Asian Soil Research Journal

2(3): 1-10, 2019; Article no.ASRJ.53037
ISSN: 2582-3973

Effect of Elemental Sulfur on Phosphorus Availability and Wheat (*Triticum aestivum* L.) Grown on a High Terrace Soil in Northern Sudan

Ahmed Mohammed-Nour[1] and Jamal Elfaki[2*]

[1]Soil and Water Research Centre, Agricultural Research Corporation, P.O.Box 126, Wad-Medani, Gezira State, Sudan.
[2]Faculty of Agriculture, Nile Valley University, P.O.Box 1843, Atbara, River Nile State, Sudan.

Authors' contributions

This work was carried out in collaboration between both authors. Author AMN designed the study, performed the statistical analysis and wrote the protocol. Author JE wrote the first draft of the manuscript, managed the analyses of the study and approved the final manuscript.

Article Information

DOI: 10.9734/ASRJ/2019/v2i330055
Editor(s):
(1) Dr. Ademir de Oliveira Ferreira, Professor, Dynamics of Organic Matter in Soil, Systems Management, University of Northern Paraná, Rua Tibúrcio Pedro Ferreira, Ponta Grossa, Paraná, Brazil.
Reviewers:
(1) Necat Togay, Mugla SK University and Fethiye ASM K Vocational High School, Turkey.
(2) Cristiane Ramos Vieira, University of Cuiabá, Brazil.
Complete Peer Review History: http://www.sdiarticle4.com/review-history/53037

Original Research Article

Received 15 November 2019
Accepted 18 December 2019
Published 25 December 2019

ABSTRACT

The effect of elemental sulfur on some chemical soil properties and wheat grown was studied by two performing experiments, under high terrace soils of northern region of the Sudan. First experiment (incubation experiment) was executed to quantify the rates and application time of elemental sulfur to be applied in the field experiment. It consisted of five rates of elemental sulfur (0, 165, 330, 495 and 660 kg sulfur feddan^{-1}) and five application times (2, 4, 6, 8 and 10 weeks). In the second experiment (field experiment), two wheat varieties (Wadi Elneel and Debeira), three sulfur rates (0 kg S feddan^{-1}, 495 kg S feddan^{-1} and 660 kg S feddan^{-1}) and three application times (0, 5 and 7 weeks) were arranged in split plot design with four replications. Wheat varieties were assigned to the main plots and the combination of the rates and time application to the sub plots. Results obtained from the incubation experiment indicated differences in soil pH among treatments. Application of elemental sulfur decreased soil pH in each of the two experiments. The effect of elemental sulfur on wheat grain yield and the other studied yield components was not limited the

**Corresponding author: E-mail: jamal.elfaki@nilevalley.edu.sd;*

plant height and the 1000 seeds weight. The nitrogen content of the plant tissue was affected by the applied elemental sulfur. Application of 495 kg sulfur feddan^{-1}, 6 weeks before sowing gave the lowest soil pH (7.8) and the least available phosphorus compared to other treatments.

Keywords: Elemental sulfur; available phosphorus; wheat; Wadi Elneel; Debeira; Northern Sudan.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most important cereal crop in the Sudan after sorghum for human consumption. Wheat consumption in the Sudan has been sharply increased in the last few years due to population increase and rising per capita consumption [1]. The origin of wheat was in the Mediterranean and its cultivation in Sudan is concentrated in the Northern Region in the past but now the crop is grown in most agricultural schemes.

The Northern Region of Sudan has relatively good advantages for wheat production for its long winter season. There are three broad soil types recognized in the Northern Region of the Sudan: flooded plain, middle and high terrace soils. The high terrace soils are potential for the expansion of wheat production in Northern Sudan. The increasing population in the Sudan necessitates an increase in wheat production especially in somewhat problematic the high terrace soils for their large areas. Wheat productivity in high terrace soil is generally low and this may be attributed to the low chemical soil fertility, salinity, sodicity and adverse physical conditions. The availability of phosphorus (P) and micronutrient cations i.e. copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) to plants is adversely affected by high calcium carbonate, high soil pH and high clay content. Generally, P deficiency widely occurs in arid climatic areas. Kaya et al. [2] reported that low availability of nutrients rather than their low content is one of the major factors for the widespread occurrence of plant nutrients deficiency in calcareous soils. The uptake of micronutrient cations and P by the plant is governed by numerous soil factors; among them are high soil pH and $CaCO_3$ content which are largely responsible for the low availability of these nutrients. The availability of P and micronutrient cations of soils can be increased through application of elemental S for its direct effect on soil pH, therefore, a field experiment was conducted at Dongola Research Station farm (DRSF), which is located in the high terrace soil to evaluate the effect of elemental S on P and micronutrient cations availability to wheat grown under such conditions. This study was carried out with the objectives; i) improve the availability of P for wheat grown under alkaline and calcareous high terrace soils of the Northern Region of Sudan. ii) specify the effect of elemental S application on wheat performance under the above-stated conditions.

2. MATERIALS AND METHODS

In this study, two experiments were conducted one under laboratory conditions and the other under field conditions at Dongola Research Station Farm (DRSF) – Sudan, to assess the effect of elemental sulfur on the availability of P and micronutrient cations. Soil samples were collected from DRSF at a depth of 0-20cm to represent the major areas of calcareous soils. Field examination for three random samples after air drying showed that the pH was moderately alkaline and that the soil matrix was calcareous.

2.1 Brief Description of the Studied Soil

The studied soil is known as "Akked" soil series which classified as: fine, mont, hyperthermic, fluventic, camborthids [3] has clay loam texture. It is calcareous, non-saline, and non-sodic, with low available P (2.8 mg P kg^{-1}) and low in organic carbon (Table 1).

Incubation experiment: This experiment was conducted under laboratory conditions composite soil samples at depth of 0-20 cm were collected from DRSF to represent the calcareous soil in the region. A weight of 300 g composite soil samples were mixed with powder elemental S to obtain: 0, 165, 330, 495, and 660 kg S feddan^{-1} and then placed in a 100 mL plastic bottle.

The different treatments were moistened with 70 mL distilled water, and during the incubation the moisture content of soils was adjusted every 7 days, by adding distilled water equivalent to the loss of water. After 2, 4, 6, 8 and 10 weeks of incubation subsamples of each bottle were taken for the determination of soil pH, available P and micronutrient cations. These analyses were regularly carried out every 10 days afterwards. The experiment was laid out in a completely randomized design with four replications.

Table 1. General properties of the studied soil

Physical properties:

Depth cm	Mechanical analysis				Dry bulk density (g cm^{-3})	H.C. (cmhr^{-1})
	%CS	%FS	%SI	%C		
0-30	25	20	17	38	1.77	2.42
30-60	22	20	24	34	1.72	2.44

Chemical properties:

Depth cm	pH paste	EC_e dSm^{-1}	$CaCO_3$	ESP	Available. P (mg kg^{-1} soil)	Total (mg kg^{-1} soil)	N%	Exch. anions		Soluble cations			Soluble anions		
								Na^+	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}
								cmol (+) kg^{-1} soil		cmol(+) kg^{-1} soil			cmol (+) kg-1 soil		
0-30	8.5	1.4	9.2	5	2.8	325	0.015	1.8	0.51	23.3	12	1.55	25.2	4.2	1.9
30-60	8.4	3.8	8.8	12	2.4	293.5	0.015	3.47	0.29	25.8	11	1.5	31.4	3.8	2.8

Field experiment: Three levels of elemental S (0 kg S feddan^{-1}, 495 kg S feddan^{-1} and 660 kg S feddan^{-1}) based on the results of the incubation experiment were used in this trial. The elemental S was incorporated into the top soil (0-20 cm). The application time of S was on 0, 5 and 7 weeks before sowing of wheat. Two wheat varieties (Wadi Elneel and Debeira) were selected for this trial. Split design with four replications was used to conduct this trial. Wheat varieties were assigned to main plots whereas the combination of levels and application time of S to the sub plots. All plots received 43 kg P_2O_5 ha^{-1} and 86 kg N ha^{-1} in form of urea. The dose of N was splitted; the first dose was at sowing and the second with the third irrigation. Plot size was 14 m^2. Sowing was in lines 0.2 m apart. Seed rate was 60 kg feddan^{-1}, and irrigation was carried out every seven days.

2.2 Soil Characterization

The following are brief general description of the chemical and physical procedures performed on the soil samples:

Soil pH: It was determined in the supernatant liquid of 1:5 (soils: water suspension), with exception of that of routine analysis (soil past).

Available P: The available P was determined following the [4] method which employs 1N $NaHCO_3$ at pH 8.5. The P was then determined by the [5].

Total P: The total P was determined first by digestion 1g soil with concentrate acid then following [4] method the same procedure of available P.

Electrical conductivity: Saturated soil paste was firstly prepared by adding soil to a known quantity of water to paste consistency. Then the soil paste was extracted using a vacuum pump. The extract was read for electrical conductivity using an EC meter. The results were expressed as dS m^{-1} at 25°C.

Sodium Adsorption Ratio (SAR): Sodium adsorption ratio was calculated by the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Calcium carbonate: A known weight of soil was treated with a standard HCl; the excess acid was titrated against a standard NaOH using phenolphthalein indicator. The result was expressed as a percentage according to Horváth et al. [6].

Organic carbon: Oxidation of soil samples was carried out using 1 N potassium dichromate and sulphuric acid. The excess potassium dichromate was titrated with a standard ferrous ammonium sulfate according to Sys et al. [7].

Total N: The total N was determined according to the modified micro-Kjeldahl method which recommended by ICARDA [8]. Pre-moistened soil digested with concentrated sulphuric acid. The digested soil sample was treated with 10 N for NaOH to liberate ammonia gas, which was received in 2% boric acid. The NH_4 thus received was obtained by titration with 0.01M H_2SO_4.

Cation exchange capacity (CEC): The soil samples indexed with 1N sodium acetate (pH 8.2). Excess salt was washed with ethanol (95%). The adsorbed sodium by the sample was extracted with 1N ammonium acetate solution (pH = 7.0) and determined using recommended method by Elfaki [9].

Exchangeable cations: Exchangeable Na and K extracted with 1N ammonium acetate at pH 7.0 and determined by flame photometer whereas soluble Ca and Mg extracted by triethanolamine plus barium chloride and titrated versus potassium permanganate according to Horneck et al. [10].

Soluble cations and anions: The Na and K were determined in the saturation extract mentioned before. Soluble Na was determined by flame photometer. Whereas soluble K was not detectable, this is the usual case in all the soil of Sudan analyzed so far. Soluble Ca and Mg were determined by titration with EDTA. Carbonate, and bicarbonate and chlorides were determined by extraction with sulphuric acid and nitrate, respectively. Sulfate ions were obtained by the difference between the summation of soluble cations and anions (Cl^- CO_3^{2-} and HCO_3^-).

Exchangeable sodium percentage (ESP): The exchangeable sodium percentage was calculated by dividing the exchangeable Na by cation exchange capacity of the soil and then multiplied by 100 according to Levy and Shainberg [11].

Mechanical analysis: All results refer to oven dry soil. The soil was treated with HCl. The excess acid was neutralized by NaOH. The soil was saturated with Na ions using NaCl for 48 hours and dispersed with calgon. Fine and coarse sand fractions were obtained by wet sieving whereas the clay fraction was obtained by the petite method the silt was determined by difference. The fractions diameters are: coarse sand 0.2 – 2.0 mm, fine sand 0.02 – 0.2 mm, silt 0.002 – 0.02 mm, clay less than 0.002 mm.

Hydraulic conductivity: The saturated hydraulic conductivity was estimated by using constant head method technique [12], based on the direct application of Darcy's equation:

$$Ks = (Q\times L)/(A\times t\times H)$$

Where:

Ks ≡ saturated hydraulic conductivity.
Q ≡ volume of water.
L ≡ length of soil column.
A ≡ cross-sectional area of the soil sample.
t ≡ time required for the volume of water Q to be discharged
H ≡ head gradient.

Dry bulk density: The dry bulk density was determined using natural soil clods and paraffin wax according to Campbell [13].

2.3 Plant Data

The following are brief description of the yield and yield components collected during and after the field experiment:

Plant height: Plant height (cm) at maturity was measured from the soil surface to the tip of the spike excluding the awns. Four readings were taken/plot and then the average plant height was calculated.

Number of spikes/m²: It was calculated from four meters within the net area and then converted to spikes/m².

Days to maturity: It was taken when loss of green color formed 90% of plants occurred.

Biomass and grain yields: At maturity, plants were cut at the ground level and tied into bundles and left to air dry, and then threshing was done mechanically and biomass and grain yields were then recorded.

Seeds/spike: Number of grains of ten spikes which were randomly taken from the net area. Was counted and their average was calculated to give seeds/spikes.

1000 seeds weight: The weight of 1000 seed was expressed in grams.

Harvest index: It was calculated as the ratio of the weight of grain yield (kg ha^{-1}) to the total weight of the biomass (kg ha^{-1}).

N tissue analysis: The total plant N was determined according to the modified micro-Kjeldahl method [14]; 0.5 g dried plant material was digested with concentrated sulphuric acid. The digested material was treated with 10N NaOH to liberate ammonia gas, which was received in 0.01M boric acid, which was then titrated using N/20 sulphuric acid.

P tissue analysis: Plants were oven dried at 70ºC for 24 h. Samples were analyzed for total P using the Ammonium molybdate ammonium vanadate method, which mentioned by Amin [15].

3. RESULTS AND DISCUSSION

3.1 Incubation Experiment

Soil pH: Soil pH decreased ($P \leq 0.01$) with an increase the applied S and the incubation period. The highest value was 8.6 which was obtained by the control and the lowest pH value was 7.78 which was obtained by highest S level (660 kg S $feddan^{-1}$ 6 weeks) (Table 2). Soil pH decreased during the oxidation of S and thus, unavailable forms of micronutrient cations and P were expected to be transformed to available forms for plant uptake. These findings were in support of the results obtained by Orman and Kaplan [16] who reported that 3 weeks after application of 200 mg kg^{-1} elemental S to calcareous sandy loam soil resulted in 0.18 unit decrease in soil pH. Also in a study on the effect of applications of elemental and S-containing waste on soil pH. Kaya et al. [2] reported that sulfur application resulted in a decreased in soil pH from 8.12 to 7.49 and the S containing waste resulted in a decrease of soil pH from 8.12 to 7.77, when 120 kg S ha^{-1} was applied.

Table 2. Effect of sulfur level and application time on soil pH

Sulfur kg feddan^{-1}	Application time (Week) 2	4	6	8	10	Mean
0	8.5	8.5	8.5	8.7	8.5	8.5
165	8.3	8.3	8.4	8.2	8.3	8.3
330	8.4	8.1	8.0	8.0	8.0	8.1
495	8.2	7.9	7.9	8.0	7.9	8.0
660	8.2	7.9	7.8	7.9	7.8	7.9
Mean	8.3	8.1	8.1	8.1	8.1	8.2

**, **, NS indicated significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively.*
*SE± Sulfur (S) = 0.033** Application time (AT) = 0.033** S × AT = 0.074 NS % C.V = 1.3*

Table 3. Effect of sulfur level and application time on soil P content

Sulfur (kg feddan^{-1})	Application time (Week) 2	4	6	8	10	Mean
0	4.7	4.3	4.2	4.3	2.4	3.0
165	4.4	5.3	3.7	3.7	3.3	3.1
330	4.4	5.0	3.7	4.1	3.1	3.1
495	4.4	4.0	3.6	4.2	3.2	3.1
660	4.6	4.1	4.0	4.4	3.0	3.0
Mean	4.5	4.5	3.8	4.1	3.0	3.0

*SE± Sulfur (S) = 0.199 NS Application time (AT) = 0.199** S × AT = 0.445 NS % C.V = 15*

Table 4. Main effect of wheat varieties on wheat yield and yield components

Varieties	GY (kg ha^{-1})	S/S	Sp/M^2	SSW	BY (kg ha^{-1})	PH (cm)	HI (%)	DM (day)	N (%)	P (%)
D	3171	43	418	36.9	10378.6	82.6	30.5	105	0.9	0.11
W	3031	42	397	36.6	9314.3	80.3	32.7	105	0.9	0.11
Means	3101	42	408	36.8	9846.0	81.5	31.5	105	0.9	0.11
SE±	101	0.9	15.9	0.4	388.7	1.2	0.6	0.2	0.1	0.01
Significant	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
CV%	14.2	13.4	10	6	9.3	4.3	10.5	0.9	32.2	11.7

** = Significant at P ≤ 0.05 SP/M^2 = spike /meter^2; PH = plant height; BY = biological yield; GY = grain yield; HI: harvest index; SSW = 1000 seed weight; S/SP = seeds/ spike; DM = days to maturity; N = tissue nitrogen; P = tissue phosphorus*

Table 5. Main effect of elemental sulfur level and application time on wheat yield and yield components

Treatments	PH (cm)	BY (kg ha^{-1})	GY (kg ha^{-1})	SSW (g)	N (%)	SP/m^2	HI (%)	S/SP	DM (day)	P (%)
(7weeks* S4)	83.0	103`00	3325	38.58	0.88	415	32.3	42	105	0.114
(7weeks* S3)	83.9	10325	3228	37.95	0.93	436	31.3	43	104	0.103
(5weeks* S4)	80.6	9850	3099	36.86	0.81	399	31.4	42	105	0.112
(5weeks* S3)	80.3	9325	2863	35.46	0.75	395	31.0	44	105	0.11
(0weeks* S4)	77.5	8975	2767	35.34	0.89	378	30.7	41	105	0.103
(0weeks* S3)	82.3	9625	3054	35.66	0.84	413	32.0	42	105	0.101
(0weeks* S0)	82.8	10525	3370	37.38	1.20	436	31.9	42	105	0.115
Means	81.5	9846.4	3100.7	36.7	0.9	410	32.0	42	105	0.11
SE±	1.2	322.1	155.5	0.78	0.1	14.6	1.2	1.0	0.29	0.005
Significant	*	*	*	*	*	NS	NS	NS	NS	NS
CV%	4.27	9.25	14.19	6.01	32.24	10.1	10.5	13.4	0.8	11.7

** = significant at p ≤ 0.05*
S0 = zero kg sulfur feddan^{-1}, S3 = 495 kg Sulfur feddan^{-1}, S4 = 660 kg Sulfur feddan^{-1};
SP/M^2 = spikes /meter^2; PH = plant height; BY = biological yield; GY = grain yield; HI = harvest index; SSW = 1000 seed weight; S/SP = seeds/ spike; DM = days to maturity; N = tissue nitrogen; P = tissue phosphorus

Table 6a. Effect of wheat variety, sulfur level and application time on wheat yield and yield components

Treatments	SP/m^2		PH(cm)		BY(kg/ha)		GY(kg/ha)		HI (%)	
	D	W	D	W	D	W	D	W	D	W
(7weeks* S4)	442	389	82.8	83.5	10700	9900	3409	3241	31.95	32.85
(7weeks* S3)	436	437	84.8	83.0	10500	10150	3163	3293	30.05	32.55
(5weeks* S4)	388	410	83.3	78.0	10300	9400	3162	3035	30.48	32.28
(5weeks* S3)	394	396	81.0	79.5	9700	8950	2760	2965	28.73	33.15
(0weeks* S4)	391	366	80.5	74.5	9850	8100	2966	2569	29.85	31.55
(0weeks* S3)	437	389	81.5	83.0	10000	9250	2897	3212	29.13	34.93
(0weeks* S0)	483	393	84.8	80.8	11600	9450	3839	2902	33.2	30.6
Means	417	397	82.6	80	10379	9314	3170.6	3031	30.5	32.6
SE±	20.58		1.74		455.54		219.98		1.65	
Significant	*		NS		NS		NS		NS	
CV%	10.1		4.3		9.3		14.2		10.5	

*=Significant at $P \leq 0.05$

S0 = zero kg sulfur $feddan^{-1}$, S3 = 495 kg Sulfur $feddan^{-1}$, S4 = 660 kg Sulfur $feddan^{-1}$; 7weeks, 5weeks, 0weeks = pre cultivation time; D = Debeira; W = Wadi Elneel; SP/M^2 = spikes /$meter^2$; PH = plant height; BY = biological yield; GY = grain yield; HI = harvest index

Table 6b. Effect of wheat variety, sulfur level and application time on wheat yield and yield components

Treatments	SSW		S/SP		DM (day)		N (%)		P (%)	
	D	W	D	W	D	W	D	W	D	W
(7weeks* S4)	39.6	37.6	44	39.3	105	105	1.00	0.75	0.11	0.12
(7weeks* S3)	38.1	37.8	44	41.3	104	105	0.70	1.15	0.11	0.10
(5weeks* S4)	37.9	35.8	42	42.3	105	105	0.90	0.73	0.11	0.12
(5weeks* S3)	35.7	35.3	44	44.5	105	105	0.75	0.75	0.11	0.11
(0weeks* S4)	34.8	35.9	42	39.5	105	105	0.83	0.95	0.10	0.10
(0weeks* S3)	35.0	36.3	41	42.5	105	105	0.85	0.83	0.10	0.10
(0weeks* S0)	37.5	37.3	42	42.5	105	105	1.15	1.25	0.12	0.11
Means	36.9	36.6	43	41.7	105	105	0.88	0.91	0.11	0.11
SE±	1.1		0.8		0.4		0.14		0.01	
Significant	NS		NS		NS		NS		NS	
CV%	6.01		13.38		0.78		32.24		11.74	

D = Debeira, W = Wadi Elneel; 7weeks, 5weeks, 0weeks = pre cultivation time; S0 = 0 kg Sulfur $feddan^{-1}$; S3 = 495 kg Sulfur $feddan^{-1}$; S4 = 660 kg Sulfur $feddan^{-1}$; D = Debeira; W = Wadi Elneel; SSW = 1000 seed weight; S/SP = Seeds/ spike; DM = days to maturity N = tissue nitrogen; P = tissue phosphorus

Available P: Available P concentrations decreased compared to that of the control Table 3, However [17] obtained contrasting results in a study on the effect of S on availability of P and micronutrient cations in a major soil series of the central clay plain of the Sudan. He reported that a gradual increase in P availability which reached a maximum value of 10, 12, 15 and 16 mg P kg^{-1} soil. However, concentrations of P enhanced with applications of 165 and 330 kg S $feddan^{-1}$. In our study the P results were inconsistent and this might be associated with other factors that affect the P availability other than soil pH. On the another hand, as time of incubation increased, available P increased e.g. available P increased to 3 and 4.5 mg P kg^{-1} soil in 10 weeks and 4 weeks' time of incubation respectively, and this was probably due to dissolution of the carbonates.

3.2 Field Experiment

Plant height: Differences in plant height ($P \leq 0.05$) were observed among treatments (Table 5). The highest plant was 83.9 cm, which was obtained by (7 weeks* S3) and shortest plant was 77.5 cm which was obtained by (0 weeks* S4). The general observed trend was an increase plant height with increase in the level of applied S and incubation time. Similar results obtained by Dewal and Pareek [18] who reported that the plant height in wheat increased as the doses of S increased and reach their maximum height at 40 kg S ha^{-1}. However, these results were not in line with the findings of those researchers. The reason for this disagreement might be from the granular form of the applied elemental S, which needs more time to be oxidized and improve soil properties to improve the plant growth.

Numbers of spikes/m^2: There were no differences in the number of spikes/m^2 between treatments and cultivars. The highest number of spikes was 436 spikes/m^2 which was obtained by (7 weeks* S3) and (0 weeks* S0); while (7 weeks* S4) showed the lowest number of spikes 378 (Tables 4 and 5). Generally, it perceived that with increasing application time and S levels more spikes will be expected, however, data in (Table 6b) did not prove this perception i.e. S3 gave more spikes/m^2 than S4 at 7 and 0 weeks of application time. Generally, Debeira gave more spike/m^2 than that of Wadi Elneel cultivars.

Numbers of seeds/spike: There was no difference in the number of seeds/spikes between S treatments as well as interaction between cultivars and treatments (Tables 4, 5 and 6b). In the present study the highest number of grains/spike was 43 which was obtained by (5 weeks* S3). Similar results were obtained by Sutaliya et al. [19] and Gupta et al. [20] who reported that the highest number of seeds per spike with 40 and 45 kg S ha^{-1} were applied as doses of S fertilizer.

Days to maturity: The data in (Tables 4, 5 and 6b) showed that the effect of S, variety and their interaction on days to maturity of wheat was not significant. The probable reason may be attributed to similarity of varieties in their days to maturity 90 days for Debeira 95 for Wadi Elneel.

Thousand seeds weight: The effect of S on the thousand grain weight of wheat was observed ($p \leq 0.05$). The highest value was 38.58 g, which was obtained by 7 weeks* S4 and; the lowest value was 35.34 g, which was obtained by 0 weeks* S4 (Table 6 a,b). The effect of cultivars and interaction between cultivars treatments was not significant (Tables 4 and 6a).

Grain yield: The mean grain yield of the two wheat cultivars and their interactions with treatments showed no difference (Tables 4 and 6a). Increase was found in yield with the increase in the application time and the levels of the S especially for Debeira. The main effect of S treatments on PH, BY, GY, SSW and N content was observed ($p \leq 0.05$). Surprising enough the highest value was obtained by control 0 weeks* S0 and the lowest was obtained when applying 0 weeks* S4. (Table 5).

The present results are in conformity with [21], who reported that wheat did not respond to S fertilization, at least for grain yield. However, the results obtain by Motior et al. [22] showed that cucumber grown in sandy calcareous soils amended with S at rates of 5000 and 10000 kg S ha^{-1} enhanced the nutrients uptake and increased crop yield and improved the fruit quality. Results obtained by Al-Abdulsalam and El-Garawany [23] showed that the highest grain yield was obtained from 500 kg S ha^{-1} application to Barley. Based on such findings it reveals that application of S has many advantages depending on crop and soil conditions under test.

Biological yield: Regarding the biomass content, differences were found between treatments. Surprisingly, the highest biomass value was obtained by the control. The interaction between varieties and S treatments was not significant (Table 3). Similar results were obtained by Kaya et al. [2] who reported that the applications of elemental S did not have positive effect on plant growth. Contrasting to these results was obtained by Togay et al. [24]. In their study on the effect of S on optimum yields of cereals, they found that the application of inorganic S increased straw yield of cereals by 34%.

Harvest index: The main effect of variety on harvest index (%) was observed ($p \leq 0.05$). Wadi Elneel harvest index was 32.7% which is higher than that of Debeira 30.5%. The effect of S treatments and interaction between varieties and treatments was not observed. Contrasting results on the effect of S on yield components of wheat grown in Central Anatolia were found by Inal et al. [25], who reported that the highest wheat harvest index was obtained by 20 kg S ha^{-1} and this might be attributed to the use of fine form of S and time application.

4. CONCLUSIONS

Elemental S in the incubation experiment decreased soil pH, and enhanced P availability. Whereas, application of 495 kg S $feddan^{-1}$, 6 weeks before sowing gave the best results on soil ECe, available P and pH compared to other treatments. Generally, utilization of S improved some chemical soil properties but did not increase wheat yields.

ACKNOWLEDGEMENTS

Special thanks to the staff of the laboratories of the Land and Water Research Centre (LWRC) at the Agricultural Research Corporation, Wad Medani, as well as the Staff of Dongola Research Station for their help and support to conduct this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ageeb OAA. Agronomic aspects of wheat production in Sudan. Wheat in heat-stressed environments: Irrigated, dry areas and rice-wheat farming systems. CIMMYT, Mexico, DF. 1994;67-74.
2. Kaya M, Küçükyumuk Z, Erdal I. Effects of elemental sulfur and sulfur-containing waste on nutrient concentrations and growth of bean and corn plants grown on a calcareous soil. *African* Journal of Biotechnology. 2009;8(18).
3. Soil Survey Staff. Keys to soil taxonomy. Department of Agriculture: Natural Resources Conservation Service; 2003.
4. Olsen SR, Cole CV, Watanable FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United State Department of Agriculture. NO. 1954;939:19.
5. Murphy J, Riley JR. A modified single solution method for determination of phosphorus in natural waters. Analytica Chimica Acta. 1962;27:31-36.
6. Horváth B, Opara-Nadi O, Beese F. A simple method for measuring the carbonate content of soils. Soil Science Society of America Journal. 2005;69:1066-1068.
Available:http://dx.doi.org/10.2136/sssaj2004.0010
7. Sys C, Van Ranst E, Debaveye Ir. J, Beernaert F. Land evaluation, part III. Crop requirements. Agriculture publication, no.7, General Administration for Development Cooperation. Brussels, Belgium. 1993;166.
8. ICARDA. Methods of soil, plant and water analysis: A manual for the West Asia and North Africa region George; 2013.
9. Elfaki J, Gafer M, Sulieman M, Ali M. Comparison and evaluation of two analytical methods for cation exchange capacity and exchangeable sodium percentage of five soil types in Central Sudan. Open Journal of Soil Science. 2015;5:311-318.
Available:http://dx.doi.org/10.4236/ojss.2015.512029
10. Horneck DA, Hart JM, Topper K, Koepsell B. Methods of soil analysis used in the soil testing laboratory at Oregon State University; 1989.
11. Levy GJ, Shainberg I. Sodic soils. Encyclopedia of soils in the environment. Elsevier, USA. 2005;504-513.
12. Klute A. Methods of soil analysis, part 1 physical and mineralogical methods, Arnold Klute ed. Agronomy. 9, (part 1); 1986.
13. Campbell DJ. Determination and use of soil bulk density in relation to soil compaction. In Developments in Agricultural Engineering. Elsevier. 1994; 11:113-139.
14. Baker WH, Thompson TL. Determination of total nitrogen in plant samples by Kjeldahl. Plant Analysis Reference Procedures for the Southern Region of the United States. Southern Cooperative Series Bulletin. 1992;368:13-16.
15. Amin M, Flowers TH. Evaluation of Kjeldahl digestion method. J. Res. Science. 2004;15:159-179.
16. Orman S, Kaplan M. Effects of elemental sulphur and farmyard manure on pH and salinity of calcareous sandy loam soil and some nutrient elements in tomato plant. Journal of Agricultural Science and Technology. USA. 2011;5(1): 20-26.
17. Fadeel YI. Effect of sulfur on availability of phosphorus and micro-nutrient cations in a major soil series of the central clay plain of Sudan. Dep. Of soil and water sciences, University of Gezira, Wad Medani, Sudan. Master of Science; 1996.
18. Dewal GS, Pareek RG. Effect of phosphorus, sulphur and zinc on growth, yield and nutrient uptake of wheat (*Triticum aestivum*). Indian Journal of Agronomy. 2004;49(3):160-162.
19. Sutaliya R, Gupta AK, Singh RN. Yield attributes of barley as influenced by phosphorus, Sulphur and their correlation and regression with yield. Crop Research-Hisar. 2003;25(3):585-586.

20. Gupta VK, Kumar S, Singh AK. Yield and quality of wheat (*Triticum aestivum*) as influenced by Sulphur nutrition and weed management. Indian Journal of Agricultural Sciences (India); 2004.
21. Sawyer JE, Ebelhar SA. Sulfur nutrition of wheat varieties with till and no-till planting on highly weathered Alfisols soil. Communications in Soil Science and Plant Analysis. 1995;26(7/8):1257-1271.
22. Motior RM, Abdou AS, Fareed AH, Faruq G, Sofian M. Azirun1. Influence of elemental sulfur on nutrient uptake, yield and quality of cucumber grown in sandy calcareous soil. Australian Journal of Crop Science. 2011;5(12):1610-1615.
23. Al-Abdulsalam MA, El-Garawany MM. Barley response to soil type, organic manure and sulphur rates. Arab Universities, Journal of Agriculture Science. 1998;6(1):135-149.
24. Togay Y, Togay N, Cig F, Erman MA, Celen E. The effect of sulphur applications on nutrient composition, yield and some yield components of barley (*Hordeum vulgare* L.) African Journal of Biotechnology; 2008.
25. Inal A, Gunes A, Alpaslan M, Adak MS, Taban S, Eraslan F. Diagnosis of sulphur deficiency and effects of sulphur on yield and yield components of wheat grown in Central Anatolia, Turkey. Journal of Plant Nutrition. 2003;26(7):1483-1498.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/53037