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Integrated nutrient management of rapeseed (*Brassica campestris* L. var. *yellow sarson*) grown in a typic haplaquept soil

Sayan Majumder[1*], Tapas Kumar Halder[2] and Dipankar Saha[1]

[1]Department of Agricultural Chemistry and Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur - 741252, District-Nadia (West Bengal), INDIA
[2]Assistant Director of Agriculture (Research), State Soil Testing Laboratory, Tollygaunge, Kolkata-700040 (West Bengal), INDIA
*Corresponding author. E-mail: 1991sayan@gmail.com

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Abstract: The present investigation was conducted to study the influence of integrated nutrient management on fertility build up in a Typic Haplaquept soil as well as its effect on yield and quality parameters of rapeseed (*Brassica campestris* L. var. *yellow sarson*). Treatments comprised of recommended doses of N, P and K fertilizers (RDF) in presence and absence of FYM along with different doses of S and Zn either alone or in combination. Results revealed that in general, available N, P, K, S and Zn in soil decreased with increase in the period of crop growth. Addition of FYM increased organic carbon content in soils (upto 104.98 g kg^{-1}increase over initial value). Application of elemental S and Zn-EDTA increased SO_4^{-2} content (upto 101.03 kg ha^{-1} increase over initial value) in S-treated and DTPA extractable Zn content (upto 0.3 mg kg $^{-1}$ increase over initial value) in Zn-treated systems respectively. Combined application of higher doses of S and Zn along with FYM and recommended doses of N, P and K fertilizers increased N, P, K, S and Zn uptake by rapeseed crop. Highest seed yield (14.2 q ha^{-1}) as well as oil (43.2 %) and protein contents (21.82 %) were recorded in rapeseed which received comparatively higher doses of S and Zn along with FYM and RDF.

Keywords: FYM, INM, Oil and protein content, RDF, Sulphur and zinc

INTRODUCTION

Integrated nutrient management (INM) aims at maintenance of plant nutrient supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients in an integrated manner, appropriate to cropping system and farming situation (Mahajan and Sharma, 2005; Rao and Reddy, 2005). Crop productivity is increased due to combined application of chemical fertilizer and organic manures. Such combination contributed to the improvement of physical, chemical and biological properties of soil (Esilaba *et al*., 2004).

Rapeseed-mustard occupies the second position in oilseeds next to the groundnut. Among the Brassica family, Indian rapeseed (*Brassica campestris*L. *var. yellow sarson*) is the 2nd most important oil-yielding crop after Indian mustard [*Brassica juncea* (L.) Czern. and Coss.] followed by toria (*Brassica campestris var. toria*). Mustard and *sarson* group of plants are cultivated in 26 states in the northern and eastern plains of the country, occupying 7.22 mha areas with 7.96 million tones of production at 11.02 q ha^{-1} productivity (Rai *et al*., 2016). India holds a premier position in rapeseed-mustard economy of the world with 3rd rank in both area and production (Rai *et al*., 2016).

The productivity of Indian rapeseed is quite low due to sub-optimal application of fertilizers and cultivation on marginal lands under rainfed conditions. Intensive cultivation and use of unbalanced and inadequate fertilizers accompanied by restricted use of organic manures have made the soils not only deficient in the nutrients, but also deteriorated the soil health. All these things resulted in poor crop yield of rapeseed in terms of quantity and quality. In order to supply all the nutrients in adequate amount and to maintain its good health, it is necessary to use organic sources like FYM in combination with fertilizers. They not only supply macronutrients but also meet the demand of micronutrients, besides improving soil health (Arbad and Ismail, 2011).

It was reported that long term combined application of zinc, sulfur and along with FYM significantly increased crop yield, uptake and availability of micronutrients in soil over chemical fertilizer alone (Ameta *et al*., 2014). Researchers (Gupta *et al*., 2014) also reported that integrated nutrient management increased the economic yield of mustard-based cropping system by 35 % than that without FYM treatment.

The present experiment was, therefore, conducted to study the influence of integrated nutrient management (especially FYM, S and Zn) on soil fertility build up as

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well as yield and quality improvement of rapeseed.

MATERIALS AND METHODS

The investigation was conducted with rapeseed (B9 / Binoy variety) in a farmer's field situated at Kalibazar, Chakdah block, Nadia, West Bengal, India (23.08° N, 88.53° E, 11 m above MSL) during November, 2013 to February, 2014. In the present investigation, both organic (FYM) and inorganic fertilizers (N, P, and K) were applied including sulphur and zinc as treatment combinations. Initial composite soil sample (0-15cm) of the field was collected and analyzed for different physical, chemical and physico-chemical properties using standard methodologies. The characteristics of the initial soil samples were: pH 6.4, EC 0.160 dSm^{-1}, Org. C 0.88 %, Clay 65.2 %, Textural class clay loam, CEC 25.3 c mol (p+) kg^{-1}, Available N 147.63 kg ha^{-1}, Available P_2O_5 70.5 kg ha^{-1}, Available K_2O 245.21 kg ha^{-1}, Available SO_4^{-2} 23.75 kg ha^{-1}, DTPA-extractable Zn O.45 mg kg^{-1}, Soil Taxonomy Typic Haplaquept.

Altogether 10 treatments were employed in the present investigation, each with 3 replications. The treatments were: T_0 = Control, $T_1 = T_0$+FYM, $T_2 = T_0$+FYM + Zn_1, $T_3 = T_0$ FYM + Zn_2, $T_4 = T_0$+ FYM + S_1, $T_5 = T_0$ + FYM + S_2,$T_6 =$ T_0+ FYM + Zn_1 + S_1, $T_7 = T_0$+ FYM + Zn_1 + S_2, $T_8 = T_0$+ FYM + Zn_2 + S_1, $T_9 = T_0$+ FYM + Zn_2 + S_2. All treatments received recommended doses of N, P_2O_5 and K_2O at 80:40:40 kg ha^{-1} through Urea, SSP and MOP respectively. Two doses of S as S_1 at 20 kg ha^{-1} and S_2 at 40 kg ha^{-1} as well as two doses of Zn as Zn_1 at 5 kg ha^{-1} and Zn_2 at 10 kg ha^{-1} were incorporated in the treatment combinations. Full dose of P_2O_5, K_2O, S, Zn and half of the total N were applied at the time of final land preparation and the remaining half of the N was applied at about 30 days after sowing and just after final weeding and thinning. The full dose of FYM at 5 t ha^{-1} was applied at the time of primary land preparation as per treatment combinations.

Soil samples were collected from each of 30 plots (15-30 cm) at flowering (30 DAS), pod formation (60 DAS) and harvesting stage (90 DAS) of the rapeseed. The samples were air dried for removal of moisture and analyzed for oxidizable organic carbon, available N, available P_2O_5, available K_2O, available SO_4^{-2} and DTPA-extractable Zn following standard methods. After harvesting, the plant samples were oven dried and analyzed for total N (Piper, 1967 1942), total P (Jackson, 1973), total K by flame photometer, total S (Chesnin and Yien, 1951) and total Zn by Atomic Absorption Spectrophotometer. Seeds were analyzed for oil content with the help of Soxhlet's extraction method (Soxhlet, 1879) and protein content by Lowry's soluble protein determination method (Lowry *et al.*, 1951). Seed yield was recorded after harvest.

Data of soil, plant and grain samples were analyzed statistically at different growth stages of rapeseed crop using Microsoft Excel. Parameters like Critical Difference (CD) at 5 % level (for test of significance), SEM i.e. Standard Error Mean were calculated.

RESULTS AND DISCUSSION

Irrespective of treatments, in general, available N significantly increased from flowering to pod formation stage and thereafter decreased at harvesting stage of the rapeseed crop (Table 1). However, available N tended to decrease from flowering to harvesting stage in control plots. The increase in available N from flowering to pod formation is due to mineralization of FYM and accumulation of available N in soils. The results find support of earlier investigation carried out

Table 1. Changes in the amount ($kgha^{-1}$) of available N, P_2O_5 and K_2O in soils at different growth stages of rapeseed amended with different treatment combinations.

Treatments	Available N			Available P_2O_5			Available K_2O		
	Stages of crop growth			Stages of crop growth			Stages of crop growth		
	Flowering	Pod formation	Harvesting	Flowering	Pod formation	Harvesting	Flowering	Pod formation	Harvesting
T_0=Soil	191.76	165.40	139.49	78.11	61.54	51.21	261.53	286.17	253.72
T_1=Soil+ FYM	200.86	220.85	206.85	91.25	77.78	66.20	284.62	298.81	268.44
$T_2 = T_1+Zn_1$	212.08	221.87	208.69	102.21	88.65	76.65	292.72	302.05	275.30
$T_3= T_1+Zn_2$	217.93	254.98	234.44	106.74	91.18	83.95	308.18	326.77	275.49
$T_4= T_1+S_1$	212.05	258.83	223.29	112.21	105.12	89.84	316.32	320.49	279.63
$T_5= T_1+S_2$	227.14	236.00	191.73	120.97	112.74	97.74	327.08	337.10	282.96
$T_6 = T_2+S_1$	241.80	254.72	204.80	121.24	118.15	101.14	335.92	332.32	289.61
$T_7= T_2+ S_2$	236.93	265.11	221.10	123.15	120.89	105.21	345.69	340.05	295.58
$T_8= T_3+S_1$	251.63	272.62	233.39	126.45	119.65	111.14	359.18	343.93	297.84
$T_9= T_3+S_2$	262.37	296.71	248.46	130.78	121.34	113.78	371.88	348.21	299.38
Mean	225.46	244.71	211.23	111.31	101.70	89.69	320.31	323.59	281.80
SEM	4.67	3.02	2.73	2.26	1.87	1.96	4.85	3.84	3.12
CD (5 %)	13.88	8.98	8.12	6.71	5.56	5.823	14.42	11.40	9.27

Where, FYM = Farm Yard Manure at 5 t ha^{-1}, Zn_1 = Zn at 5 kg ha^{-1} as Zn-EDTA, Zn_2 = Zn at 10 kg ha^{-1} as Zn-EDTA, S_1 = S at 20 kg ha^{-1} as Elemental S, S_2 = S at 40 kg ha^{-1} as Elemental S"

Table 2. Changes in the amount of Oxidizable organic carbon (g kg^{-1}), available SO_4^{-2} (kg ha^{-1}) and DTPA-extractable Zn (mg kg^{-1}) in soils at different growth stages of rapeseed amended with different treatment combinations.

Treatments	Oxidizable organic carbon			Available SO_4^{-2}			DTPA-extractable Zn		
	Stages of plant growth			Stages of plant growth			Stages of plant growth		
	Flowering	Pod formation	Harvesting	Flowering	Pod formation	Harvesting	Flowering	Pod formation	Harvesting
T_0=Soil	6.42	6.23	6.87	27.35	20.66	22.63	0.50	0.52	0.36
T_1=Soil+ FYM	7.54	6.71	7.10	33.54	25.61	26.38	0.55	0.59	0.40
$T_2 = T_1+Zn_1$	7.41	7.82	7.89	35.28	30.55	26.41	0.66	0.69	0.45
$T_3= T_1+Zn_2$	8.17	7.55	8.65	37.02	30.47	28.77	0.70	0.74	0.48
$T_4= T_1+S_1$	8.61	6.76	8.83	42.20	36.32	32.26	0.73	0.74	0.56
$T_5= T_1+S_2$	8.63	7.19	8.86	45.39	40.02	33.92	0.78	0.79	0.59
$T_6 = T_2+S_1$	8.18	7.83	8.75	47.13	40.24	36.10	0.85	0.80	0.62
$T_7= T_2+ S_2$	7.68	6.67	7.87	48.57	42.91	38.34	0.88	0.82	0.69
$T_8= T_3+S_1$	8.50	8.28	9.74	49.12	43.52	39.32	0.93	0.87	0.73
$T_9= T_3+S_2$	8.71	8.62	9.80	50.07	42.96	40.12	0.94	0.89	0.75
Mean	7.99	7.37	8.33	41.57	35.32	32.43	0.75	0.75	0.56
SEm	0.02	0.03	0.04	1.99	1.55	1.15	0.01	0.01	0.01
CD (5 %)	0.07	0.08	0.11	5.82	4.60	3.43	0.03	0.04	0.03

Where, FYM = Farm Yard Manure at 5 t ha^{-1}, Zn_1 = Zn at 5 kg ha^{-1} as Zn-EDTA, Zn_2 = Zn at 10 kg ha^{-1} as Zn-EDTA, S_1 = S at 20 kg ha^{-1} as Elemental S, S_2 = S at 40 kg ha^{-1} as Elemental S

Table 3. N, P, K, S and Zn uptake by stover at harvest of rapeseed grown under different treatment combinations.

Treatments	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
	%	Uptake (kg ha^{-1})	%	Uptake (kg ha^{-1})	%	Uptake (kg ha^{-1})	%	Uptake (kg ha^{-1})	%	Uptake (kg ha^{-1})
T_0=Soil	0.31	8.86	0.10	2.86	0.41	11.74	0.15	4.29	0.0040	0.1143
T_1=Soil+ FYM	0.37	11.07	0.12	3.60	0.50	14.96	0.17	5.09	0.0042	0.1256
$T_2 = T_1+Zn_1$	0.42	12.94	0.13	4.02	0.58	17.85	0.19	5.85	0.0046	0.1438
$T_3= T_1+Zn_2$	0.50	16.26	0.13	4.24	0.61	19.84	0.19	6.06	0.0050	0.1627
$T_4= T_1+S_1$	0.53	18.54	0.14	4.94	0.66	23.04	0.23	8.07	0.0051	0.1783
$T_5= T_1+S_2$	0.59	21.15	0.14	5.03	0.75	26.91	0.25	9.00	0.0052	0.1803
$T_6 = T_2+S_1$	0.66	24.25	0.15	5.54	0.81	29.74	0.26	9.58	0.0053	0.1949
$T_7= T_2+ S_2$	0.69	25.94	0.18	6.78	0.87	32.78	0.29	10.90	0.0053	0.1993
$T_8= T_3+S_1$	0.73	28.33	0.18	7.00	0.89	34.53	0.29	11.27	0.0057	0.2212
$T_9= T_3+S_2$	0.78	30.95	0.19	7.57	0.96	38.10	0.31	12.31	0.0059	0.2343
Mean	0.56	19.83	0.15	5.16	0.70	24.95	0.23	8.24	0.0050	0.1757
SEm	0.01	0.38	0.01	0.32	0.01	0.36	0.01	0.29	0.0001	0.0035
CD (5 %)	0.03	1.12	0.02	0.96	0.03	1.08	0.02	0.88	0.0002	0.0103

Where, FYM = Farm Yard Manure at 5 t ha^{-1}, Zn_1 = Zn at 5 kg ha^{-1} as Zn-EDTA, Zn_2 = Zn at 10 kg ha^{-1} as Zn-EDTA, S_1 = S at 20 kg ha^{-1} as Elemental S, S_2 = S at 40 kg ha^{-1} as Elemental S"

by De *et al.* (2014) using combination of RDF along with various doses of vermicompost, poultry manure, FYM, neem cake as treatment combinations in rapeseed. Furthermore, roots are proliferated during these stages of crop growth. As the root rhizosphere is increased, the activities of microorganisms are supposed to be increased with the liberation of exudates which are rich in carbohydrates and other energy rich food materials (Arshad and Frankenberger, 1998). The activities of ammonifying and nitrifying microorganisms liberate nitrogen from organic source to available form by the process of N-mineralization (Alexander, 1977). Although, consumption of available N by the growing rapeseed crop is at peak at these stages but still considerable amount remained in the soil systems. Balanced nutrition and appropriate doses of fertilizers not only encourage production of more dry matter and accumulation of photosynthates (Shukla *et al.*, 2002) but also enhance the proliferation of microbial activities in soils as established by the earlier works of Mukherjee (2014) who used varying fertilizer doses (150 %, 100 %, 50 % and 25 % of RDF) in maize-yellow sarson cropping system. Comparatively higher amount of available N is utilized by the growing rapeseed crop from the soils which had received higher doses of S and Zn along with FYM. The present results are par with earlier work carried out by Baudh and Prasad (2012) integrating separate doses of organic manure, Zn and S fertilizers with RDF in mustard.

Irrespective of treatments, available P_2O_5 decreased significantly with increase in the period of crop growth (Table 1). The decrease in available P_2O_5 with time is due to its utilization by the growing rapeseed crop. Comparatively higher amount of available P_2O_5 is ac-

Table 4. N, P, K, S and Zn uptake by seeds of rapeseed grown under different treatment combinations.

Treatments	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
	N %	Uptake (kg ha^{-1})	P%	Uptake (kg ha^{-1})	K %	Uptake (kg ha^{-1})	S%	Uptake (kg ha^{-1})	Zn %	Uptake (kg ha^{-1})
T_0=Soil	1.62	15.59	0.12	1.16	1.22	11.74	0.45	4.44	0.0050	0.0385
T_1=Soil+ FYM	1.91	19.35	0.15	1.52	1.51	15.30	0.47	4.77	0.0051	0.0426
$T_2 = T_1+Zn_1$	2.02	21.36	0.16	1.68	1.95	20.28	0.50	5.29	0.0056	0.0487
$T_3= T_1+Zn_2$	2.15	23.92	0.16	1.80	2.13	23.69	0.51	5.69	0.0059	0.0558
$T_4= T_1+S_1$	2.35	28.90	0.18	2.22	2.30	28.28	0.57	7.01	0.0060	0.0628
$T_5= T_1+S_2$	2.47	31.24	0.19	2.42	2.45	30.98	0.60	7.60	0.0060	0.0659
$T_6 = T_2+S_1$	2.51	33.05	0.19	2.52	2.64	34.77	0.60	7.92	0.0061	0.0699
$T_7= T_2+ S_2$	2.59	34.65	0.21	2.82	2.79	37.32	0.62	8.31	0.0062	0.0710
$T_8= T_3+S_1$	2.65	36.66	0.22	3.05	2.84	39.30	0.63	8.73	0.0065	0.0790
$T_9= T_3+S_2$	2.69	38.21	0.23	3.27	2.89	41.04	0.66	9.38	0.0066	0.0838
Mean	2.30	28.29	0.18	2.25	2.27	28.27	0.56	6.91	0.0059	0.0618
SEm	0.01	0.48	0.01	0.12	0.01	0.45	0.01	0.16	0.0005	0.0014
CD (5 %)	0.02	1.43	0.02	0.35	0.02	1.35	0.02	0.48	0.0002	0.0040

Where, FYM = Farm Yard Manure at 5 t ha^{-1}, Zn_1 = Zn at 5 kg ha^{-1} as Zn-EDTA, Zn_2 = Zn at 10 kg ha^{-1} as Zn-EDTA, S_1 = S at 20 kg ha^{-1} as Elemental S, S_2 = S at 40 kg ha^{-1} as Elemental S

cumulated in soils at flowering stage of rapeseed is due to mineralization of organic P from the FYM treated systems. The results find support of earlier works carried out by Reddy *et al.* (1999). Combined application of S and Zn along with FYM significantly increased available P_2O_5 content in soils at flowering stage of rapeseed. Accumulation of higher amount of available P_2O_5 in soils treated with higher doses of S and Zn along with FYM is due to the creation of favourable microenvironment for P-solubilizing microorganisms which solubilizes organic P from FYM treated systems (Mafongoya *et al.*, 2000). The decrease in available P_2O_5 with the advancement of crop growth is not only due to its utilization by rapeseed (Urricariet *et al.*, 1995) but also due to conversion of some amount of available P_2O_5 into organic form and fixation by other soil components (Qiu *et al.*, 2004).

Available K_2O tended to increase in soils treated identically either with Zn or S along with FYM up to pod formation stage and thereafter showed a decreasing trend at harvesting stage of rapeseed (Table 1). However, combined application of Zn and S along with FYM showed a different trend of results. Irrespective of addition of different doses of S and Zn, available K_2O tended to decrease significantly throughout the cropping season of mustard. Balanced nutrition of crops encouraged both vegetative and root growth of rapeseed (De *et al.*, 2014) which in turn utilizes more amount of available K_2O from soils throughout the cropping season. The results of the present investigation are in conformity with earlier study carried out by Basak and Mitra (2002). A consistent decrease in available K_2O is observed in soils which received combined application of higher doses of S and Zn fertilizers along with FYM throughout the cropping period of rapeseed.

Results in Table 2 revealed that irrespective of treatments, oxidizable organic carbon decreased significantly from flowering to pod formation and thereafter increased up to harvesting stage of rapeseed. Organic carbon content tended to decrease significantly at pod formation stage because of its utilization by the growing rapeseed. The increase in organic carbon in soils at harvesting stage is due to accumulation of dead roots and rootlets of rapeseed crop (Gaudinski *et al.*, 2000) along with incorporation of dead cells of microorganisms. Comparatively higher amount of organic carbon is accumulated in soils treated combinedly with S and Zn fertilizers along with FYM. Balanced fertilization encourages both vegetative and root growth of rapeseed (Datta *et al.*, 2009) and as such more number of roots and rootlets are decayed which are converted to organic forms showing comparatively higher amount of accumulation of organic carbon in soils (Swarup and Yaduvanshi, 2000).

Irrespective of treatments, SO_4^{-2} tended to decrease significantly with increase in the period of crop growth (Table 2). Furthermore, addition of S-fertilizer increased SO_4^{-2} content of soils. Addition of lower and higher doses of S-fertilizer increased SO_4^{-2} content by 7.51 kg ha^{-1} and 10.17 kg ha^{-1} in absence of added Zn compared to control. However, addition of either doses of S-fertilizer further increased SO_4^{-2} content in soils in presence of either doses of Zn at the flowering stage of rapeseed. However, the increment is maximum in soils which received higher dose of S and Zn. The increase of SO_4^{-2} in soils treated with elemental S is obvious. Higher amount of accumulation of SO_4^{-2} in FYM treated system is due to the mineralization of organic S present in FYM (Wang *et al.*, 2006). The decrease in SO_4^{-2} with advancement of growth of rapeseed is due to its utilization by the growing crop. Higher amount of utilization of SO_4^{-2} by the rapeseed crop treated combinedly with higher doses of S and Zn along with FYM is due to supply of balanced and higher amount of available nutrients to plants resulting more height and

Table 5. Seed yield (q ha^{-1}), Protein (%) and Oil (%) content of rapeseed grown under different treatment combinations.

Treatments	Seed Yield	Quality parameters	
		Protein Content	Oil Content
T_0=Soil	9.62	17.20	35.31
T_1=Soil+ FYM	10.13	18.23	40.54
$T_2 = T_1+Zn_1$	10.58	18.79	40.30
$T_3= T_1+Zn_2$	11.12	19.15	40.92
$T_4= T_1+S_1$	12.29	19.22	41.16
$T_5= T_1+S_2$	12.64	19.89	41.57
$T_6 = T_2+S_1$	13.16	20.15	41.69
$T_7= T_2+ S_2$	13.37	20.76	42.66
$T_8= T_3+S_1$	13.83	21.43	42.35
$T_9= T_3+S_2$	14.2	21.82	43.20
Mean	12.09	19.66	40.97
SEm	0.19	0.01	0.01
CD (5%)	0.57	0.03	0.03

Where, FYM=Farm Yard Manureat 5tha^{-1},Zn_1=Znat 5 kgha^{-1} asZn-EDTA,Zn_2=Znat10kgha^{-1} as Zn-EDTA, S_1=Sat 20 kgha^{-1} as Elemental S, S_2=Sat 40kgha^{-1}as Elemental S

dry matter accumulation (Shukla *et al*., 2002; Singh and Pal, 2011).

DTPA-extractable Zn tended to increase slightly in soils which are amended either with Zn or with S fertilizer along with FYM from flowering to pod formation stage but decreased thereafter up to harvesting stage of rapeseed (Table 2). However, soils treated combinedly with Zn and S fertilizers along with FYM showed a decreasing trend of DTPA-extractable Zn in soils throughout the cropping period of rapeseed under these treatments. This is due to proper growth of crop in presence of inorganic and organic fertilizers (Aswal and Yadav, 2007).

N, P, K, S and Zn percentages and N, P, K, S and Zn uptake by stover and seeds of rapeseed differ significantly grown under different treatment combinations (Tables 3 and 4). Addition of FYM along with recommended doses of N, P and K in combination with either Zn or S or together not only increased dry matter production but also increased uptake of all the nutrients by crops. Treatments which received combined application of Zn and S along with FYM and recommended doses of N, P and K fertilizers showed higher values of N, P, K, S and Zn uptake by both stover and seed. Besides, combined application of Zn and S with FYM further improved uptake of nutrients mainly due to better growth and dry matter accumulation (Singh and Pal, 2011). The balanced nutrition also exerted the synergistic effect on uptake of other nutrients (Ahmad *et al*., 2007). As the uptake data is obtained by multiplying percentage data with that of dry matter yield, so where dry matter production is higher, uptake will be of higher order. Furthermore, balanced nutrition encourages more vegetative growth and in turn acquisition of higher amount of nutrients in plant. These results corroborate with previous findings of Tripathi *et al*. (2010) who incorporated RDF, S, $ZnSO_4$, Boron, Azotobacter and FYM as treatments in mustard and Singh and Pal (2011) who considered application of RDF, $ZnSO_4$, FYM and Azotobacteras treatments in the experiment with mustard.

Integrated application of recommended doses of fertilizers along with FYM, S and Zn significantly increased oil and protein content as well as seed yield compared to alone application of any of the chemical or organic fertilizer (Table 5). However, the highest protein and oil content as well as seed yield were recorded in rapeseed crop grown in soils treated with recommended doses of N, P and K along with FYM as well as higher doses of S and Zn fertilizers. The increase in oil content under FYM, S, and Zn treatment (T_9) might be due to the increased availability of S and Zn that are involved in increased conversion of primary fatty acid metabolites to the end products of fatty acid as supported by earlier works (Tripathi *et al*., 2010; Singh and Pal, 2011). Furthermore, higher levels of chemical fertilizer application improved N availability that helped in higher protein production and made potential deficiency of carbohydrates (Shukla *et al*., 2002). The increase in oil content with sulphur fertilization may be attributed due to its role in oil synthesis. Highest seed yield in rapeseed grown in soils treated combinedly with FYM and higher doses of S and Zn along with recommended doses of N, P and K fertilizers is due to formation of more number of branches under above treatment which may be correlated with more plant height and dry matter accumulation as a result of better nutrient supply to the test crop rapeseed.

Conclusion

Combined application of higher doses S (40 kg ha^{-1}) and Zn (10 kg ha^{-1}) along with recommended doses of N, P and K as well as FYM not only increased organic carbon by 42.65 % (over that of control) and available SO_4^{-2} by 77.29 % (over that of control) but also enhanced the yield by 47.61 % (over that of control) and quality (protein content by 26.86 % and oil content by 23.34 % over that of control) in yellow sarson.

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