Effect of sulphur supplementation on micronutrients, fatty acids and sulphur use efficiency of soybean seeds

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Abstract**—** *The present study was aimed at finding the influence of different sources and doses of sulphur fertilizers on micronutrient status and oil composition in soybean seeds. Soybean is the major source of edible vegetable oils and high protein seed supplements in the world. Sulphur deficiency causes soybean protein quality to decline and also decreases nitrogen-use efficiency of fertilizers. Soybean is a good source of nutrients which could further be amended with biofortification and use of fertilizers, to meet the nutrient deficiencies. Various limiting factors affect the yield of soybean crop by affecting the yield potential. Sufficient sulphur deficiency is one such limiting factor and have become common all over due to intensive crop systems and higher yielding varieties. Micronutrients play an important role in quality and quantity of soybean yield. Sulphur fertilizers viz gypsum and single super phosphate (SSP) were used at three different doses. Soil analysis have been done to evaluate the fertility status of soil prior to the experiment. Different treatments of sulphur supplementation had significant effect on seed micronutrient accumulation, nitrogen sulphur ratio and fatty acid profile. Sulphur supplementation increased zinc and iron content in mature soybean seeds, however, copper and manganese were found to be least effective. Sulphur supplementation with gypsum @ 20 kgha^{-1} increased plant height and pods per plant. Increase of oleic acid coincided with the decrease of linoleic acid with sulphur supplementation during both the cropping seasons of study.*

Keywords—fatty acids, gypsum, micronutrient, soybean, single super phosphate.

I. INTRODUCTION

Soybean has a great potential as a source of important nutrients and nutraceuticals of implication to human health. Soybean contains a high nutritional value due to the high concentration of oil (18-25%) and protein (38-50%) and is a popular food all over the world (Tidke *et al* .,2015). Soybean is the major source of edible vegetable oils and of high protein seed supplements in the world. Sulphur deficiency causes soybean protein quality to decline (Gayler and Sykes 1985) and also decreases nitrogen-use efficiency of fertilizers (Ceccoti 1996). Various limiting factors affect the yield of a particular crop by affecting the yield potential. One such limiting factor is sufficient nutrient supply (Sahu *et al.*, 2017). Sulphur deficiencies have become common all over due to intensive crop systems and higher yielding varieties.

The agronomic productivity of soybean plants is dependent upon their capacity to partition a significant proportion of assimilates to the seeds, and the economic value of the crop is directly related to the seed composition (Sebastia *et al.*, 2005). But the current practice of applying large amounts of nitrogen fertilizers to crops without considering sulphur requirements is becoming a concern for crop quality (Tea *et al.*, 2007). Sulphur plays a very important role in various plant growth and developmental processes being the constituent of sulphur containing amino acids methionine (21% S) and cysteine (27% S), and other metabolites such as glutathione (Devi *et al.*, 2012). The sulphur requirement by plants varies with the developmental stage and with species whereas its concentration in plants varies between 0.1 and 1.5% of dry weight. Even if sulphur is only 3% to 5% as abundant as nitrogen in plants, it plays essential roles in various important mechanisms such as Fe/S clusters in enzymes, vitamin cofactors, GSH in redox homeostasis, and detoxification of xenobiotics (Anjum *et al.*, 2011). Oilseeds not only respond to applied sulphur, but their requirement for sulphur is also the highest among other crops, thereby attributing a role for the nutrient in oil biosynthesis (Ahmed *et al.*, 2007)

Micronutrients have the potential to contribute in maximizing yields. Nutrients evaluated in the studies presented here include Fe, Cu, Mn and Zn. Soybean also contains ~5% minerals. It is relatively rich in K, P, Ca, Mg and Fe. Soil conditions must be taken in consideration when evaluating micronutrients. Organic matter plays an essential role and is the main source of most micronutrients, especially for Zn and Cu. Soil pH influences the bioavailability of micronutrients in the soil. Availability of B, Cu, Fe, and Zn tends to decrease as pH increase. Soil texture can also affect the availability of micronutrients; coarse texture soils have the tendency to be low on B concentration. Soils with poor aeration are more likely to have Fe, Zn and Mn deficiencies.

Soybean oil makes up nearly 60% of the world's oil seed production and is by far the world's dominant vegetable oil (http://www.soystats.com) which has also been employed as source of bio-diesel fuels (Graham and Vance 2003). The fatty acid composition in oilseeds is an important consideration for breeding programs (Daun 1998). Five fatty acids make up nearly the entire oil portion of soybean seed. Soybean oil averages 12% palmitic acid (16:0), 4% stearic acid (18:0), 23% oleic acid (18:1), 53% linoleic acid (18:2), and 8% linolenic acid (18:3) (Wilson 2004). The 16:0 and 18:0 fractions are saturated fatty acids and constitute 15% of the soybean oil. The remainder of the oil (about 85%) is made up of unsaturated fatty acids. Soybean lines are currently being developed to express modified fatty acid profile thus increasing the potential uses of oil (Spencer *et al.*, 2003). Sulphur interactions with nitrogen nutrients are directly related to the alteration of physiological and biochemical responses of crops, and thus required to be studied in depth.

II. MATERIALS AND METHODS

Soybean var. SL525 was raised in the experimental fields of Pulses Section of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana by recommended packages and practices. The experiment was laid out in Randomized Block design (RBD) with three replications. The field and the plots were of sizes 21.7 m × 17.4 m and 5 m × 2.7 m respectively. Each plot comprised of 6 rows which were 45 cm apart. The spacing between the blocks was 1.2 m. Two different sulphur sources i.e. Gypsum and Single Super Phosphate (SSP) were used at three different dose rates respectively. There were seven treatments including control 0, 10 kg S ha^{-1}, 20 kg S ha^{-1}, 30 kg S ha^{-1} through gypsum and 10 kg S ha^{-1} , 20 kg S ha^{-1}, 30 kg S ha^{-1} through SSP. The soil of each plot was uniformly fertilized with urea as a nitrogen source and rock phosphate as phosphorus source. In calculating the amount of phosphorus, its content in SSP was reduced from the rock phosphate. Fertilizers were applied at the time of final land preparation as basal dose. The composite soil samples from 0-15 cm and 15-30 cm profile layers were collected before sowing from randomly selected sites from experimental area and analyzed for initial soil fertility status and other soil characteristics**.**

Plant height (cm) was measured from the base of the main stem to the tip of the youngest leaf using measuring tape at maturity. The number of pods per plant was taken by counting all pods in the tagged plants, and the average number of pods per plant was determined.

The micronutrients were determined from 1:2; soil-extractant ratio using DTPA-TEA (Diethylene triamine penta acetic acid-triethanolamine) buffer (0.005 M DTPA+ 0.001 M $CaCl_2$ + 0.1M TEA, pH 7.3) as per method proposed by Lindsay and Norvell (1978) and concentration of these micronutrients was measured on an atomic absorption spectrophotometer (AAS). Water extractable sulphate was determined by Tabatabai (1974).

N: S ratio was determined by estimating the total nitrogen content by Microkjeldahl method (McKenzie and Wallace 1954) and total sulphur content (Chesnin and Yien 1950) by wet digestion with nitric acid-perchloric acid mixture.

Fatty acids were analyzed by forming their ethyl esters (Uppstrom and Johansson 1978). The ethyl esters prepared were identified and estimated as relative percentage by gas liquid chromatography (GLC). The esters thus prepared were analysed using M/s Nucon Engineers AIMIL Gas chromatograph (solid state) model: 57 or equipped with a flame ionization detector fitted with a 6' x 1/8" stainless steel column, packed with 6% BDS (Butane diol succinate) on 100-120 mesh chromosorb HP. The conditions for the separation were as follows: Oven temperature : 190-200ºC ; Injector and flame ionization detector temperature: 240-250ºC; Hydrogen flow: 40 ml min^{-1} ; Nitrogen pressure: 2.5 kg sq^{-1} inch ; Air flow : 300-400 ml min^{-1}. The sample (0.2 µl) was injected into the GLC by means of a 10 µl 'Hamilton' syringe. Tentative identification of the peaks was done by comparison of their retention time with those of standard fatty acyl esters. The relative percentage of different fatty acids was analysed using Nuchrom software.

III. RESULTS AND DISCUSSIONS

Plant height showed insignificant variation under the influence of different treatments of gypsum and SSP as sulphur source. Pods per plant is an important component of yield which did not reveal any significant differences among various treatments of sulphur and in comparison to control. However, number of pods per plant increased to 47.5 with gypsum @ 20 kg S ha^{-1}, in comparison to control (42.9). With SSP as sulphur source, number of pods per plant increased to 46.7 with the dose rate of 30 kg S ha^{-1}. Increase in plant height and other yield attributes such as pods per plant, 1000 seed weight indicated the positive effect of sulphur nutrition on vegetative growth because of the availability of more photoassimilates.

Table.1: Soil characteristics of the experimental site

Soil Characteristics	**2011**		**2012**		**Methods used**
	Depth		**Depth**		
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	
Soil texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	
pH	7.60	7.50	7.70	8.00	1:2 soil : water suspension (Jackson 1967)
Electrical Conductivity (mmoles cm^{-1}) at 25ºC	0.10	0.06	0.15	0.10	Solubridge conductivity meter (1:2 soil : water suspension) (Jackson 1967)
Organic carbon (%)	0.60 (High)	0.48 (Medium)	0.51 (Medium)	0.36 (Low)	Walkley and Black's rapid titration method (Walkley and Black 1934)
Available Phosphorus (kg/acre)	11.4 (High)	11.4 (High)	14.3 (High)	11.8 (High)	0.5 N sodium bicarbonate extractable P by Olsen's method (Olsen *et al* 1954)
Potassium (kg/acre)	138 (High)	105 (High)	30 (Low)	72 (High)	Ammonium acetate extraction method (Piper 1966)
Sulphur (%)	0.20	0.08	0.22	0.10	Williams amd Steinbergs (1959).
Nitrogen (%)	0.23	0.19	0.26	0.21	McKenzie and Wallace (1954)
Zinc (kg acre^{-1})	1.38	1.28	1.56	1.04	Lindsay and Norvell (1978)
Iron (kg acre^{-1})	3.76	4.0	6.94	4.88	Lindsay and Norvell (1978)
Manganese (kg acre^{-1})	7.14	7.74	9.28	8.54	Lindsay and Norvell (1978)
Copper (kg acre^{-1})	0.32	0.44	0.40	0.34	Lindsay and Norvell (1978)

Mohanti *et al* (2004) recorded highest plant height with 30 kg S ha-1 in soybean. Similarly, Ravi *et al* (2008) reported significant increase in height of safflower with sulphur application @ 30 kg S ha-1. Nasren and Farid (2006) recorded highest number of pods per plant with 60 kg S ha-1 followed by 40 kg S ha-1 in soybean. Application of sulphur @ 40 kg ha-1 enhanced plant height, branches, pod per plant and 1000 seed weight in green gram (Sharma and Singh 1979) whereas application @ 60 kg S ha-1 produced higher pod length, seed per pod and 1000 seed weight in black gram (Singh and Aggrawal 1998).

Nitrogen and sulphur assimilation get restrained in plants with the deficiency of either of the nutrient. Nitrogen content in seeds was not significantly influenced by different treatments of sulphur fertilization. The highest nitrogen content was observed in control soybean seeds, where no sulphur was applied. Nitrogen content decreased to minimum value with gypsum @ 20 kg S ha^{-1}. Significant variations in sulphur content was observed in mature soybean seeds under the influence of sulphur fertilization. With gypsum, highest sulphur content was observed in seeds treated @ 20 kg S ha^{-1}. Similarly, with SSP, maximum sulphur content was observed @ 20 kg S ha^{-1} in soybean seeds. N:S ratio was highest in control seeds (49.56), and decreased with sulphur supplementation in comparison to control. With gypsum and SSP both @ 20 kg S ha^{-1}, N:S ratio reduced to 24.2 and 28.38 respectively (Table 2).

Table.2: Effect of different levels and sources of sulphur on physiological parameters and sulphur use efficiency in soybean seeds

TREATMENT Amount of sulphur added to soil (kg ha^{-1})	**Plant Height**	**Pods per plant**	**Water extractable sulphate**	**N:S Ratio**	**Fetilizer sulphur use efficiency**
Control	55.3±2.08	42.9±0.70	0.88±0.03	49.56	-

Gypsum	**10**	55.0±3.93	46.8±3.43	0.85±0.02	30.00	8.72
	20	56.3±2.51	47.5±5.20	0.79±0.01	24.22	12.75
	30	55.6±1.52	46.4±1.36	0.77±0.02	26.81	15.11
SSP	**10**	57.5±3.0	42.6±3.70	0.81±0.01	31.90	7.17
	20	59.4±4.93	46.2±2.80	0.77±0.01	28.38	12.63
	30	58.4±1.40	46.7±1.61	0.73±0.02	34.86	10.32
Overall mean		56.78	45.58	0.80	32.24	11.11
Critical difference ($p<0.05$)		NS	NS	0.033		

*Data is represented as mean ± S.D of three replications

Sulphur fertilization affected nitrogen assimilation as indicated by decreased N:S ratio which is an indicator of quality of legumes (Eppendorfer 1971) and decrease in this ratio suggested more uptake of sulphur. Increased sulphur uptake had increased nitrogen utilization assisting in synthesis of certain biochemicals in the seed. Soybean seed have intrinsic biochemical ability to synthesize high amount of protein when sufficient raw material is available. Kumar *et al* (2013) also reported decrease in N:S ratio with sulphur and nitrogen treatments in mungbean seeds although higher effect was observed to be with sulphur fertilizers. In cowpea, N:S ratio decreased with the increasing dose of sulphate fertilizers (Evans *et al*., 2006). Minimum N:S ratio was recorded with application of 40 kg S ha^{-1} over control treatment in soybean seeds (Najar *et al.,* 2011). On the contrary, N:S ratio increased in soybean under sulphur stress (Sexton *et al*., 1998). Sharma and Gupta (1992) reported that the application of 60 kg S ha^{-1} caused significant increase in sulphur and nitrogen content whereas Fazili *et al* (2010) reported increase in sulphur content in mustard seeds with 40 kg S ha^{-1}.Significant variation was observed in content of water extractable sulphate in soybean seeds under the influence of sulphur supplementation (Table 2). The amount of water extractable sulphate was reduced with the different treatments of sulphur in the form of gypsum and SSP during both the cropping seasons in dose dependent manner. Sulphur application affected crop yield through the effect on S-use efficiency and its components (uptake efficiency and utilization efficiency). Data on fertilizer sulphur use efficiency (FSUE) revealed that gypsum showed FSUE in the range of 8.72 to 15.11, highest @30 kg ha^{-1} (Table 2). Comparatively, SSP showed lesser FSUE upto 7.11 with 10 kg ha^{-1}. Highest FSUE (15.11) was recorded with gypsum applied @ 30 kg S ha^{-1}. SSP also showed highest FSUE (12.63) with 20 kg S ha^{-1} . In the present study, gypsum was found to be efficient fertilizer in terms of sulphur use as compared to SSP. In addition to the sulphur, calcium present in gypsum might have created a favourable environment for efficient sulphur utilization, thereby leading to higher yield and higher sulphur-use efficiency and its components. Najar *et al* (2011) reported highest sulphur use efficiency with 10 kg S ha^{-1} in soybean whereas Sriramachandrasekharan (2012) reported highest FSUE @ 50 kg S ha^{-1} applied as gypsum in radish.

Soybean is also a good source of micronutrients which could further be amended with biofortification and use of fertilizers, to meet the nutrient deficiencies. Micronutrients play an important role in quality and quantity of soybean yield. Different treatments of sulphur supplementation had significant effect on seed micronutrient accumulation. Sulphur supplementation increased zinc and iron content in mature soybean seeds, however, copper and manganese were found to be least effective (Table 3). Both gypsum and SSP @ 10 kg S ha^{-1} increased Zn content upto 62 and 60 mg kg^{-1} respectively, in comparison to control seeds (39 mg kg^{-1}) where no sulphur was applied. But, with the increase in sulphur doses, Zn content showed a decreasing trend and was minimum with both the fertilizers when applied @ 30 kg S ha^{-1}. Iron concentration was higher in soybean seeds under sulphur nutrition, as compared to control seeds (58 mg kg^{-1}). Maximum iron concentration (90 mg kg^{-1}) was observed with gypsum applied @10 kg S ha^{-1}, and it decreased to 63.5 and 69.5 mg kg^{-1} with increase in sulphur dose upto 20 and 30 kg S ha^{-1} respectively. Similar changes in iron concentration was observed when SSP was applied at different levels.

Table.3: Effect of different levels and sources of sulphur on micronutrients (mgkg^{-1}) in soybean seeds

TREATMENT Amount of S added to soil (kg ha^{-1})		**Zinc (Zn)**	**Copper (Cu)**	**Iron (Fe)**	**Manganese (Mn)**
Control		39	9	58	22.5
Gypsum	**10**	62	10.5	90	22.5
	20	42	10	63.5	21
	30	35	10	69.5	21.5
SSP	**10**	60	9	79.5	25
	20	41	6.5	64.5	19.5
	30	40.5	6	71.5	23
Overall Mean		45.64	8.71	70.92	22.14

Gypsum applied at different dose rates resulted in higher copper concentration in soybean seeds as compared to control whereas application of various levels of SSP showed reverse trend. Manganese concentration was not affected by application of different doses of gypsum but SSP @ 10 kg S ha^{-1} increased manganese concentration as compared to control. The results are in agreement with the previous studies on micronutrient concentration in soybean where significant increase in their concentrations with soil fertilizer application have been reported (Jha and Chandel 1987, Rhoads 1984). Nutrients gets partitioned according to their mobile ability. Optimum metal homeostasis is achieved by the plant through precise regulation of transport, distribution and remobilization of elements, which is controlled by source and sink signals. Variations in micronutrient concentration by sulphur application might be due to changes in any of the processes involved in the nutrient partitioning.

Fatty acid composition of seed lipid is an important determinant of oil quality. Soybean oil is highly demanding worldwide in terms of total fat supplies of world (Soya and Oilseed Bluebook 2010), because of high content of polyunsaturated fatty acids essential for human nutrition (Emken 1995). They are precursors of prostaglandins and hormones that play an important activity in the regulation of physiological and biochemical functions of human body. The relative content of fatty acids influences the physical and chemical characteristics of the oil, thus the suitability of the oil for a particular use.

Fatty acid composition of soybean seeds as affected by sulphur supplementation is presented in Table 4. Different treatments of sulphur supplementation exhibited non-significant differences for palmitic acid during both the years. Seeds treated with gypsum @ 30 kg S ha^{-1} and SSP @ 10 kg S ha^{-1} registered maximum palmitic acid content upto 14.54 and 14.04%, as compared to control (13.72%). Similar results were found during second year of study. Maximum palmitic acid content recorded was 13.90 and 14.33% with gypsum @ 30 kg S ha^{-1} and SSP @ 10 kg S ha^{-1} respectively, which was statistically similar to palmitic acid in control seeds. Stearic acid was found to be higher (4.47%) in treatment with gypsum @ 10 kg S ha^{-1}, as compared to control (3.57%) during first year of study. Gypsum @ 10 and 20 kg S ha^{-1} and SSP @ 30 kg S ha^{-1} significantly increased stearic acid content in soybean seeds, with maximum content of 4.34% obtained with gypsum @ 10 kg S ha^{-1}.

In 2011, oleic acid was significantly reduced with sulphur supply @ 30 kg S ha^{-1} with gypsum, upto 30.29%, as compared to control (32.06%). Gypsum @ 10 and 20 kg S ha^{-1} did not reveal any significant differences in oleic acid content. With SSP, higher value of oleic acid was registered upto 32.27% and 32.13% with 10 kg S ha^{-1} and 30 kg S ha^{-1}, respectively, although the results were found to be non-significant. However, during second year of study, oleic acid increased significantly with all the treatments of sulphur supplementation except with SSP @ 30 kg S ha^{-1}, where its content significantly decreased. Maximum content of oleic acid (29.59%) was registered with gypsum @ 20 kg S ha^{-1}, and the lowest content (27.05%) was registered in control seeds, where no sulphur was applied. With SSP, maximum oleic acid content (28.95%) was recorded @ 20 kg S ha^{-1}.

Linoleic acid was found to be unaffected with sulphur supplementation with all the treatments except SSP @ 20 kg S ha^{-1}, where its content significantly increased to 47.51 % as compared to control (46.70%) during first cropping season. However, during second cropping year, linoleic acid significantly decreased with gypsum and SSP @ 10 kg S ha^{-1} and 20 kg S ha^{-1} respectively.

Linolenic acid increased significantly with all the treatments of sulphur supplementation as compared to control during first cropping season. Although, during second year, insignificant variations in linolenic acid content was observed. In 2011, maximum linolenic acid content registered was 4.79 and 4.78% with both the fertilizers @ 10 kg S ha^{-1}. In year 2012, maximum linolenic acid recorded was 5.33 and 5.21% with gypsum @ 20 kg S ha^{-1} and SSP @ 30 kg S ha^{-1} respectively, but found to be non-significantly affected as compared to control (4.81%).

In present study, very narrow differences in fatty acids content were observed under the influence of sulphur fertilization.

Table.4: Effect of different treatments of sulphur on fatty acid composition (relative percentage) in soybean seeds.

	TREATMENT Amount of S added to soil (kg ha^{-1})		**Palmitic acid (16:0)**	**Stearic acid (18:0)**	**Oleic acid (18:1)**	**Linoleic acid (18:2)**	**Linolenic acid (18:3)**	**Unsaturation (%)**	**Oleic: Linoleic Ratio**
2011	**Control**		13.72 ± 0.21	3.57 ± 0.21	32.06 ± 1.01	46.70 ± 1.75	3.94 ± 0.45	82.40	0.68
	Gypsum	**10**	13.78 ± 0.77	4.47 ± 0.07	31.05 ± 1.59	46.43 ± 0.50	4.79 ± 0.24	82.75	0.67
		20	13.98 ± 0.88	3.77 ± 0.35	31.26 ± 1.42	46.55 ± 1.21	4.43 ± 0.31	82.24	0.66
		30	14.54 ± 0.98	3.63 ± 0.18	30.29 ± 1.10	46.88 ± 0.26	4.66 ± 0.02	81.83	0.64
	SSP	**10**	14.04 ± 1.29	3.10 ± 0.44	32.27 ± 1.02	45.79 ± 0.06	4.78 ± 0.11	82.85	0.70
		20	13.12 ± 0.50	3.75 ± 0.36	30.96 ± 1.20	47.51 ± 0.99	4.65 ± 0.66	83.12	0.72
		30	13.02 ± 0.60	4.07 ± 0.21	32.13 ± 1.23	46.29 ± 1.18	4.48 ± 0.33	82.91	0.69
	Overall Mean		13.74	3.76	31.43	46.59	4.53	82.58	0.68
	Critical difference (P<0.05)		NS	0.51	1.05	0.77	0.38		
2012	**Control**		13.17 ± 0.62	3.63 ± 0.10	27.05 ± 1.18	51.33 ± 1.55	4.81 ± 0.31	83.19	0.52
	Gypsum	**10**	12.92 ± 0.06	4.34 ± 0.08	28.39 ± 1.81	49.56 ± 1.14	4.78 ± 0.97	83.14	0.57
		20	13.60 ± 0.64	4.08 ± 0.36	29.59 ±0.41	47.38 ± 0.65	5.33 ± 0.40	82.31	0.62
		30	13.90 ± 0.13	3.52 ± 0.02	28.38 ± 1.59	49.88 ± 1.38	4.30 ± 0.58	82.56	0.56
	SSP	**10**	14.33 ± 0.79	3.07 ± 0.41	29.17 ± 0.57	48.81 ± 0.86	4.61 ± 0.08	82.59	0.59
		20	13.31 ± 0.16	3.58 ± 0.24	28.95 ± 0.28	49.22 ± 0.69	4.93 ± 0.59	83.10	0.58
		30	13.89 ± 0.27	3.99 ± 0.60	28.04 ± 1.35	48.85 ± 1.66	5.21 ± 0.72	82.11	0.57
	Overall Mean		13.58	3.74	28.51	49.29	4.85	82.71	0.57
	Critical difference (P<0.05)		NS	0.34	1.23	1.75	NS		

In the earlier studies reported in literature, changes in fatty acid profile of soybean seeds with sulphur fertilization has been reported when applied in higher doses i.e. more than 80 kg S ha^{-1}. Response of oleic acid to sulphur supply during both the cropping seasons was found to be inconsistent, and is supported by the findings of Ahmed and Abdin (2000), who reported non-significant differences among sulphur levels for oleic acid content in rapessed. Differences in the composition of fatty acid in seed oil can be due to environmental conditions also (Boschin *et al.,* 2007). Fatty acid composition of soybean oil changes considerably with maturity along with seed oil deposition (Graef *et al.,* 1985, Ishikawa *et al* 2001). Triacylglycerols, palmitic acid, linolenic acid tend to decrease with maturity whereas linoleic acid increases. Oleic acid tends to increase to a maximum and then decline slightly. Linolenic acid was significantly affected by sulphur supplementation during first cropping season as compared to the second season. Interaction of sulphur with climatic conditions at the time of seed development might have influenced the fatty acid composition and shown variations in their relative proportions due to certain environmental factors and nutrient availability. Cazzato *et al* (2012) reported increase in monounsaturated and polyunsaturated fatty acids in lupin seeds with 30 kg S ha^{-1} and the improvement in lupin seed composition through the increase in oleic and linolenic acids whereas Howell and Collins (1957) observed very little effect of nitrogen, phosphorus and sulphur on fatty acid profile of soybeans. Correlation studies revealed significant inverse relationship between oleic acid and linoleic acid of r = -0.880 (2011) and r = -0.639 (2012) at $p<0.05$. Increase of oleic acid coincided with the decrease of linoleic acid during both the cropping seasons. This might be due to the effect of sulphur nutrition on ω-6-destaurase activity which converts oleic to linoleic acid. This supported the hypothesis of sequential desaturation of formation of unsaturated fatty acids in soybean oil. Inverse relationship of oleic and linoleic has also been reported by Flagella *et al* (2002) in safflower.

IV. CONCLUSION

Sulphur application affected crop yield through the effect on sulphur use efficiency, uptake efficiency and utilization efficiency. Sulphur fertilization affected nitrogen assimilation as indicated by decreased N:S ratio. This ratio depicts the quality of legumes as decrease in this ratio suggested more uptake of sulphur. Increased sulphur uptake had increased nitrogen utilization. Nutrients gets partitioned according to their mobile ability. Optimum metal homeostasis is achieved by the plant through precise regulation of transport, distribution and remobilization of elements, which is controlled by source and sink signals. Variations in micronutrient concentration by sulphur application might be due to changes in any of the processes involved in the nutrient partitioning. Fatty acid composition of soybean oil changes considerably with maturity along with seed oil deposition. Interaction of sulphur with climatic conditions at the time of seed development might have influenced the fatty acid composition and shown variations in their relative proportions due to certain environmental factors and nutrient availability. Increase of oleic acid coincided with the decrease of linoleic acid during both the cropping seasons. This might be due to the effect of sulphur nutrition on ω-6-destaurase activity which converts oleic to linoleic acid. This supported the hypothesis of sequential desturation of formation of unsaturated fatty acids in soybean oil.

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