Original Research Article

Effect of Elemental Sulfur on Availability of Phosphorus for Wheat Grown on a High Terrace Soil of Northern Sudan

Abstract

The effect of elemental sulfur on some chemical soil properties and wheat grown was studied under high terrace soils of northern region of the Sudan. 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 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 highly significant 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 statistically significant except for the plant height and the 1000 seeds weight. The nitrogen content of the plant tissue was significantly affected by the applied elemental sulfur. Application of 495 kg sulfur feddan^{-1}, 6 weeks before sowing gave the lowest soil pH and the highest available phosphorus compared to other treatments.

Key word: elemental sulfur, available phosphorus, wheat grown, Wadi Elneel, Debeira, northern Sudan

Introduction:

Wheat (Tritcum 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 (Ageeb, 1994). 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 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, phosphorus (P) deficiency widely occurs in arid climatic areas. Kaya et al., (2009) 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 phosphorus by 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 phosphorus and micronutrient cations of soils can be increased through application of elemental sulfur 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 sulfur on phosphorus 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 Northern Region of Sudan. ii) specify the effect of elemental sulfur application on wheat performance under the above stated conditions.

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 phosphorus 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.

Brief description of the studied soil:

The studied soil is known as "Akked" soil series which classified as: fine, mont, hyperthermic, fluventic, camborthids (soil survey staff, 2003) has clay loam texture. It is calcareous, non-saline, and non-sodic, with low available phosphorus (2.4 mg P kg^{-1}) and low in organic carbon (Table 1).

Depth cm	pH paste	ECe dSm^{-1}	$CaCO_3$	ESP	Available. P	Total	N%	O.C%	Ex. Anions Cmol (+) Kg^{-1} soil		CEC Cmol (+) Kg^{-1} soil	Soluble cations Meq L^{-1}			Soluble anions Meq L^{-1}		
									Na^+	K^+		Na^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{-2}
0-30	8.5	1.4	9.2	5	2.8	325	0.015	0.047	1.8	0.51	34						
30-60	8.4	3.8	8.8	12	2.4	293.5	0.015	0.052	3.47	0.29	28	25.8	11	1.5	31.4	3.8	2.8

Table 1: General properties of the studied soil

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 300g composite soil samples were mixed with powder elemental sulfur to obtain: 0, 165, 330, 495, and 660 kg sulfur $feddan^{-1}$, 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.

Field experiment:

Three levels of elemental sulfur (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 sulfur was incorporated into the top soil (0-20cm). The application time of sulfur 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 sulfur 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 $14m^2$. Sowing was in lines 0.2m apart. Seed rate was 60 kg $feddan^{-1}$, and irrigation was carried out every seven days.

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 phosphorus: The available phosphorus was determined following the Olsen et al., (1954) method which employs 1N $NaHCO_3$ at pH 8.5. The phosphorus was then determined by the Murphy and Riley method (1962).

Total phosphorus: The total phosphorus was determined first by digestion 1g soil with concentrate acid then following Olsen et al. (1954) method the same procedure of available phosphorus.

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:

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

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 at. (2005).

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. (1993).

Total nitrogen: The total nitrogen was determined according to the modified micro–Kjeldahl method which recommended by ICARDA, (2013). 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 et al. (2005).

Exchangeable cations: Exchangeable sodium and potassium extracted with 1N ammonium acetate at pH 7.0 and determined by flame photometer whereas soluble calcium and magnesium extracted by triethanolamine plus barium chloride and titrated versus potassium permanganate according to Horneck et al. (1989).

Soluble cations and anions: The sodium and potassium were determined in the saturation extract mentioned before. Soluble sodium 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 calcium and magnesium 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 sodium by cation exchange capacity of the soil and then multiplied by 100 according to Levy et al. (2005).

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 (Klute and Dinauer, 1986), 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 (1994).

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}).

Nitrogen tissue analysis: The total plant nitrogen was determined according to the modified micro-kjeldahl method (Baker, 1992); 0.5g 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.

Phosphorus tissue analysis: Plants were oven dried at 70 ^{o}C for 24 h. Samples were analyzed for total P using the Ammonium molybdate ammonium vanadate method, which mentioned by Amin and Flowers (2004).

Results and discussion:

Incubation experiment:

Soil pH:

Soil pH decreased significantly (P ≤ 0.01) with an increase the applied sulfur 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 sulfur 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, (2011) who reported that 3 weeks after application of 200 ppm elemental Sulphur 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., (2009) 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 from8.12 to 7.77 when 120 kg S ha^{-1} was applied.

Table (2): Effect of sulfur level and application time on soil pH:

Sulfur	Application time (Week)					Mean
kg	2	4	6	8	10	

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 $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

SE± Sulfur (S) = 0.033** Application time (AT) = 0.033** S × AT = 0.074 NS % C.V = 1.3

C. Available phosphorus:

Available P concentrations decreased compared to that of the control Table (3), However Fadeel, (1996) obtained contrasting results in a study on the effect of sulfur on availability of phosphorus 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 slightly 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 phosphorus availability other than soil pH. On the another hand, as time of incubation increased, available phosphorus 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.

Table (3): Effect of sulfur level and application time on soil P content:

Sulfur	Application time (Week)					**Mean**
(kg $feddan^{-1}$)	2	4	6	8	10	
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

Field experiment:

A. Plant height:

Significant differences in plant height ($P \leq 0.05$) were observed among treatments (Table 4). 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 sulfur and incubation time. Similar results obtain by Dewal and Pareek., (2004) who reported that the plant height in wheat increased as the doses of sulfur 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 sulfur, which needs more time to be oxidized and improve soil properties to improve the plant growth.

B. Numbers of spikes/m^2:

There were no significant 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 (Table 4). Generally, it perceived that with increasing application time and sulfur levels more spikes will be expected, however, data in Table (10b) 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.

C. Numbers of seeds / spike:

There was no significant difference in the number of seeds/spikes between sulfur treatments as well as interaction between cultivars and treatments, (Table 4). 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., (2003) and Gupta et al., (2004) who reported that the highest number of seeds per spike with 40 and 45 kg S ha^{-1} were applied as doses of sulfur fertilizer.

D. Days to maturity:

The data in Table (4) showed that the effect of sulfur, variety and their interaction on days to maturity of wheat was not statistically significant. The probable reason may be attributed to similarity of varieties in their days to maturity 90 days for Debeira 95 for Wadi Elneel.

E. Thousand seeds weight:

The effect of sulfur on the thousand grain weight of wheat was significant ($p \leq 0.05$). The highest value was 38.58g which was obtained by 7 weeks* S4 and the lowest value was 35.34 g which was obtained by 0 weeks* S4 (Table 4).

F. Grain yield:

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

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 $P \leq 0.05$ SP/M^2 = spike /meter^2. P H = 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

The present results are in conformity with Sawyer and Ebelhar, 1995, who reported that wheat did not respond to S fertilization, at least for grain yield. However, the results obtain by Motior et al., (2011) 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, (1998) 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 sulfur has many advantages depending on crop and soil conditions under test.

G. Biological yield:

Regarding the biomass content, significant differences were found between treatments. Surprisingly, the highest biomass value was obtained by the control. The interaction between varieties and sulfur treatments was not significant (Table 3). Similar results were obtained by Kaya et al., (2009) 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., (2008). In their study on the effect of sulphur on optimum yields of cereals, they found that the application of inorganic sulfur increased straw yield of cereals by 34%.

H. Harvest index:

The main effect of variety on harvest index (%) was significant ($p \leq 0.05$). Wadi Elneel harvest index was 32.7% which is higher than that of Debeira 30.5%. The effect of sulfur treatments and interaction between varieties and treatments was not significant. Contrasting results on the effect of sulphur on yield components of wheat grown in Central Anatolia were found by Inal et al., (2003), 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 sulfur and time application.

Conclusions:

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

References:

Ageeb, O. A. A. (1994). Agronomic aspects of wheat production in Sudan. Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems. CIMMYT, Mexico, DF, 67-74.

Al-Abdulsalam M. A., El-Garawany M. M. (1998). Barley response to soil type, organic manure and sulphur rates. Arab Universities, Journal of Agriculture Science. 6(1): 135-149.

Amin, M., & Flowers, T. H. (2004). Evaluation of Kjeldahl digestion method. J. Res. Science, 15, 159-179.

Azirun1 (2011). Influence of elemental sulfur on nutrient uptake, yield and quality of cucumber grown in sandy calcareous soil. Australian Journal of Crop Science. 5(12): 1610-1615.

Baker, W. H., & Thompson, T. L. (1992). 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, 368, 13-16.

Campbell, D. J. (1994). Determination and use of soil bulk density in relation to soil compaction. In Developments in Agricultural Engineering (Vol. 11, pp. 113-139). Elsevier.

Dewal, G. S., & Pareek, R. G. (2004). Effect of phosphorus, sulphur and zinc on growth, yield and nutrient uptake of wheat (Triticum aestivum). *Indian Journal of Agronomy*, *49*(3), 160-162.

Elfaki, J., Gafer, M., Sulieman, M. and Ali, M. (2015) 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, 5, 311-318. http://dx.doi.org/10.4236/ojss.2015.512029

Fadeel. Y. I. (1996). 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.

Gupta, V. K., Kumar, S., & Singh, A. K. (2004). Yield and quality of wheat (Triticum aestivum) as influenced by Sulphur nutrition and weed management. *Indian Journal of Agricultural Sciences (India)*.

Horneck, D. A., Hart, J. M., Topper, K., & Koepsell, B. (1989). Methods of soil analysis used in the soil testing laboratory at Oregon State University.

Horváth, B., Opara-Nadi, O. and Beese, F. (2005) A Simple Method for Measuring the Carbonate Content of Soils. Soil Science Society of America Journal, 69, 1066-1068. http://dx.doi.org/10.2136/sssaj2004.0010

ICARDA, 2013. Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region George.

Inal A., Gunes A., Alpaslan M., Adak M. S., Taban S., Eraslan F. (2003).Diagnosis of sulphur deficiency and effects of sulphur on yield and yield components of wheat grown in Central Anatolia, Turkey. Journal of Plant Nutrition. 26(7): 1483-1498.

Kaya M., Zeliha K., Erdal I. (2009). 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. 8(18): 4481-4489.

Kaya M., Zeliha K., Erdal I. (2009). 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. 8(18): 4481-4489.

Kaya, M., Küçükyumuk, Z., & Erdal, I. (2009). 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, 8(18).

Klute, A., and Dinauer, R. C. (1986). Physical and mineralogical methods. Planning, 8,79.

Levy, G. J., & Shainberg, I. (2005). Sodic soils. Encyclopedia of soils in the environment. Elsevier, USA, 504-513.

Motior R. M., Abdou A. S, Fareed A., H., Faruq G., and M. Sofian.

Murphy J. and Riley J. R. (1962). A modified single solution method for determination of phosphorus in natural waters. Analytica Chimica Acta 27: 31-36.

Olsen S. R., Cole C. V., Watanable F. S., and Dean L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United State Department of Agriculture. NO 939. pp 19.

Orman S., Kaplan M. (2011). 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. 5(1): 20-26.

Orman S., Kaplan M. (2011). 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. 5(1): 20-26.

Sawyer J. E., and Ebelhar S. A. (1995). Sulfur nutrition of wheat varieties with till and no-till planting on highly weathered Alfisols soil. Communications in Soil Science and Plant Analysis. 26(7/8): 1257-1271.

Soil Survey Staff. (2003). Keys to soil taxonomy. Department of Agriculture: Natural Resources Conservation Service.

Sutaliya, R., Gupta, A. K., & Singh, R. N. (2003). Yield attributes of barley as influenced by phosphorus, Sulphur and their correlation and regression with yield. *CROP RESEARCH-HISAR-*, *25*(3), 585-586.

Sys, C., Van Ranst, E., Debaveye, Ir.J & Beernaert, F. 1993. Land evaluation, part III. Crop requirements. Agriculture publication, no.7, General Administration for Development Cooperation. Brussels, Belgium, 166p.

Togay Y., Togay N.,Cig F., Erman M. and A and Celen E (2008). The effect of sulphur applications on nutrient composition, yield and some yield components of barley (Hordeum vulgare L.) African Journal of Biotechnology. 7 (18): 3255-3260.