INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
13S–009/2013/15–6–1301–1306
http://www.fspublishers.org

Full Length Article

Sulphur Fertilization Improves the Sesame Productivity and Economic Returns under Rainfed Conditions

Muhammad Asghar Shah[1, 2], Abdul Manaf[2], Mubshar Hussain[1]*, Shahid Farooq[1] and Muhammad Zafar-ul-Hye[3]
[1]*Department of Agronomy, Bahauddin Zakariya University, Multan-60000, Pakistan*
[2]*Department of Agronomy, PMAS, Arid Agriculture University, Rawalpindi, Pakistan*
[3]*Department of Soil Science, Bahauddin Zakariya University, Multan-60000, Pakistan*
*For correspondence: mubashiragr@gmail.com

Abstract

Sulphur (S) plays an important role particularly in the nutrition of oilseed crops as it is a key element of S containing amino acids. Therefore, this study was conducted to evaluate the effect of S application on the productivity and oil quality of sesame at Research Farm of PMAS, Arid Agriculture University, Rawalpindi, during Kharif 2008 under rainfed conditions. Elemental S was applied as basal dose @ 0, 30, 45 and 60 kg ha^{-1} to three sesame cultivars viz. SG-18, SG-27 and TS-3. Sulphur application at all levels significantly improved the yield and related traits of sesame like number of capsules per plant, 1000-seed weight, and biological and seed yields; however S application @ 45 kg ha^{-1} was the best. Sesame cultivars behaved differently under different levels of S application and TS-3 proved more productive. According to economic and marginal analysis, S application @ 45 kg ha^{-1} seemed highly practical due to higher net returns, benefit-cost ratio (BCR) and marginal rate of return. In conclusion, to attain maximum sesame productivity along with higher net returns, BCR and marginal rate of return under rainfed conditions, cultivar TS-3 should be grown with S application @ 45 kg ha^{-1}.

Keywords: Sesame; Sulphur; Seed yield; Oil quality

Introduction

Sulphur (S) is the 4th major plant nutrient after nitrogen (N), phosphorous (P) and potassium (K) (Jamal *et al*., 2010). It plays a very vital role in the nutrition of oilseed crops particularly as it is a key element of S containing amino acids. It is one of the essential nutrients for plant growth and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis. It is required in similar amount as that of P (De Kok *et al*., 2002; Ali *et al.*, 2008). It is a building block of protein and a key ingredient in the formation of chlorophyll. Without adequate S, crops cannot reach their full potential in terms of yield or protein content (Zhao *et al.*, 1999). It is required for the synthesis of S containing amino acids such as cystine, cysteine and methionine. Its deficiency results in reduced plant height and stunted growth, impairs tillering capacity and delayed maturity. Sulfur deficient plants have also less resistance under stress conditions (Dobermann and Fairhurst, 2000).

Majority of Pakistan soils are calcarious ($CaCO_3$>3%) and alkaline (pH>7) in nature (Sharif *et al*., 2000; Jafar *et al*., 2012); therefore, low availibility of nutrients like P and S is a big problem due to greater fixation. Sulphur fertilization helps in improving the uptake of N, P, K and Zn in the plant due to its synergistic effect with these elements. Likewise, S application is a feasible technique to suppress the uptake of undesired toxic elements (Na and Cl) because of the antagonistic relationship (Tandon, 1991; Zhang *et al*., 1999). Sulfur improves K/Na selectivity and increases the capability of calcium ion to decrease the injurious effects of sodium ions in plants as well (Wilson *et al*., 2000; Badr *et al*., 2002).

Sesame (*Sesamum indicum* L.) is an ancient and important oilseed crop being cultivated for centuries, particularly in Asia and Africa, for its higher oil and protein contents. Its seeds contain about 50-52% oil, 17-19% protein, 0.1-0.5% fatty acids and 16-18% carbohydrates (Kahyaoglu and Kaya, 2006). Moreover, its seeds not only contain all essential amino acids and fatty acids but also a good source of vitamins (pantothenic acid and vitamin E) and minerals like calcium (1450 mg/100 g) and phosphorous (570 mg/100 g). Its byproduct; seed cake is also an imperative and highly nutritinous livestock feed (Balasubramaniyan and Palaniappan, 2001). India, China, Sudan and Myanmar are the leading producer contributing approximately 60% of the total world production (Gharbia *et al*., 2000). The oilseeds entail more S than other crops; and its concentration and uptake vary with the availability of S in the soil and its fertilization (Nasreen and Huq, 2002). Inadequate S supply can affect the yield and quality of the crop owing to impaired protein and enzyme synthesis (Scherer, 2001). It also plays an important role in the chemical composition of seeds and improves the percentage of oil contents (Hassan *et al*., 2007).

The facts that crop deficiencies of S have been reported with increasing frequency over the past several years; greater attention has been focused on the importance of S in plant nutrition. For instance, S deficiency has been recognized as a limiting factor for crop production in many regions of the world like India (Scherer, 2001). Sulphur nutrition plays an important role in improving the growth and productivity of sesame (Saren *et al*., 2004).

Areas of S deficiency are becoming more prevalent throughout the world due to use of high analysis low S fertilizers, low S returns with farmyard manure, cultivation of high yielding varieties and intensive agriculture, and declined use of S containing fungicides etc. Moreover, continuous use of NPK fertilizers results in S deficiency along with very much deficit of organic matter make the situation more worst for oil seed crops. Oil seed crops gives significant results with S use. Performance of oil seed crops significantly increase with S use regardless of its source (Rahmatullah *et al*., 1999).

Although some reports earlier elucidated the positive effects of S application in improving the productivity and oil quality of sesame (Raja *et al.,* 2007a, b) but, to best of our knowledge, no comprehensive study has been conducted to evaluate the role of S application in improving the yield and oil quality of sesame planted on calcareous alkaline soils under rainfed conditions. Therefore, this study was conducted with the hypothesis that S application can improve the yield and oil quality of sesame planted on calcareous alkaline soils (as found in Pakistan) under rainfed conditions.

Materials and Methods

Site Description and Experimental Details

This field study was conducted at the Research Farms of Pir Meher Ali Shah (PMAS), Arid Agriculture University, Rawalpindi during Kharif 2008 under rainfed conditions. Three sesame cultivars viz., SG-18, SG-27 and TS-3 were grown under four S levels viz. 0, 30, 45 and 60 kg ha^{-1}. Experiment was laid out in randomized complete block design with factorial arrangement and replicated 4 times with a net plot size of 4 m × 5 m. Sesame cultivars were arranged in main plots, while S levels were randomized in sub plots. Experimental soil was quite uniform and sandy clay loam in nature. Pre-sowing and after harvesting soil analysis was conducted to determine the soil S status (Table 1). Overall 742 mm rainfall was received during the whole crop growing season.

Crop Husbandry

Trial was conducted under rainfed area; therefore seedbed was prepared on the already stored moisture regime by rains. Sowing was done on July 02, 2008 by using single row hand drill by keeping row to row distance of 60 cm with seed rate of 5 kg ha^{-1}. After attaining constant emergence count, plant to plant distance of 10 cm was maintained by thinning. Fertilizers at the rate of 60 kg N and P both were applied as basal dose by using urea and di-ammonium phosphate (DAP) as source. Sulphur was applied in the elemental form at sowing according to the treatment requirements. Weeds were controlled by manual hoeing while Imidacloprid and triazophos were applied sprayed to control sucking insects. Mature crop was harvested manually on November 2, 2008.

Observations

Plant height of ten randomly selected plants at maturity from each treatment was taken with meter rod and averaged to record plant height. Likewise, total number of primary and secondary branches, and capsules of ten random selected plants from each plot were counted to record number of primary and secondary branches and capsules per plant. Total seeds present in 100 randomly selected capsules from each plot were count and averaged to record number of seeds per capsule. Three random samples of 1000 seeds were taken from each seed lot, weighed and averaged to record 1000-seed weight. At maturity, total plants present in each plot were harvested, tied into bundles, dried four days and weighed by using spring balance to record biological yield, which was then converted into kg ha^{-1}. The tied bundles were sun dried for 10 days by keeping their heads towards sun and harvested manually to separate seeds from capsules and then weighed to record seed yield, which was then converted into kg ha^{-1}. Harvest index was taken as ratio between seed yield and biological yield expressed in percentage. Seed oil contents, protein and fatty acid profile was determined with the help of Near-Infrared Reflectance Spectroscopy (NIR) System; oil content (%), protein contents (%), palmitic acid (%), stearic acid (%), oleic acid (%) and linoleic acid (%) was recorded to evaluate seed quality of three sesame cultivars (Schulz *et al.,* 2003).

Statistical Analysis

The data collected was statistically analyzed by using statistical program MSTAT C. Fisher's analysis of variance technique (ANOVA) was employed to test the overall significance of the data. Least significance difference (LSD) test at 5% probability level was used to compare the means (Steel *et al.,* 1997).

Economic and Marginal Analysis

Economic and marginal analysis was conducted to determine the economic viability of different S application levels. Cost involved for seedbed preparation, purchasing of seed, sowing of crop, fertilizers, crop protection measures, land rent and harvesting of crops was added to estimate the production cost of sesame. Gross income was estimated according the current average market prices of sesame in Pakistan. After that net income was estimated by deducting total expenses from gross income and benefit-cost ratio (BCR) was estimated by dividing the gross income with total production cost. Marginal analysis was conducted on the basis of variable costs and net benefits following the procedure devised by CIMMYT (1988).

Results

A gradual rise in soil S contents after harvesting of sesame compared with pre-sowing soil S contents, in 0-30 cm soil depth, was observed with every higher level of applied S compared with control (Table 1). Different sesame cultivars had non-significant effect on plant population, plant height and number of primary branches per plant and had significant effect on number of secondary branches and capsules per plant (Table 2). Sesame cultivar TS-3 observed maximum number of secondary branches and capsules per plant but it was at par with SG-18 for number of capsules per plant (Table 2). Sulphur application had non-significant effect on plant population, while plant height, primary branches, secondary branches and number of capsules per plant were gradually improved with increasing levels of S application (Table 2). More plant height, number of primary and secondary branches and number of capsules per plant were observed with S application of 60 kg ha^{-1} was applied. Interaction between cultivars and different levels of S application had non-significant effect on plant population, plant height, and number of primary and secondary branches and number of capsules per plant of sesame (Table 2).

Sesame cultivars and different levels of S application had significant effect on number of seeds per capsule, 1000-seed weight, seed and biological yield and harvest index except the non-significant effect of cultivars on harvest index (Table 3). Cultivar TS-3 outperformed with notably higher seed and biological yield coupled with significant rise in number of seeds per capsule and 1000-seed weight compared with other cultivars under study (Table 3). Sulphur application @ 45 kg ha^{-1} substantially improved the seed yield and harvest index along with elevated number of seeds per capsule and 1000-seed weight but it was at par with S application @ 60 kg ha^{-1}. However, maximum biological yield was recorded with S application @ 60 kg ha^{-1} (Table 3). Moreover, interaction among cultivars and S application was only significant for 1000-seed weight and biological yield of sesame (Table 3).

Different cultivars had non-significant effect on oil and protein contents, and fatty acid profile of sesame oil (Table 4). However, S application substantially increased and decreased the oil and protein contents of sesame seeds, respectively. S application @ 45 kg ha^{-1} observed maximum seed oil contents, while control (0 kg S ha^{-1}) noted maximum seed protein contents but it was at par with lower level of S (30 kg ha^{-1}) application (Table 4). Control (0 kg S ha^{-1}) and lower dose (30 kg ha^{-1}) of S application observed higher contents of palmitic, stearic, oleic and linoleic acids contents of sesame oil compared with higher levels of S (45 and 60 kg ha^{-1}) application (Table 4). Nonetheless, interactive effect of cultivars and S levels had non-significant effect on oil and protein contents, and fatty acid profile of sesame oil (Table 4).

Economic analysis affirmed that 45 kg ha^{-1} application of S and cultivar TS-3 is more profitable compared with all other levels of S application and cultivars respectively. Higher net income and benefit–cost ratio (BCR) was observed with S application of 45 kg ha^{-1}, while among cultivars, TS-3 observed higher net income and BCR (Table 5). Moreover, marginal analysis also indicated the supremacy of S application @ 45 kg ha^{-1} with maximum (900%) marginal rate of return (Table 6).

Table 1: Sulphur status of soil before sowing and after harvesting of sesame

Time of sampling	Depth	SO_4-S mg kg^{-1}
	0 -15 cm	5.30
Before sowing	15-30 cm	6.70
	S levels	SO_4-S mg kg^{-1}
After harvesting	Depth	0-30 cm
	S_1 0 kg ha^{-1}	6.10
	S_2 30 kg ha^{-1}	7.70
	S_3 45 kg ha^{-1}	8.90
	S_4 60 kg ha^{-1}	10.50

Discussion

Pre-sowing and after harvesting soil analysis report indicated that external S application significantly improved the soil S contents, which were higher at top levels of S application (Table 1). Higher soil S contents at higher levels of S application after harvesting the crop might be due more S fixation, because of calcareous alkaline nature of soil under S fertilization. Recently Rehim *et al.* (2012) also quoted higher soil P contents after wheat harvesting in consequence of fertilization. In consequence of improved soil S contents with S fertilization, higher availability of essential nutrients with S application notably improved the sesame productivity due to significant improvement in yield related traits under rainfed conditions, although the cultivars behaved differently in this regard (Tables 2, 3). Higher seed yield under S application @ 45 kg ha^{-1} might be due to significant expansion in entire yield related traits like number of branches (primary and secondary) and capsules per plant, number of seeds per capsule and 1000-seed weight (Tables 2 and 3). Earlier Amudha *et al.* (2005) and Sarkar and Saha (2005) also reported higher seed yield of sesame with 45 kg ha^{-1} S application. Raja *et al.* (2007b) quoted that S application improved the number of primary and secondary branches compared with control (no application of S). Vaiyapuri *et al.* (2004) and Thakur and Patel (2004) reported maximum seed weight with S application level of 45 and 30 kg ha^{-1}.

Table 2: Effect of sulphur application on allometric and yield related attributes of different sesame cultivars

Treatment	Plant population	Plant height (cm)	Number of primary branches per plant	Number of secondary branches per plant	Number of capsules per plant
Sesame cultivars (C)					
C_1 = SG-18	57.81	144.00	18.10	9.62 b	298.06 a
C_2 = SG-27	57.44	144.71	18.01	9.63 b	281.86 b
C_3 = TS-3	57.44	143.98	18.25	10.26 a	292.39 a
LSD at 5%	NS	NS	NS	0.49	6.65
S levels (kg ha^{-1})					
S_1 = 0	57.68	134.74 d	16.81 c	8.59 d	280.06 b
S_2 = 30	57.17	138.98 c	17.35 b	9.36 c	283.03 b
S_3 = 45	57.50	149.44 b	19.03 a	10.37 b	299.56 a
S_4 = 60	57.67	153.76 a	19.28 a	11.03 a	300.51 a
LSD at 5%	NS	2.84	0.41	0.42	5.76
Interaction (C × S)	NS	NS	NS	NS	NS

Means sharing the same letters in common within a column do not differ significantly from each other at 5% level of probability

Table 3: Effect of sulphur application on yield related traits and productivity of different sesame cultivars

Treatment	Number of seeds per capsule	1000-seed weight (g)	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)
Sesame cultivars (C)					
C_1 = SG-18	72.74 b	3.64 a	1625.86 b	537.63 b	33.01
C_2 = SG-27	79.25 a	3.51 b	1596.54 c	556.76 b	34.68
C_3 = TS-3	79.01 a	3.64 a	1659.31 a	583.14 a	35.04
LSD at 5%	2.90	0.05	15.94	25.18	NS
S levels (kg ha^{-1})					
S_1 = 0	67.53 c	3.27 d	1510.64 d	470.92 c	31.15 b
S_2 = 30	73.16 b	3.51 c	1565.03 c	506.57 b	32.39 b
S_3 = 45	83.31 a	3.72 a	1705.88 b	641.18 a	37.66 a
S_4 = 60	84.01 a	3.64 b	1727.17 a	618.04 a	35.77 a
LSD at 5%	2.51	0.07	15.94	33.72	2.05
Interaction (C × S)	NS	*	*	NS	NS

Means sharing the same letters in common within a column do not differ significantly from each other at 5% level of probability

Table 4: Effect of sulphur application on oil quality of different sesame cultivars

Treatment	Oil contents (%)	Protein contents (%)	Palmitic acid (%)	Stearic acid (%)	Oleic Acid (%)	Linoleic acid (%)
Sesame Cultivars (C)						
C_1 = SG-18	39.06	20.44	6.90	4.87	32.04	41.35
C_2 = SG-27	39.38	19.63	7.12	4.78	31.50	40.54
C_3 = TS-3	39.81	19.50	6.53	4.59	32.43	39.21
LSD at 5%	NS	NS	NS	NS	NS	NS
Sulphur Levels (S) (kg ha^{-1})						
S_1 = 0	35.25 d	21.00 a	7.26 a	5.20 a	34.00 a	42.38 a
S_2 = 30	38.33 c	20.00 ab	7.18 ab	4.89 a	33.78 a	41.44 a
S_3 = 45	43.17 a	18.83 bc	6.35 c	4.38 b	29.41 b	38.16 b
S_4 = 60	40.92 b	19.58 c	6.62 bc	4.52 b	30.76 b	39.48 b
LSD at 5%	1.03	1.39	0.59	0.32	2.56	1.93
Interaction (C × S)	NS	NS	NS	NS	NS	NS

Means sharing the letters in common within a column do not differ significantly from each other at 5% level of probability

Applied S maybe improved the production of S containing amino acids, which resulted in better growth and development of the plants at early stages. Moreover balanced supply of nutrients owing to S addition might be involved in the improvement of yield related traits of sesame leading to higher seed yield. Published literature highlighted that S fertilization helps in improving the uptake of N, P, K and Zn in the plant due to its synergistic effect with these elements however, S application is a feasible technique to suppress the uptake of undesired toxic elements (Na and Cl), because of the antagonistic relationship (Tandon, 1991; Zhang *et al*., 1999). Sulfur improves K/Na selectivity and increases the capability of calcium ion to decrease the injurious effects of sodium ions in plants as well (Wilson *et al*., 2000; Badr *et al*., 2002). Moreover, it is one of the essential nutrients for plant growth accumulating 0.2 to 0.5% in plant tissue on dry matter basis. It is a building block of protein and a key ingredient in the formation of chlorophyll (Duke and Reisenaue, 1986). It is also required for the synthesis of S containing amino acids such as cystine, cysteine and methionine etc.

Table 5: Effect of S application on net income and BCR of sesame cultivar

Treatment	Total expenditure (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	BCR
Sesame Cultivars (S)				
C_1 = SG-18	17500	32257	14757	1.84
C_2 = SG-27	17500	33405	15905	1.91
C_3 = TS-3	17500	34988	17488	2.00
Sulphur Levels (S) (kg ha^{-1})				
S_1 = 0	14550	28200	13650	1.93
S_2 = 30	16600	30360	13760	1.82
S_3 = 45	17500	38460	20960	2.19
S_4 = 60	18400	37080	18680	2.01

Table 6: Marginal analysis of different levels of sulphur application

Sulphur levels	Variable cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Change in variable cost (Rs. ha^{-1})	Change in net benefits (Rs. ha^{-1})	Marginal rate of return (%)
0 kg ha^{-1}	-	28200	-	-	-
30 kg ha^{-1}	2050	30360	2050	2160	105.37
45 kg ha^{-1}	2950	38460	900	8100	900.00
60 kg ha^{-1}	3850	37080	900	-	D

Elevated biological yield with increasing levels of S application might be linked with increased plant height and higher canopy area as well due to more number of primary and secondary branches per plant of sesame under S application (Table 2). As S application is involved in improving nutrient uptake and chlorophyll contents (Duke and Reisenaue, 1986; Tandon, 1991; Zhang *et al*., 1999); hence it might improve the growth and finally biological yield of sesame. Interestingly accelerated harvest index at higher levels of S application elaborated the better assimilate portioning towards developing seeds (Sriramachandrasekharan, 2004), we also confirmed it (Table 3). Different cultivars of a species behaved differently owing to their different genetic makeup. Cultivar TS-3 out yielded the other cultivars due to notable expansion in yield components like number of capsules per plant, number of seeds per capsule and 1000-seed weight (Tables 2 and 3). However this higher seed yield of cultivar TS-3 might be linked with its better genetic makeup. Moreover cultivars had non-significant on seed and oil quality of sesame.

With respect to seed quality, higher levels of S application improved the oil contents on the expense of protein contents (Table 4). However, contrast to the our results Raja *et al*. (2007b) observed significant elevation in protein contents with increasing level of S fertilization in sesame. More interestingly, the higher levels of S improved the seed oil contents but on the other hand it decreased the contents of important fatty acids like palmitic, stearic, oleic and linoleic acid of oil (Table 4).

The success and commercial acceptance of any technique depends on its economic viability and cost involved. According to economic analysis, S application @ 45 kg ha^{-1} recorded higher net income and BCR than all other treatments including control, and thus, proved its economic feasibility for sesame cultivation under rainfed area of Pakistan (Table 5). Moreover, higher net income and BCR with S application @ 45 kg ha^{-1} might be the direct result of higher sesame yield (Table 3). Likewise, higher net income and BCR exhibited by cultivar TS-3 was the direct result of higher seed yield (Table 3). Higher marginal rate of return (Table 6) with S application @ 45 kg ha^{-1} indicated higher output per unit of S input at that level.

In summary, S fertilization improved the productivity and economic returns of sesame cultivars under rainfed cultivation and cultivar TS-3 performed better than other cultivars. Therefore to attain maximum sesame productivity along with higher net returns, BCR and marginal rate of return under rainfed conditions, cultivar TS-3 should be grown with S application @ 45 kg ha^{-1}.

References

Ali, R., M.J. Khan and R.A. Khattak, 2008. Response of rice to different sources of Sulfur (S) at various levels and its residual effect on wheat in rice-wheat cropping system. *Soil Environ*., 27: 131–137

Amudha, A., V. Vaiyapuri, M.V. Sriramachandrasekharan and M. Ravichandran, 2005. Effect of sulphur and organics on yield and sulphur use efficiency in sesame. *Res. Crops*, 6: 468–469

Badr, Z., A. Ali, M. Salim and B.H. Niazi, 2002. Role of sulphur for potassium/sodium ratio in sunflower under saline conditions. *Helia*, 25: 69–78

Balasubramaniyan, P. and S.P. Palaniappan, 2001. *Field crops: An overview*, p: 47. In: Principles and practices of agronomy, *Agrobios*, India

CIMMYT, 1988. *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*. Mexico, DF

De Kok, L.J., A. Castro, M. Durenkamp, C.E.E. Stuiver, S. Westerman, L. Yang and I. Stulen, 2002. *Sulphur in Plant Physiology*, pp: 1–26. Proceedings No. 500, The International Fertiliser Society, New York, USA

Dobermann, A. and T. Fairhurst, 2000. *Rice: Nutrient Disorder and Nutrient Management*, p: 91. Handbook Series. Potash and Phosphate Institute of Canada and International Rice Research Institute

Duke, S.H. and H.M. Reisenaue, 1986. Roles and requirements of sulfur in plant nutrition. *In: Sulfur in Agriculture*, pp: 124–168. Tabatabai, M.A. (ed.). Agronomy Series No. 27, American Society of Agronomy, Madison, Wisconsin, USA

Gharbia, H.A.A., A.A.Y. Shehata and F. Shahidi, 2000. Effect of processing on oxidative stability and lipid classes of sesame oil. *Food Res. Int*., 33: 331–340

Hassan, F., A.S. Hakim, A. Manaf, G. Qadir and S. Ahmad. 2007. Response of sunflower (*Helianthus annuus* L.) to sulphur and seasonal variations. *Int. J. Agric. Biol*., 9: 499–503

Jafar, M.Z., M. Farooq, M.A. Cheema, I. Afzal, S.M.A. Basra, M.A. Wahid, T. Aziz and M. Shahid. 2012. Improving the performance of wheat by seed priming under saline conditions. *J. Agron. Crop Sci*., 198:38–45.

Jamal, A., Y.S. Moon and M.Z. Abdin, 2010. Sulphur - A general overview and interaction with nitrogen. *Aust. J. Crop Sci*., 4: 523–529

Kahyaoglu, T. and S. Kaya, 2006. Modelling of moisture, color and texture changes in sesame seeds during the conventional roasting. *J. Food Eng*., 75: 167–177

Nasreen, S. and S.M.I. Huq, 2002. Effect of sulphur fertilization on yield and nutrient uptake of sunflower crop in an albaquept soil. *Pak. J. Biol. Sci*., 5: 533–536

Rahmatullah, G. Nabi, M.S. Salim and M.S. Zia, 1999. Relationship between seed sulphur and seed phosphorus and seed yield of *Brassica napus* on two alfisols fertilized with different sulphur sources. *Pak. J. Biol. Sci*., 2: 262–265

Raja, A., K.O. Hattab, L. Gurusamy and S. Suganya, 2007a. Sulphur levels on nutrient uptake and yield of sesame varieties and nutrient availability. *Int. J. Soil Sci*., 2: 278–285

Raja, A., K.O. Hattab, L. Gurusamy, G. Vembu and S. Suganya, 2007b. Sulphur application on growth and yield and quality of sesame varieties. *Int. J. Agric. Res*., 2: 599–606

Rehim, A., M. Farooq, F. Ahmad and M. Hussain, 2012. Band placement of phosphorus improves the phosphorus use efficiency and wheat productivity under different irrigation regimes. *Int. J. Agric. Biol*., 14: 727–733

Saren, B.K., S. Tudu and P. Nandi, 2004. Effect of irrigation and sulphur on growth and productivity of summer sesame (*Sesamum indicum* L.). *Madras Agric. J*., 91: 56–60

Sarkar, R.K. and A. Saha, 2005. Analysis of growth and productivity of sesame (*Sesamum indicum*) in relation to nitrogen, sulphur and boron. *Ind. J. Plant Physiol*., 10: 333–337

Schulz, H., R. Quilitzsch and H. Kruger, 2003. Rapid evaluation and quantitative analysis of thyme, origano and chamomile essential oils by ATR-IR and NIR spectroscopy. *J. Mol. Str*., 661-662: 299–306

Sharif, M., M.S. Sarir and F. Rabi, 2000. Biological and chemical transformation of phosphorus in some important soil series of NWFP. *Sarhad J. Agric*., 16: 587–592

Sriramachandrasekharan, M.V., 2004. Integrated sulphur management on sesame. *J. Interacademicia*, 8: 187–190

Scherer, H.W., 2001. Sulphur in crop production. *Eur. J. Agron*., 14: 81–111

Steel, R.G.D., J.H. Torrie and D.A. Deekey, 1997. *Principles and Procedures of Statistics: A Biometrical Approach*, 3rd edition, pp: 400–428. McGraw Hill Book, New York, USA

Tandon, H.L.S., 1991. *Sulfur Research and Agricultural Production in India*, 3rd edition. The Sulphur Institute, Washington, DC USA

Thakur, D.S. and S.R. Patel, 2004. Response of sesame (*Sesamum indicum*) to different levels of potassium and sulphur in light-textured Inceptisols of eastern part of Chhattisgarh. *Ind. J. Agric. Sci*., 74: 496–498

Vaiyapuri, V., A. Amudha, M.V. Sriramachandrasekharan and V. Imayavaramban, 2004. Effect of sulphur levels and organics on growth and yield of sesame. *Adv. Plant Sci*., 17: 681–685

Wilson, C., S.M. Lesch and C.M. Grieve, 2000 Growth stage modulates salinity tolerance of New Zealand Spinach (*Tetragonia tetragonioides*, Pall.) and Red Orach (*Atriplex hortensis* L.). *Ann. Bot*., 85: 501–509

Zhang, Z.Y., K.G. Sun, A.Y. Lu and X.B. Zhang, 1999. Study on the effect of S fertilizer application on crops and the balance of S in soil. *J. Agric. Sci*., 5: 25–27

Zhao, F.J., S.E. Salmon, P.J.A. Withers, J.M. Monaghan, E.J. Evans, P.R. Shewry and S.P. McGrath, 1999. Variation in the bread making quality and mineralogical properties of wheat in relation to sulfur nutrition under field conditions. *J. Cereal Sci*., 30: 19–31

(Received 12 March 2013; Accepted 03 July 2013)