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Interaction effect of nitrogen and sulphur on yield, oil and nutrient content of mustard (*Brassica juncea* L.) in an inceptisol

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Abstract
The pot experiment was conducted during *Rabi* season of the year 2016-17 followed by laboratory analysis of soil and plant samples in the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (UP), India. To accomplish the objective four different levels of nitrogen (0, 50, 100, 150 kg ha^{-1}) and three different levels of sulphur (0, 25, 50 kg ha^{-1}) fertilization experiment was laid out in factorial complete randomized design with three replication. Observations concerning growth and yield parameters of mustard recorded using standard methods. The results divulge that highest seed (18.89 q ha^{-1}) and stover yield (60.25 q ha^{-1}) obtained with treatment T_8 (100 kg N ha-1 and 25 kg S ha-1). Oil content of seeds increases with increasing levels S and N but maximum oil content is procured with treatment T_8 (37.62%) when both nutrient interacted synergistically with each other. Nutrient content of both seed and stover also increased from control with all the increasing levels of applied nutrients.

Keywords: Interaction, nitrogen, sulphur, oil content, nutrient content

Introduction
Rapidly increasing population and changes in dietary habits are increasing pressure on agriculture. India's expenditure is in billions of dollars for importing food commodities, out of which edible oil is the single largest food item. India secured 3rd position in production of rapeseed mustard after China and Canada contributing 14.8% of total global production. The contribution of rapeseed-mustard to the total oilseed production in India is 26.0%. Our production of edible oils meets near about 50% of the total requirements, while rest is imported. This Huge gap between the consumption and domestic production of edible oils can be filled either by increasing the area under oilseed crops or increasing production per unit area. Productivity and quality of oilseed crops can be possibly improved by adopting better agronomic practices, improving nutrient use efficiency, applying balance dose of nutrients and replacing conventional rapeseed and mustard varieties, which has the potential to fit in the current cropping systems due to its premium quality oil. Imbalanced and injudicious use of fertilizers also limits the crop production. In general, mustard seed contain 35-45% oil and 22-24% protein. Oil quality is determined by fatty acid profile. Mustard oil has 1-3% palmatic, 12-16% oleic, 14-16% linolaic, and 40-50% erucic acid. Plant protein requires nitrogen and sulphur as the integrated Components, mostly in sulphur containing amino acids, cysteine and methionine. Methionine is an essential amino acid and serves as methyl (CH3) donor in many trans methylation reaction of metabolic significance. In mustard methionine is precursor of glucosinolates. Thus, sulphur is not only required for protein and sulpholipid synthesis, but also required for formation of glucosinolates and because of this requirement the need of sulphur for Brassica crops is much higher. Thus a proper balance in the N: S ratio in these crops is essential for production and quality of crops. Sulphur (S) and nitrogen (N) are closely related, synergistic and of vital importance for plants because S is part of a major constituent of amino acids, which in turn constitute the building blocks of proteins. A strong interaction between sulphur and nitrogen for seed and oil production in oilseed crops has been reported by Abdin *et al. (*2003) [1], Jamal *et al.* (2006) [14], Farahbakhsh *et al. (*2006) [8], Malhi *et al.* (2007) [15], Fazil *et al*. (2010b) [9]. It is, therefore, likely that the interaction between S and N metabolism is stronger in oilseed crops.

Keeping this in view the present studies were carried out to determine the interactive effects of S and N on the growth, yield and oil quality of Indian mustard crop.

Materials and methods

A pot experiment was conducted on sandy loam soil of the Agricultural Research Farm, using mustard (var. Varsha) as a test crop during the year 2016-17 in the net house of department of soil science and agricultural chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, during *Rabi* season. The twelve treatments consisting of four levels of N (0, 50, 100 and 150 N kg ha^{-1}) and three levels of S (0, 25 and 50 kg S ha^{-1}) were laid in Factorial complete randomized design (FCRD) with three replications. Nitrogen and sulphur were applied through urea and gypsum ($CaSO_4.H_2O$), respectively. The full amount of N and S is applied as basal dose along with recommended dose of P_2O_5 (50 kg $ha^{-}1$) and K_2O (50 kg $ha^{-}1$) Through Di ammonium phosphate and Muriate of potash, uniformly to all the pots. The soils of experimental fields was slightly alkaline in reaction (pH 8.31), low in organic carbon (0.37%), CEC (6.63 mol $(p^+)kg^{-1}$) and medium in available P (10.53 kg ha^{-1}) and available S (14.25 kg ha^{-1}), respectively. Seeds of mustard were sown in the third week of November. At harvest, grain and straw yield were recorded on an air dry basis. Plant samples were collected at harvesting stage. The samples were washed well in distilled water, dried in the air and then in an oven at 60^0C to constant weight. Straw samples were ground to pass a 1 mm sieve, whereas the ground seeds were taken for chemical analysis (Jackson, 1973) [13]. The samples were digested in a mixture of HNO_3:$HClO_4$ (3:1). After proper dilution of the digested material analysis was carried out for P, K and S by suitable colorimetric, flame photometric methods (Jackson, 1973) [13]. For N determination, plant material was digested separately and analysed by Kjeltec Auto 1030 Analyser. Protein content was computed by multiplying the nitrogen content with factor 6.25. Soil samples were collected from each pot for chemical analysis after harvesting the crop. Soil texture was determined by international pipette method, and pH in soil samples were measured with Beckman glass electrode in (1:2) soil: water suspension. Electrical conductivity in (1:2) soil: water suspension was determined in saturation extracts with digital EC meter (Richards, 1954) [18]. The soil samples were analysed for organic carbon by the method of Walkley and Black (1934) [20], available nitrogen determined by alkaline permanganate method (Subbiah and Asija, 1956) [19], available phosphorus by extraction 0.5M $NaHCO_3$ solution buffered at pH 8.5 and determined by spectrophotometer at wavelength 780 nm using blue color method of Olsen's *et al*., (1954) [17], available potassium by extraction with 1N ammonium acetate at pH 7.0 (Jackson, 1973) [13] and available S by turbidimetric method (Chesnin and Yien, 1950) [5].

Results and discussion

Plant height

As the data presented in table 1, plant height increases as the level of application of N increases. Application of 150 kg N ha^{-1} increases the plant height at 30 and 60 days after sowing of mustard. Application of N and S together till (150 kg N ha^{-1} with 50 kg S ha^{-1}) resulted in maximum increase in plant height. This result may be due to the positive interaction effect of nitrogen and sulphur on the development of stem and leaf, this is reflected into taller plants according to Chngo and Mcvetty (2001) [6]. Plant height at 30 and 60 days after sowing in mustard ranged from 24.73 to 37.23cm, 98.10 to 128.83 cm respectively.

Table 1: Interaction effect of N X S on plant height of mustard

N levels (N kg ha^{-1})	S levels (kg ha^{-1})							
	0	25	50	Mean	0	25	50	Mean
	30 days after sowing(cm)				60 days after sowing(cm)			
0	24.73	26.03	32.36	27.70	98.10	100.26	103.03	100.46
50	30.86	31.70	33.83	32.13	104.20	114.66	109.06	109.30
100	35.80	35.86	31.66	34.44	118.23	127.36	127.46	124.35
150	33.33	36.00	37.23	35.52	124.43	121.30	128.83	124.85
Mean	31.18	32.39	33.77		111.24	115.89	117.09	
CD(P=0.05)	N=2.34	S=2.03	NxS=4.06		N=4.44	S=3.84	NxS=7.69	

Number of siliqua $plant^{-1}$

Increasing level of N and S shows significant effect on number of siliqua $plant^{-1}$, as result shown in Table 2, Application of N and S together (100 kg N ha^{-1} with 25 kg S ha^{-1}) resulted in maximum number of siliqua $plant^{-1}$, that is114.66 and 213.33 at 60 and 90 days after sowing. These results are confirmed by Hopkinson *et al*., (2002) [11] and fazli *et al*., (2010 b). This response of added N and S increase in number of siliqua $plant^{-1}$, of mustard might be due to the role of nitrogen and sulphur in activating the growth and yield components.

Table 2: Interaction effect of N X S on number of Siliqua $plant^{-1}$ of mustard

N levels (N kg ha^{-1})	S levels (kg ha^{-1})							
	0	25	50	Mean	0	25	50	Mean
	60 days after sowing				90 days after sowing			
0	84.00	86.66	94.66	88.44	120.66	126.33	134.33	127.11
50	87.66	98.33	103.33	96.44	128.66	146.00	156.33	143.66
100	94.00	114.66	112.00	106.88	150.66	213.33	197.33	187.11
150	108.00	103.66	99.33	103.66	160.00	146.66	126.33	144.33
Mean	93.41	100.83	102.33		139.99	158.08	153.58	
CD(P=0.05)	N=3.61	S=3.13	NxS=6.26		N=15.02	S=13.0	NxS=26.01	

Grain and straw yield

Interaction effect of N and S found synergistic for both grain and straw yield, maximum synergistic effect was found with 100 kg N ha^{-1} and 25kg S ha^{-1} followed by 100 kg N ha^{-1} and 50 kg S ha^{-1}. The magnitude of increase in grain and straw yield was 99.26% and 28.93% due to combined application of N and S (100 kg N ha^{-1} and 25kg S ha^{-1}) over control, respectively. Increased grain and straw yield may be due to balanced doses of S and N which promote growth and development by producing optimum number, size and length of siliqua per plant and because of the availability of more photoassimilates. This represents an increased physiological capacity to mobilize photosynthesis and translocate them to organs of economic value (Malhi *et al*., 2007) [15]. The improvement in growth and yield attributes after combined application of N and S led to higher seed and biological yield. Yield components are positively correlated with seed yield (Farahbakhsh *et al*., 2006) [8]. A strong interaction of S and N for seed yield was found in rapeseed and mustard (Ahmad and Abdin 2000) [2]. Aulakh *et al.,* (1977) [3] reported the maximum grain yield in mustard was obtained with 30 kg S ha^{-1} supplied as gypsum along with 120 kg N ha^{-1} as urea.

Oil content and Oil yield

As indicated by table 4, Oil content not respond positively with increasing levels of N, but it increased with increase in sulphur level from 0 to 25 kg ha-1, but further increase in S level did not enhance the oil content. The N and S interaction values indicated that oil content is found higher when N and S applied in combination at the rate of 100 kg N ha^{-1} and 25kg S ha^{-1}.combined application of S and N enhances the oil content of the seeds of *Brassica* genotypes (McGrath and Zhao, 1996) [16]. The results are in agreement with those documented by Jackson (2000) [12] who reported that decreasing trends in oil content with increasing nitrogen rate is probably due to N delaying plant maturity. Decrease in oil content with increase in N may be due to the fact that N is the major constituent of the protein so it might be increased the percentage of protein there might be a decrease in percentage of oil content as it has inverse relationship with protein (Cheema *et al*., 2001) [4].

Nitrogen, Phosphorus, Potassium and Sulphur content

Data presented in Table 5 indicates that the combined application of 100 kg N ha^{-1} and 25 kg S ha^{-1} significantly increases the N, P, K and S content in mustard which ranges from 2.71to 3.54%, 0.48 to 0.72%, 0.85 to 0.88% and 0.16 to 0.29% in seed and 0.55 to 0.78%, 0.19 to 0.30%, 0.94 to 1.20% and 0.20 to 0.89% in stover respectively. A number of studies (Dev *et al.*, 1979, Fazli *et al.*, 2008) [7, 10] indicated synergistic effect of combined application of S and N on the content of these nutrients by maize, rapeseed reported that S and N fertilization increased the percent total nutrient content in corn grains.

Table 3: Interaction effect of N X S on seed and Stover yield of mustard

N levels (N kg ha^{-1})	S levels (kg ha^{-1})							
	0	25	50	Mean	0	25	50	Mean
	Seed Yield (q ha^{-1})				Stover Yield (q ha^{-1})			
0	9.48	10.78	12.56	10.94	46.73	48.13	50.50	48.45
50	9.86	12.96	13.20	12.00	52.27	54.34	55.74	54.11
100	11.51	18.89	17.07	15.82	51.72	60.25	58.20	56.72
150	15.10	14.94	14.33	14.79	57.60	56.05	55.00	56.21
Mean	11.48	14.39	14.29		52.08	54.69	54.86	
CD(P=0.05)	N=1.64	S=1.42	NxS=0.03		N=6.53	S=5.66	NxS=11.32	

Table 4: Interaction effect of N X S on oil content (%) and oil yield (kg ha-1) of mustard

N levels (N kg ha^{-1})	S levels (kg ha^{-1})							
	0	25	50	Mean	0	25	50	Mean
	Oil content (%)				Oil yield (kg ha^{-1})			
0	31.33	36.47	37.25	35.01	296.98	393.35	471.26	387.20
50	35.69	37.27	35.61	36.19	351.22	483.24	470.46	434.97
100	37.55	37.62	37.20	37.45	431.47	703.12	626.94	587.17
150	36.63	36.33	35.14	36.03	478.48	662.95	656.15	599.19
Mean	35.30	36.92	36.30		389.53	560.66	556.20	
CD(P=0.05)	N=2.03	S=1.76	NxS=3.52		N=59.16	S=51.23	NxS=102.47	

Table 5: Interaction effect of N X S on N, P, K and S content (%) in seed and stover of mustard

N levels (N kg ha^{-1})	Seed				Stover			
	S levels (kg ha^{-1})							
	0	25	50	Mean	0	25	50	Mean
N content (%)								
0	2.71	2.84	2.94	2.83	0.55	0.58	0.62	0.58
50	3.12	3.25	3.29	3.22	0.58	0.61	0.50	0.56
100	3.06	3.54	3.52	3.37	0.66	0.78	0.75	0.73
150	3.42	3.21	3.20	3.27	0.70	0.69	0.62	0.67
Mean	3.07	3.21	3.23		0.62	0.66	0.62	
CD(P=0.05)	N=0.10	S=0.08	NxS=0.17		N=0.17	S=NS	NxS=NS	
P content (%)								
0	0.48	0.53	0.57	0.52	0.19	0.21	0.23	0.21
50	0.65	0.67	0.69	0.67	0.25	0.26	0.26	0.25
100	0.63	0.72	0.70	0.68	0.24	0.30	0.28	0.27
150	0.70	0.68	0.65	0.67	0.27	0.26	0.24	0.25

Mean	0.61	0.65	0.65		0.23	0.25	0.25	
CD(P=0.05)	N=0.03	S=0.03	NxS=0.06		N=0.03	S=0.02	NxS=NS	
K content (%)								
0	0.85	0.89	0.84	0.86	0.94	0.98	1.05	0.99
50	0.85	0.86	0.81	0.84	1.12	1.16	1.18	1.15
100	0.86	0.88	0.89	0.87	1.11	1.20	1.19	1.16
150	0.75	0.86	0.85	0.82	1.02	1.19	1.17	1.12
Mean	0.83	0.87	0.85		1.04	1.13	1.15	
CD(P=0.05)	N=0.06	S=NS	NxS=NS		N=0.03	S=0.02	NxS=0.05	
S content (%)								
0	0.16	0.21	0.23	0.20	0.20	0.31	0.39	0.30
50	0.26	0.26	0.27	0.26	0.57	0.68	0.70	0.65
100	0.24	0.29	0.28	0.27	0.48	0.89	0.85	0.74
150	0.21	0.27	0.26	0.24	0.35	0.53	0.48	0.45
Mean	0.21	0.25	0.26		0.40	0.60	0.60	
CD(P=0.05)	N=0.03	S=0.02	NxS=0.05		N=0.09	S=0.08	NxS=0.16	

Conclusions
N and S interactions are directly related to the alteration of physiological and biochemical responses of crops, and thus required to be studied in depth. This would help to understand nutritional behavior of sulphur in relation to nitrogen nutrients and provide guidelines for inventing balanced fertilizer recommendations in order to optimize yield and quality of crops. It is concluded from the present investigation as regarded the levels of Nitrogen and Sulphur 100 kg N ha^{-1} + 25 kg S ha^{-1} produced maximum economic yield attributes i.e. seed yield, stover yield, oil content, test weight and yield maximizing characters the growth, nutrient content and uptake of the produce in the area under study. Based on the discussion we can say that 100 kg N ha^{-1} + 25 kg S ha^{-1} performs best over other higher doses, so we can recommend this dose for the mustard growing farmers of eastern Uttar Pradesh.

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