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

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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 SO₄²⁻ 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
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 S 147.63 kg ha⁻¹, Available P₂O₅ 70.5 kg ha⁻¹, Available K₂O 245.21 kg ha⁻¹, Available SO₄²⁻ 2.75 kg ha⁻¹, DTPA-extractable Zn 0.45 mg kg⁻¹, Soil Taxonomy Typic Haplaquept.

Altogether 10 treatments were employed in the present investigation, each with 3 replications. The treatments were:  
- **T₀** = Control,  
- **T₁ = T₀+FYM**,  
- **T₂ = T₀+FYM + Zn₁**,  
- **T₃ = T₀+FYM + Zn₂**,  
- **T₄ = T₀+FYM + S₁**,  
- **T₅ = T₀+FYM + S₂**,  
- **T₆ = T₀+FYM + Zn₁ + S₁**,  
- **T₇ = T₀+FYM + Zn₂ + S₁**,  
- **T₈ = T₀+FYM + Zn₁ + S₂**,  
- **T₉ = T₀+FYM + Zn₂ + S₂**.

All treatments received recommended doses of N, P₂O₅ and K₂O at 80:40:40 kg ha⁻¹ through Urea, SSP and MOP respectively. Two doses of S as S₁ at 20 kg ha⁻¹ and S₂ at 40 kg ha⁻¹ as well as two doses of Zn as Zn₁ at 5 kg ha⁻¹ and Zn₂ at 10 kg ha⁻¹ were incorporated in the treatment combinations. Full dose of P₂O₅, K₂O, 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 analyzes for oxidizable organic carbon, available N, available P₂O₅, available K₂O, available SO₄²⁻ 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 (Chesn in 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 (kg ha⁻¹) of available N, P₂O₅ and K₂O in soils at different growth stages of rapeseed amended with different treatment combinations.

| Treatments         | Available N | Available P₂O₅ | Available K₂O |
|--------------------|-------------|---------------|---------------|
|                    | Flowering   | Pod formation | Harvesting    | Flowering   | Pod formation | Harvesting    |
| T₀=Soil            | 191.76      | 165.40        | 139.49        | 78.11       | 61.54         | 51.21         | 261.53       | 286.17       | 253.72       |
| T₁=T₀+FYM          | 200.86      | 220.85        | 206.85        | 91.25       | 77.78         | 66.20         | 284.62       | 298.81       | 268.44       |
| T₂=T₀+Zn₁          | 212.08      | 221.87        | 208.69        | 102.21      | 88.65         | 76.65         | 292.72       | 302.05       | 275.30       |
| T₃=T₀+Zn₂          | 217.93      | 254.98        | 234.44        | 106.74      | 91.18         | 83.95         | 308.18       | 326.77       | 275.49       |
| T₄=T₀+S₁           | 212.05      | 258.83        | 223.29        | 112.21      | 105.12        | 89.84         | 316.32       | 320.49       | 279.63       |
| T₅=T₀+S₂           | 227.14      | 236.00        | 191.73        | 120.97      | 112.74        | 97.74         | 327.08       | 337.10       | 282.96       |
| T₆=T₂=Zn₁          | 241.80      | 254.72        | 204.80        | 121.24      | 118.15        | 101.14        | 335.92       | 332.32       | 289.61       |
| T₇=T₂=Zn₂          | 236.93      | 265.11        | 221.10        | 123.15      | 120.89        | 105.21        | 345.69       | 340.05       | 295.58       |
| T₈=T₂+S₁           | 251.63      | 272.62        | 233.39        | 126.45      | 119.65        | 111.14        | 359.18       | 343.93       | 297.84       |
| T₉=T₂+S₂           | 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        | 2.17          | 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, Zn₁ = Zn at 5 kg ha⁻¹ as Zn-EDTA, Zn₂ = Zn at 10 kg ha⁻¹ as Zn-EDTA, S₁ = S at 20 kg ha⁻¹ as Elemental S, S₂ = S at 40 kg ha⁻¹ as Elemental S²
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$_2$+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$_3$+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$_4$+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$_5$+Zn$_1$ | 0.66 | 24.25 | 0.15 | 5.54 | 0.81 | 29.74 | 0.26 | 9.58 | 0.0053 | 0.1949 |
| T$_7$ = T$_6$+Zn$_2$ | 0.69 | 25.94 | 0.18 | 6.78 | 0.87 | 32.78 | 0.29 | 10.90 | 0.0053 | 0.1993 |
| T$_8$ = T$_7$+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$_8$+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 | 0.0010 |

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$_2$O$_5$ decreased significantly with increase in the period of crop growth (Table 1). The decrease in available P$_2$O$_5$ with time is due to its utilization by the growing rapeseed crop. Comparatively higher amount of available P$_2$O$_5$ is ac-
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 P2O5 content in soils at flowering stage of rapeseed. Accumulation of higher amount of available P2O5 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 P2O5 with the advancement of crop growth is not only due to its utilization by rapeseed (Urricaret et al., 1995) but also due to conversion of some amount of available P2O5 into organic form and fixation by other soil components (Qiu et al., 2004).

Available K2O 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 K2O 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 K2O 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 K2O 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 Yadavanshi, 2000).

Irrespective of treatments, SO42− tended to decrease significantly with increase in the period of crop growth (Table 2). Furthermore, addition of S-fertilizer increased SO42− content of soils. Addition of lower and higher doses of S-fertilizer increased SO42− 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 SO42− 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 SO42− in soils treated with elemental S is obvious. Higher amount of accumulation of SO42− in FYM treated system is due to the mineralization of organic S present in FYM (Wang et al., 2006). The decrease in SO42− with advancement of growth of rapeseed is due to its utilization by the growing crop. Higher amount of utilization of SO42− 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

| Treatments | 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) |
|------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| T0=Soil   | 1.62                 | 15.59                | 0.12                 | 1.16                 | 1.22                 | 11.74                | 0.45                 | 4.44                 | 0.0050               | 0.0385               |
| T1=Soil+ FYM | 1.91                | 19.35                | 0.15                 | 1.52                 | 1.51                 | 15.30                | 0.47                 | 4.77                 | 0.0051               | 0.0426               |
| T2= T1+Zn1 | 2.02                 | 21.36                | 0.16                 | 1.68                 | 1.95                 | 20.28                | 0.50                 | 5.29                 | 0.0056               | 0.0487               |
| T3= T1+S1  | 2.15                 | 23.92                | 0.16                 | 1.80                 | 2.13                 | 23.69                | 0.51                 | 5.69                 | 0.0059               | 0.0558               |
| T4= T1+S1  | 2.35                 | 28.90                | 0.18                 | 2.22                 | 2.30                 | 28.28                | 0.57                 | 7.01                 | 0.0060               | 0.0628               |
| T5= T1+S1  | 2.47                 | 31.24                | 0.19                 | 2.42                 | 2.45                 | 30.98                | 0.60                 | 7.60                 | 0.0060               | 0.0659               |
| T6= T2+S1  | 2.51                 | 33.05                | 0.19                 | 2.52                 | 2.64                 | 34.77                | 0.60                 | 7.92                 | 0.0061               | 0.0699               |
| T7= T2+S1  | 2.59                 | 34.65                | 0.21                 | 2.82                 | 2.79                 | 37.32                | 0.62                 | 8.31                 | 0.0062               | 0.0710               |
| T8= T3+S1  | 2.65                 | 36.66                | 0.22                 | 3.05                 | 2.84                 | 39.30                | 0.63                 | 8.73                 | 0.0065               | 0.0790               |
| T9= T3+S2  | 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               |
| SDn (5 %)  | 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, Zn1 = Zn at 5 kg ha−1 as Zn-EDTA, Zn2 = Zn at 10 kg ha−1 as Zn-EDTA, S1 = S at 20 kg ha−1 as Elemental S, S2 = S at 40 kg ha−1 as Elemental S.
Table 5. Seed yield (q ha⁻¹), Protein (%) and Oil (%) content of rapeseed grown under different treatment combinations.

| Treatments | Seed Yield | Quality parameters |
|------------|------------|--------------------|
| T₀=Soil   | 9.62       | 17.20              | 35.31 |
| T₁=Soil+ FYM | 10.13     | 18.23              | 40.54 |
| T₂= T₁+Zn₀ | 10.58     | 18.79              | 40.30 |
| T₃= T₁+Zn₁ | 11.12     | 19.15              | 40.92 |
| T₄= T₁+S₁  | 12.29     | 19.22              | 41.16 |
| T₅= T₁+S₂  | 12.64     | 19.89              | 41.57 |
| T₆= T₂+S₁  | 13.16     | 20.15              | 41.69 |
| T₇= T₂+S₂  | 13.37     | 20.76              | 42.66 |
| T₈= T₃+S₁  | 13.83     | 21.43              | 42.35 |
| T₉= T₃+S₂  | 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; Zn₀=Znat 5 kg ha⁻¹ asZn-EDTA, Zn₁=Zn₁0kg ha⁻¹ as Zn-EDTA, S₀=Sat 20 kg ha⁻¹ as Elemental S, S₁=Sat 40kg ha⁻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 absence 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, ZnSO₄, Boron, Azotobacter and FYM as treatments in mustard and Singh and Pal (2011) who considered application of RDF, ZnSO₄, 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 (T₃) 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 SO₄²⁻ 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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