased wheat grain and straw yields by 15.7 and 16.5%, respectively, over the NPK application alone. Gupta *et al.,* (2019) showed that biochar at rate 5 Mg ha^{-1} in sandy loam soil significantly increased wheat yield, P and K concentration as compared to control. Gondek and Kopeć (2010) found that application sulphur at rates 0.04 and 0.14g S kg soil led to increased wheat grain and straw yield. S-application at the levels 400 and 600 kg powdered S/fed in calcareous soil caused significant or highly significant increases in plant growth and N and P uptakes as well as in yield and yield components compared with zero S or the treatment supplied with 200 kg S/fed. The application of 400 kg S and 600 kg S/fed resulted in 11.5 % and 17.8 % increases in grain yield, and 12.5 and 21 % in straw yield, respectively (Badawy *et al.,* 2011).

b- N, P and K concentration and uptake of wheat and soybean grain and straw.

Data in Tables (6 and 7) and (Fig 1, 2 and 3) indicate that N, P and K concentrations in wheat and soybean grain and straw significantly increased by the application of all the experimental treatments. It is also clear that the values of such nutrients were higher under the adding sulphur + biochar mixture applications than the other

treatments.The best treatment was increasing N, P and K by sulphur + biochar mixture applications., as the rate of increment over the control in wheat grains due to such treatment reached to 7.87, 75.00 and 71.79% in sandy soil, 15.43, 57.14 and 70.83% in calcareous soil and recorded 28.72, 50.00 and 67.27% in clay soil for N, P and K concentrations, respectively. The respective values for wheat straw were 30.00, 50.00 and 17.22% in sandy soil, 36.76, 57.14 and 18.35%in calcareous soil, and 46.34, 112.50 and 24.00% in clay soil. It is also clear that the values of such nutrients took the same trends previously mentioned for N, P and K concentrations in soybean grain and straw. The highest increases of N, P and K concentrations in soybean grain were found with the sulphur and biochar mixture application treatment, as the increases reached to 24.67, 48.00 and 71.64% in sandy soil, 28.50, 42.86 and 50.00% in calcareous soil and recorded 21.54, 43.75 and 34.31% in clay soil, respectively. The respective increases for N, P and K concentrations in soybean straw were 31.18, 73.33 and 19.76% in sandy soil, 27.32, 50.00 and 27.43% in calcareous soil and 20.67, 54.55 and 35.00% in clay soil as compared with control. The application of sulphur and biochar mixture led to increase in NPK uptake (kg ha^{-1}) by grain and straw of wheat and soybean for all the two seasons as compared with control treatment, where the percentage increases N, P, K uptake of wheat grain values reached 21.70, 97.60 and 93.82% in sandy soil, 44.11, 96.25 and 113.30% in calcareous soil and 58.25, 84.36 and 105.64% in clay soil, as compared control, respectively. The respective N, P, K uptake of wheat straw values under sulphur + biochar mixture application were 50.20, 88.62 and 35.42%in sandy soil, 51.36, 66.86 and 30.99% in calcareous soil, and 79.18, 150.78 and 51.82% in clay soil over the control. The positive effect of such materials on increasing macro-nutrients concentrations in wheat and soybean may be attributed to that these materials serve as valuable soil amendments that provide a balanced pattern of release of nutrients to plants, and provide nutrients in a readily available form that plants can easily take (Ferreras *et al.,* 2006). Furthermore, biochar have been reported to enhance mineral nutrient uptake by plants, because it affects the Permeability of root membranes. Sulphur + biochar added to the soil resulted in statistically significant increase in NPK uptake by grain and straw of wheat and soybean compared to the control treatment. Application of biochar on crop production may be determined by changes in soil properties and/or the nutrients availability. The data indicated the progressive increment in NPK uptake of wheat and soybean grain and straw by sulphur, biochar and sulphur + biochar mixture application rate and residual effect rate. The elemental uptake of nutrients within the different parts of soybean plants grown on the studied soils as affected by different amendments are also shown in Fig (1, 2 and 3). Results revealed that uptake nutrients were significantly higher under sulphur + biochar mixture application compared to control. Moreover, such concentrations were higher in plants grown on the clayey soils than corresponding ones obtained from plants grown on the calcareous and sandy soil. It was obvious from the results that the movement of macronutrients from roots to grains was, generally, higher in plants sulphur + biochar mixture application compared to control treatment. The percent increases in the uptake of N, P and K in grain soybean were 115.64, 156.06 and 197.06% in sandy soil, 126.29, 151.81 and 164.04% in calcareous soil and 114.25, 153.53 and 136.79% in clay

soil under sulphur + biochar mixture application as compared control.

Data in Fig (1, 2 and 3) declare a noticeable increasing in uptake of wheat as a result of sulphur + biochar mixture application as compared with without treatments during the two seasons, NPK uptake of soybean was high significantly increased in the combined treatments of sulphur + biochar mixture applied than those under their sole application and control, during the two growing seasons. Consequently the effect of treatments application on uptake can be arranged in the following order sulphur + biochar mixture > biochar > sulphur > control. The percent increases in the uptake of N, P and K in grain soybean were 112.52, 180.30 and 94.04% in sandy soil, 86.10, 119.23 and 86.24% in calcareous soil and 104.26, 161.45 and 128.51% in clay soil under sulphur + biochar mixture application as compared control. Also, NPK content and uptake of grain and straw of wheat and soybean could be placed according to its content in the following descending sequence: clay soil > calcareous soil > sandy soil. This finding may be due to the higher indigenous fertility and CEC values of the clay soil compared to the corresponding ones of the calcareous soil and sandy soil. The reported changes produced by the application of elemental sulfur to sandy soil were decreased soil pH and increased wheat yield and macronutrients uptake (Badawy *et al.,* 2011).

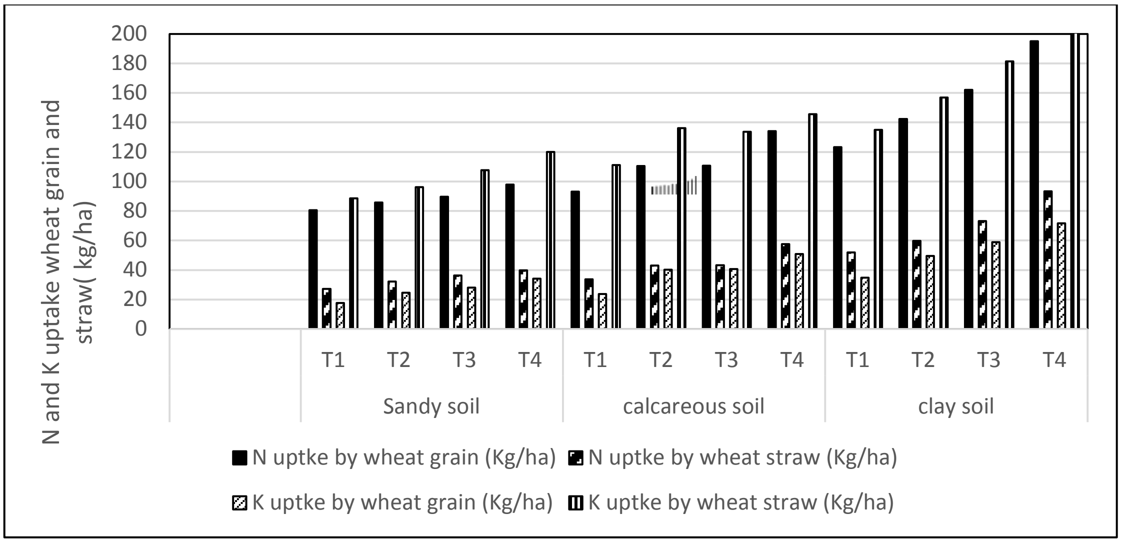

Figure (1): Impact of sulphur and biochar on N and K uptake of grain and straw of wheat under different soils

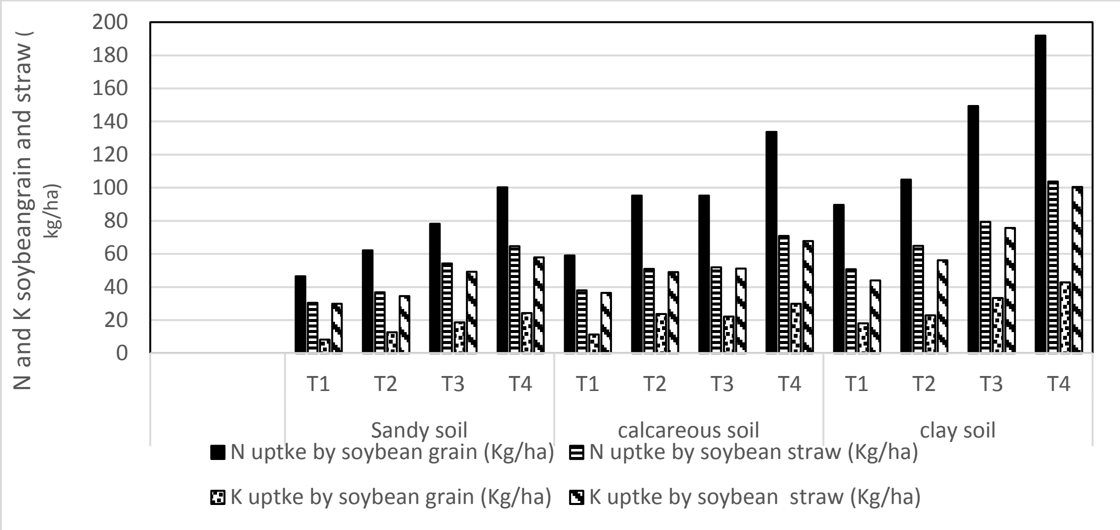

Figure (2): Impact of sulphur and biochar on N and K uptake of grain and straw of soybean under different soils

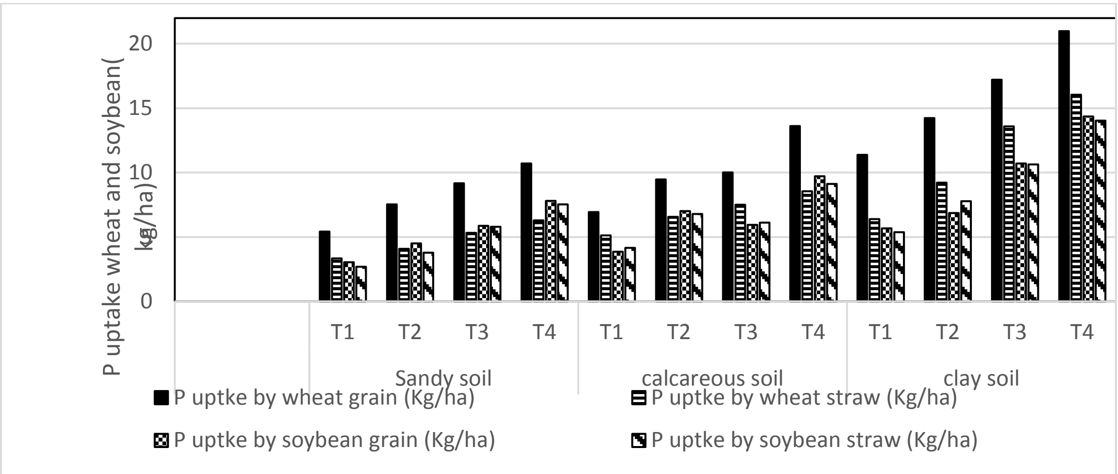

Figure (3): Impact of sulphur and biochar on P uptake of grain and straw of wheat and soybean under different soils.

Biochemical oxidation produces the sulphur dioxide H_2SO_4 that reduces soil pH and solubilizes calcium carbonate in calcareous soils conditions more suitable for plant growth, this is availability by plant nutrients (El-Tarabily *et al.,* 2006). Abdallah *et al.,* (2010) and Dhage *et al.,* (2014) Showed that the impact of different levels of sulphur on the crop, the concentration of plant nutrients, and uptake and availability of nutrients in the harvesting of soybeans. In Egypt, a number of investigators reported the combined impact of applying sulphur (200-500 kg/fed) or gypsum (2.67 ton/fed) with FYM in calcareous soils, on yields obtained as well as on concentrations and uptake of macronutrients. (Awad *et. al.,* 2002). Wheat yield as affected by various sources and level of sulphur at rates of 0, 20, 40 and 60 mg kg^{-1} soil revealed that grain and straw yield and NPK concentrations and uptake significant increase with increasing level of sulphur

than control in sandy soil. (Sharma and Sharma, 2014 and Sangwan *et al.,* 2018).

Conclusion

It could be concluded that, Results of the current study indicated the beneficial application of sulphur (S) and biochar (B) alone or in combination can improve soil fertility, soil physical and chemical properties. Also, these applications caused high increases in availability of N, P and K and high enhancements in exchangeable Ca, K, Na ,Mg, CEC, ESP and organic carbon) . Therefore, it is recommended that farmers can apply the studied amendments for increasing the productivity of wheat and soybean crops with good seed quality under Egypt soil different conditions.

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تأثير الكبريت والبيوشار علي خواص التربة وإنتاجية كل من القمح وفول الصويا فى أراضي مختلفة القوام

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الملخص العربى

أقيمت تجربة ليزيمترات بمحطة البحوث الزراعية بالجميزة التابعة لمركز البحوث الزراعية لدراسة تأثير الكبريت والبيوشار علي خواص التربة وإنتاجية كل من القمح وفول الصويا في أراضي مختلفة القوام. تم تصميم التجربة قطع منشقة. وكانت القطع الرئيسية أنواع الأراضي (رملية – جيرية– طينية) والقطع المنشقة هي (كنترول بدون أضافة محسنات –الكبريت بمعدل 1.50 طن للهكتار –البيوشار بمعدل 5 طن للهكتار– وخليط من الكبريت مع البيوشار بمعدل كبريت 1.50 طن للهكتار+5 طن بيوشارللهكتار).

أوضحت النتائج المتحصل عليها ما يلي :

-أدت إضافة محسنات التربة إلي الاراضي مختلفة القوام إلي خفض كل من درجة تفاعل التربة والتوصيل الكهربي والصوديوم المتبادل ونسبة الصوديوم وزيادة كل من النيتروجين والفوسفور والبوتاسيوم الميسر ونسبة ثاني أكسيد الكربون والسعة التبادلية الكاتيونية والكالسيوم والماغنسيوم والبوتاسيوم المتبادل وخاصة عند إضافة الكبريت مختلط مع البيوشار ادي تحسين معنوي في الخواص الكيميائية مقارنة بباقي المعاملات الاخري.

-إضافة الكبريت بمعدل 1.50 طن للهكتار مختلط مع البيوشار بمعدل 5 طن للهكتار أدت إلي تحسين الصفات الطبيعية(الكثافة الظاهرية والمسامية والتوصيل الهيدروليكي) لكل من الأراضي الرملية والجيرية والطينية مقارنة بإضافة المحسنات منفرد أومعاملة الكنترول.

-إضافة محسنات التربة منفردة أو مختلطة أدت إلي تحسين إنتاجية الأراضي المختلفة من محصول القمح وفول الصويا والمحتوي والممتص من النيتروجين والفوسفور والبوتاسيوم من نباتات القمح وفول الصويا مقارنة بالأراضي الغير معاملة بالمحسنات.

توصي الدراسة:

نوصي بإضافة الكبريت مختلط مع البيوشار لتحسين الخواص الطبيعية والكيميائية للأراضي الرملية والجيرية والطينية ورفع إنتاجية القمح وفول الصويا والممتص من العناصر الغذائية.

<u>السادة المحكمين</u>

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Table (3): Influence of sulphur and biochar on chemical properties of the three soilunder different soils after harvesting of wheat and soybean yields.

Soils	Treatments	After harvesting of wheat							After harvesting of soybean						
		pH (1:2.5)	EC (dsm^1)	Available NPK ($mg Kg^{-1}$)			CO_2 meg CO_2/100g soil	OM (%)	pH (1:2.5)	EC (dsm^{-1})	Available NPK ($mg Kg^{-1}$)			CO_2 meg CO_2/100g soil	OM (%)
				N	P	K					N	P	K		
Sandy	T1	8.39	4.05	16.84	1.55	67.10	20.20	0.30	8.28	3.86	17.83	1.88	68.84	23.83	0.38
	T2	8.21	3.90	18.45	2.84	69.55	25.48	0.42	7.99	3.17	19.72	3.69	71.62	28.29	0.52
	T3	8.33	3.74	19.28	3.95	71.28	27.68	0.59	8.21	3.29	21.67	5.37	73.19	33.19	0.72
	T4	8.14	3.09	20.79	4.89	73.20	30.20	0.71	7.84	2.66	23.30	6.73	75.59	36.30	0.86
Mean		8.28	3.70	18.84	3.31	70.28	25.89	0.50	8.08	3.25	20.63	4.42	72.31	30.40	0.62
Calcareous	T1	8.22	2.82	25.26	3.08	116.72	32.96	0.52	8.14	2.62	26.44	3.75	120.44	36.83	0.60
	T2	7.98	2.35	26.41	4.20	123.47	37.71	0.72	7.76	2.08	27.96	5.17	125.82	43.45	0.83
	T3	8.19	2.51	28.42	5.19	126.83	40.81	0.81	8.05	2.34	30.37	6.43	129.00	53.15	0.99
	T4	7.90	2.21	30.83	5.98	129.62	50.96	0.88	7.69	1.74	33.35	7.52	131.47	62.10	1.10
Mean		8.07	2.47	27.73	4.61	124.16	40.61	0.73	7.91	2.20	29.53	5.72	126.68	48.88	0.88
Clay	T1	8.39	5.20	44.08	6.20	374.37	101.27	0.85	8.31	4.66	45.08	6.88	395.33	109.67	1.07
	T2	8.27	4.58	46.11	8.14	413.53	109.98	1.09	8.17	3.90	47.77	9.56	419.73	121.20	1.18
	T3	8.33	4.30	48.3	9.46	423.73	125.58	1.24	8.28	3.46	50.00	11.2	433.60	135.65	1.37
	T4	8.18	4.08	50.13	10.2	436.93	137.37	1.42	8.00	3.03	53.14	12.73	453.57	142.58	1.55
Mean		8.29	4.54	47.15	8.50	412.14	118.55	1.15	8.19	3.76	49.00	10.1	425.56	127.28	1.29
L.S.D. $_{0.05}$ S		0.08	0.01	0.60	0.09	3.34	2.35	0.03	0.002	0.1	0.14	0.55	4.99	3.34	0.03
L.S.D. $_{0.05}$ T		0.04	0.13	0.85	0.56	4.63	4.84	0.08	0.07	0.1	0.53	0.33	3.51	3.36	0.08
L.S.D. $_{0.05}$ S*T		ns	ns	0.31	ns	3.18	2.91	ns	0.11	ns	0.38	0.26	2.73	2.54	ns

OM = organic matter S= soils T= Treatments S*T= soils* Treatments

Table (4): Influence of sulphur and biochar on cation exchange capacity (CEC), exchangeable cations and exchangeable sodium percentage (ESP) under different soils after harvesting of wheat and soybean yields.

Soils	Treatments	After harvesting of wheat						After harvesting of soybean					
		Exchangeable cations (cmol Kg^{-1})				CEC (cmol Kg^{-1})	ESP	Exchangeable cations (cmol Kg^{-1})				CEC (cmol Kg^{-1})	ESP
		Ca	Mg	Na	K			Ca	Mg	Na	K		
Sandy	T1	1.87	2.43	2.04	0.49	7.01	29.04	1.95	2.50	1.92	0.61	7.28	26.33
	T2	1.93	2.49	1.88	0.58	7.26	25.96	2.60	2.73	1.73	0.63	7.86	22.04
	T3	2.40	2.70	1.70	0.63	7.88	21.57	3.07	2.98	1.50	0.75	8.39	17.90
	T4	2.72	3.02	1.50	0.70	8.15	18.46	3.08	3.43	1.28	0.85	8.89	14.45
Mean		2.23	2.66	1.78	0.60	7.58	23.76	2.68	2.91	1.61	0.71	8.11	20.18
Calcareous	T1	7.53	4.95	4.58	0.72	17.96	25.52	7.60	5.07	4.27	0.77	18.09	23.59
	T2	7.90	5.23	4.10	0.83	18.40	22.28	8.63	5.75	3.10	0.95	18.74	16.54
	T3	8.37	5.60	3.82	0.93	18.90	20.19	9.03	6.23	2.77	1.14	19.37	14.31
	T4	8.65	5.77	3.64	1.20	19.39	18.77	9.47	6.52	2.37	1.27	19.90	11.89
Mean		8.11	5.39	4.04	0.92	18.66	21.90	8.68	5.89	3.13	1.03	19.03	16.58
Clay	T1	11.83	15.85	15.25	1.48	44.67	34.14	12.28	16.10	14.82	1.55	45.33	32.68
	T2	12.95	16.50	14.60	1.73	46.31	31.53	14.67	17.00	12.87	1.95	46.95	27.41
	T3	14.50	17.17	13.43	2.02	47.43	28.33	16.00	17.68	11.63	2.20	47.92	24.28
	T4	15.93	18.13	12.42	2.25	48.92	25.39	17.48	19.00	9.77	2.28	49.42	19.77
Mean		13.80	16.91	13.93	1.87	46.83	29.85	15.11	17.45	12.27	2.00	47.41	26.04
L.S.D. $_{0.05}$ S		0.40	0.19	0.33	0.080	0.25	0.60	0.40	0.23	0.35	0.08	0.14	0.59
L.S.D. $_{0.05}$ T		0.20	0.17	0.14	0.05	0.18	0.75	0.21	0.19	0.17	0.10	0.32	0.81
L.S.D. $_{0.05}$ S*T		0.11	0.07	0.17	0.036	0.14	0.41	0.11	0.09	0.25	0.05	0.13	0.43

CEC= Cation exchange capacity, ESP= exchangeable sodium percentage