INTEGRATED EFFECT OF PHOSPHORUS, SULPHUR AND ZINC ON THE PRODUCTIVITY OF CANOLA PLANTS GROWN ON A NEWLY RECLAIMED SANDY SOIL

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ABSTRACT:

A field experiment was conducted on a sandy soil at Ismailia Agric. Res. Station, during the winter season of 2009/2010 to study the effect of phosphorus at the rates of 0, 30 and 60 kg P_2O_5/fed, sulphur (0, 150 and 300 kg S/fed) and zinc (0, 10 and 20 kg $ZnSO_4.7H_2O$/fed) as well as their interactions on canola yield (Serw 4 cv.), its components (*i.e.,* plant height, number of branches plant^{-1}, dry matter weight of shoots plant^{-1} at early flowering stage, number of pods plant^{-1} and 1000 seeds weight) and seed quality parameters (*i.e*., seed oil and protein contents).

In general, the obtained results reveal that the application of phosphorus, sulphur and zinc as solely treatments at the different added rates display an effective role on increasing dry matter weight of shoots at early flowering stage, nutrient contents of plant tissues at 90 days after sowing, seed yield and its quality. However, applying such nutrient treatments (*i.e.*, P, S and Zn) showed significant increases for canola yield and its components, which their values were maximized with increasing the applied rates up to the highest ones for each nutrient, with superiority for applied P treatment as compared to either S or Zn as a solely one.

The application of the combined treatments, *i.e.,* (P x S), (P x Zn) and (S x Zn) exhibited more pronounced increases for canola seed yield and its components, with significantly differences as compared to such solely ones. These increases were maximized in case of the triple treatments of P in combination with S and Zn as compared to the applied combined couple ones. Also, increasing the applied rates of P, S and Zn significantly increased the contents of N, P and S in canola plant tissues at 90 days after sowing. Meanwhile, Zn content in the plant tissues tended to decrease with the applied P, the reverse was true for both applied S and Zn that resulted in a significantly increased for Zn-content of plant tissues. The triple combination of P, S and Zn showed a synergistic relationship between them as well as the triple combined treatment 60, 300 and 20 kg fed^{-1} for P, S and $ZnSO_4$, respectively, was the most appropriate one for canola nutrition.

Under the current experiment conditions, it could be concluded that the applied P, S and Zn as solely treatments showed a beneficial effect on canola seed quality parameters, where seed oil and protein contents exhibited significantly increases, and in turn in case of the combined treatments. Actually, the applied triple combined treatment of P_{60} S_{300} Zn_{20} was optimal for obtaining the highest values in canola seed quality parameters, *i*.e., greatest seed oil and protein contents.

Key words: Sandy soil, canola, phosphorus, sulphur, zinc, plant growth and seed quality parameters.

INTRODUCTION:

Mineral fertilization management practices are ones of the most important agro-management factors that affect the yield and its components of the different crops, especially those grown on the desert sandy soils **(Patel and**

Shelke, 1998). Canola is a specific type of oil seed rape associated with high quality oil and meal. The high nutritional values of oilseed rape meal are resulting from the high energy, protein content and favourable amino acid composition. Balance and effective fertilization management is critical to optimize crop yields and profitability, to ensure crop quality and to sustain soil productivity. The quantity of mineral nutrients required to optimize production depends on the yield potential of the crop, the methods or forms of applied fertilizers and the levels of available nutrients in the soil.

Canola has a relatively high nutrient requirement and most soils on which the crop is grown are deficient in one or more nutrients for optimum seed yield, oil and protein contents **(Grant and Bailey, 1993)**. Deficiencies of P are common and frequently limit canola yield. Therefore, proper P fertilization is important in optimizing canola production. Phosphorus deficiency in canola restricts both top and root growth. With mild deficiencies plant may appear normal but small. With more severe deficiency, the root system is poorly developed and stems are thin and erect with few branches and small, narrow leaves **(Bidwell, 1979)**.

Phosphorus is needed during the earliest stage of plant growth. Any P deficiency during early growth can great reduce yield potential of tops and seeds. Therefore, the amount of P in canola seeds can be important to help seedling establishment and in determining final seed yields **(Bolland, 1997)**. In studies by **Patel and Shelke (1998) and Cheema *et al.* (2001)**, found that yield and its components were generally increased with increasing applied phosphorus. Phosphorus fertilization has only a small influence on canola quality. High rates of applied P increased oil percentage and protein content.

Sulphur is the fourth major nutrient in crop production, however, most crops require as much sulphur as phosphorus. The N and S requirements of crops are closely related to optimize the yield of oil crops, because both nutrients are required for protein synthesis. Sulphur is especially critical in canola production and S deficiencies frequently restrict canola yield **(Grant and Bialey, 1993)**. Sulphur is taken up by plant primarily in the SO_4^{2-} form by a specific transport protein. It is a component of the amino acids cysteine and methioniene, essential amino acids for protein synthesis **(Bidwell, 1979)**. Sulphur, while not a constituent of chlorophyll, is needed in the formation of chlorophyll for the photosynthesis process and is also required in crucifera for the synthesis of the volatile oils which accumulate as glucosionlates **(Marchner, 1986)**.

The higher protein content of canola as compared with cereals, combined with canola's higher proportion of cysteine and methionine contribute to the larger sulphur requirement **(Zhao *et al.*, 1993; Nuttall *et al.*, 1987; Malhi and Gill, 2002 & 2006 and Malhi *t al.*, 2007)**. Production of oil seeds rape aims to produce seeds which are rich in oil and protein contents. The extracted rape seed meal is widely used as feed for farm animals and poultry **(Hanekaus *et al.*, 1999 and Zhao e*t al.*, 1999)**.

Adequate soil sulphur in the absence of other limiting factors dramatically increases vegetative growth and total dry matter production. The larger photosynthetically efficient leaf area increases pod numbers and seed yield with increased amounts of protein in the seeds **(Ceccotti, 1996)**. Application of sulphate-S to canola at seeding time gives the highest increase in yield and S uptake. Deficiencies of S in canola plants can be prevented and/or corrected and seed yield improved with the use of sulphate-S fertilizer in the growing seasons **(Das *et al.,* 2004 and Malhi, 2006)**. Therefore, adoption of any practice of a nutrient management particularly of zinc which either decreases or increases the apply of other nutrient elements like sulphur or translocation and mobility within the plant may influence the nutrition of sulphur, its use efficiency, crop yields and quality. However, it has been reported that zinc plays most important role in increasing yield and improving quality of crops especially oilseeds **(Sharma *et al.,* 1990)**.

Soil application of zinc was found to be more effective in correcting Zn deficiency for shoot dry matter production at 60 days after sowing **(Grewal *et al.,* 1997 and Grewal and Graham, 1997 and 1999)**. A significant increase in shoot dry matter and seed yield also oilseed rape wit Zn application has been observed under field condition **(Hu *et al.,* 1996 and Grewal *et al.,* 1997)**. Sulphur is an important macronutrient in the production of canola, in the absence of adequate S, canola yield response to added fertilizer eliminated.

As regards to interaction between Zn and S, it was observed that an initial increase in the total S content in soil due to Zn application might be owing to stimulating effect of Zn on S oxidizing microorganisms resulting greater release of SO_4-S in the soil as well as greater absorption of SO_4-S by plants. However, the results suggested a synergistic relationship between Zn and S in maintaining both the nutrient in soils with the stimultanous increase in stover, seed yield and quality of rape **(Das *et al.,* 2004)**. Also, the interaction between P and Zn had significantly beneficial effect on growth and yield of oilseed rape **(Dingiin *et al.,* 1996)**.

The P and Zn fertilizers increased shoot dry matter at rosette and green bud stages leading later to increase seed yield **(Pinkerton *et al.,* 1989)**. It was hypothesized that like other crops, an increment supply of P may accentuate Zn deficiency and depresses the early vegetative growth of oilseed rape. As a result, Zn deficiency has become an important limiting factor in sustainable production of crops **(Lu *et al.,* 1998)**.

In view of the above, the present investigation was undertaken to study the integrated effect of applied P, S and Zn as solely or combined treatment on seed yield and quality of canola plants.

MATERIALS AND METHODS:

A field experiment was conducted on a sandy soil cultivated with canola (Serw 4 cv.) at Ismailia Agric Res. Station, Egypt during the winter season of 2009/2010. Some physical and chemical characteristics of the experimental soil were determined according to **Jackson (1973)**, and the obtained data are presented in Table 1.

Table 1. Some physical, chemical and fertility characteristics of the studied soil.

Soil characteristics	Value	Soil characteristics.	Value
Particle size distribution %:		*Analytical analysis of soil paste extract:*	
Sand	87.71	EC (dS/m)	0.45
Silt	6.86	*Soluble ions (m molc L^{-1}):*	
Clay	5.43	Ca^{++}	1.20
Textural class	Sand	Mg^{++}	1.65
Some soil physio-chemical properties:		Na^{+}	1.42
Saturation percen	12.90	K^{+}	0.13
$CaCO_3$ %	0.29	CO_3^{--}	0.00
Organic matter %	0.33	HCO_3^{-}	2.35
pH (1:2.5 soil water suspension)	7.81	Cl^{-}	1.45
CEC (c molc kg^{-1} soil)	5.75	SO_4^{--}	0.60

Available contents of some macro and micronutrients (mg kg^{-1} soil)			
N	P	S	Zn
17.22	6.51	8.13	0.38

The trail was laid out in split-split plot designed with three replicates and combination levels of three phosphorus rates, *i.e.*, 0, 30 and 60 kg P_2O_5/fed in main plot; sulphur rates of 0, 150 and 300 kg S/fed in sub-plot, and zinc sulphate at the rates of 0, 10 and 20 kg $ZnSO_4.7H_2O$/fed in sub-sub-plot, where the number of treatments were twenty-seven combinations. The experimental unit area was 10.5 m^2 (1/400 fed) with dimensions of 3.0 x 3.5 m, each plot included 4 ridges (3.5 m length and 30 cm width).

Phosphorus fertilizer was applied as superphosphate (15.5 %P_2O_5) and thoroughly mixed with topsoil during the final stage of soil preparation, whereas the entire quantity of elemental sulphur was incorporated into the soil 21 days before sowing and followed by light irrigation in order to mix it thoroughly with the soil. All treatments received N at a rate of 60 kg N/fed as ammonium nitrate (33.5 % N) in two equal doses after thinning and at flowering stage. Potassium was also added as potassium sulphate (48 % K_2O) at a rate of 50 kg K_2SO_4/fed added in two equal splits, *i.e.*, before planting and 30 days from sowing.

At the start of flowering stage, the shoots of five plants were taken at random from each plot for determining growth parameters such as plant height (cm) and dry weight (g/plant). The plants were transferred immediately from the experimental area to laboratory and dried in an electrical air-draft at 70 ^{0}C for chemical determinations of N, P, K, S and Zn. Harvesting was carried out after about 170 days from planting. The plants were dried under sunshine for one week. There after, the pods threshed and seed were cleaned after separation from pods, and then seeds and straw yields were determined as ton/fed. Also, yield components, *i.e.*, number of pods/plant, number of branches/plant and 1000 seed weight in g were estimated.

Seed samples were dried, weighted and analyzed for oil and protein contents. Oil content of seed was determined by solvent extraction method in Soxhlets apparatus with N-hexane as solvent according to **A.O.C.S. (1990)**. Protein content in seeds was calculated through multiplying N content by 6.25. Sulphur was determined using Turbidimetric method according to **Tabatabi and Bremner (1970)**. All data of the two growing seasons were subjected to the statistical analysis according to the used design. The least significant difference test (LSD) at p = 0.05 level was used to verify the differences between treatments as mentioned by **Snedecor and Cochran (1980)**.

RESULTS AND DISCUSSION:

I. *Growth parameters, yield and its attributes of canola:*

Data presented in Table 2 reveal that the values of growth parameters increased with increasing the applied rates of P, S and Zn as compared to the control treatment. As for the solely treatments, the obtained data show that the beneficial effect of applied P-rates was greater than those of either S or Zn ones. Meanwhile, successive additions of P in combination with S and Zn increased the growth parameters of canola at 90 days after planting as well as the other yield attribute ones were more attributed with the well developed root-system, which resulted in higher pod yield.

Table 2. Effect of phosphorus, sulphur and zinc application on some plant growth parameters.

Treat-	S_0			S_{150}			S_{300}			Mean values		
meant	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}
Plant height (cm)												
P_0	141	143	144	146	149	153	159	161	165	150	156	111
P_{30}	155	158	159	162	165	170	172	175	179	116	165	165
P_{60}	163	169	173	176	181	186	189	194	199	181	175	169
Dry matter weight/plant (g)												
P_0	70.5	73.6	75.7	76.7	77.5	79.2	86.0	90.5	98.1	80.9	90.2	100.6
P_{30}	89.8	91.4	95.5	106.3	108.8	110.9	112.1	117.2	118.9	105.6	104.3	104.0
P_{60}	110.3	115.3	118.3	122.1	126.4	131.2	131.7	135.4	139.0	125.5	114.3	107.4

L.S.D. at 0.05							
Plant character	P	S	Zn	P x S	P x Zn	S x Zn	P x S x Zn
Plant height	1.0	0.7	2.2	3.4	3.4	2.8	5.3
Dry weight/plant	6.7	2.9	1.8	3.5	3.1	2.8	5.1

Application of P as a solely treatment significantly increased the plant height and total dry matter weight/plant of canola at 90 days after planting. These findings are in harmony with those reported by **Pinkerton *et al.* (1989) and Dingüin *et al.* (1996)** who reported that P fertilizer increased shoot dry matter at the rosette and green bud stages that are leading later to increased seed yield.

Data presented in Table 2 revealed that the application of elemental sulphur alone at the rates of 150 and 300 kg/fed significantly increased canola plant height by about 3.5 and 12.7 % over the control treatments, respectively. The corresponding relative increase percentages in dry matter weight of canola shoots at 90 days from sowing reached 8.8 and 22.0 %, respectively. The increase in dry matter weight of whole plant due to sulphur application can be explained as to enhance cell division and capacity of sulphur cell elongation or expansion. It is also interpreted to have favourable effect of chlorophyll synthesis resulting in more number of leaves with bigger size and higher chlorophyll content. Thus, sulphur helps in increasing the photosynthetic activity of plant **(Upasami and Sharma, 1986)**. Data presented in Table 2 also revealed that seed yield showed apparent correlation with dry matter production and yield components.

With regard to Zn fertilization, data in Table 2 also showed that Zn application up to 20 kg/fed significantly increased the plant height of canola at 90 days from sowing. This increase was more obvious with increasing the applied Zn rates as compared with the control. Likewise, the main affect showed that the applied Zn resulted in significant increases in shoot dry matter weight at 90 days from sowing. The relative increase percentage of dry matter weight reached about 7.4 % at the applied rate of Zn_{20} over the control treatment. That was occurred in the absence of other two tested fertilizers (*i.e.*, P and S). That was true, since the applied Zn played a vital role in activating many enzyme reactions, which in turn makes the plant produce more growth. These results are in harmony with those obtained by **Marschner (1986)**. **Lu-Zhong *et al.* (1998), Bell *et al.* (2004) and Grewal *et al.* (1997 and 1998)** mentioned that oilseed rape shoot and root dry matter productions were significantly influenced by Zn supply at early vegetative growth in sand culture.

Data also in Table 2 revealed that the combined treatment of (300 kg S/fed + 20 kg $ZnSO_4.7H_2O$/fed) recorded an increase in plant height and dry matter accumulation when compared with300 kg S/fed in the absence of P and Zn. Though there was an improvement for plant growth parameters with S application, which was more pronounced when S was combined with Zn. This might be due to greater availability of S and Zn to the crop. **Kasturikrishan and Ahlawat (1999)** also observed an increase in growth attributes such as plant height and dry matter accumulation with Zn.

The growth of canola plants at early flowering stage was significant due to the favourable effects of the applied P, S and Zn treatments. However, the plant height increased from 141 cm at the treatment of (P_0 S_0 Zn_0) to 173 cm at (P_{60} S_0 Zn_{20}). The highest plant height (199 cm) was recorded at the combined treatment of (P_{60} S_{300} Zn_{20}), as shown in Table 2.

The number of branches/plant, number of pods/plant and 1000 seed weight were substantially improved by the application of P, as shown in Table 3. The stimulatory effect of P on canola growth might lead to increase in all the yield attributes. These results are in accordance with the findings of Thakur and Chand (1998) who found that P fertilization increased seed and straw yields, which were favourable affected by applied P that might be due to the improvement of the growth parameters and yield attributes of canola plants**.** Also, yield attributes like number of branches/plant, number of pods/plant and 1000 seed weight were substantially improved due to the combined application of S and Zn.

Table 3. Effect of phosphorus, sulphur and zinc application on number of branches/plant, number of pods/plant and 1000 grain weight.

Treat-	S_0			S_{150}			S_{300}			Mean values		
meant	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}
Number of branches/plant												
P_0	6	6	7	8	8	9	10	11	12	9	8	10
P_{30}	8	8	9	10	10	11	12	13	14	10	10	10
P_{60}	10	10	11	11	12	13	14	15	16	14	13	11
Number of pods/plant												
P_0	143.1	148.5	150.3	155.2	164.9	170.5	177.4	180.3	184.6	163.9	159.8	169.9
P_{30}	151.3	155.9	161.4	165.8	172.4	177.3	180.5	191.7	196.7	172.5	175.3	176.6
P_{60}	170.2	175.8	181.5	186.9	190.1	194.5	199.2	210.3	220.9	192.1	193.5	182.0
1000 seed weight (g)												
P_0	1.40	1.43	1.44	1.46	1.49	1.53	1.54	1.57	1.61	1.50	1.73	1.82
P_{30}	1.55	1.58	1.59	1.62	1.65	1.79	2.02	2.11	2.39	1.81	1.92	1.94
P_{60}	2.06	2.19	2.33	2.46	2.59	2.66	2.75	2.89	2.90	2.53	2.19	2.02

L.S.D. at 0.05

Plant character	P	S	Zn	P x S	P x Zn	S x Zn	P x S x Zn
Branches No./plant	1.80	1.90	0.90	1.00	1.20	1.10	1.70
Pods No./plant	6.10	4.30	2.90	5.20	6.60	6.10	7.50
1000 seed weight	0.17	0.13	0.11	0.20	0.17	0.14	0.22

The 1000 seed weight was increased steadily by graded applied rates of P with Zn. There was concomitant increase in 1000 seed weight by application of S at a rate of 300 kg/fed with P and Zn, as shown in Table 2. The interaction effects of (P x S), (P x Zn) and (S x Zn) were significant, and the best combination doses were (P_{60} x S_{300}), (P_{60} x Zn_{20}) and (S_{300} x Zn_{20}) and (P_{60} x S_{300} x Zn_{20}), however, a significant response for canola seed yield was seen to the applied P, S and Zn rates. The seed yield of 345 kg/fed was obtained at the treatment of (P_0 x S_0 x Zn_0), and increased to a greatest amount of 530 kg/fed at (P_{60} x S_{300} X Zn_{20}) treatment, as shown in Table 3.

The crop responded fovourably with increasing the P rates up to 60 kg P_2O_5/fed, indicating higher needs of P by the crop. The increase in seed and straw yields with applied P alone at 30 and 60 kg P_2O_5/fed over the control were 20.2 and 22.9 % for seed yield vs 22.0 and 24.7 % for straw yield, respectively, as shown in Table 4. **Bolland (1997)** reported that canola may require a higher P content in seed to supply the germinating seedling with enough P during the early stages of plant growth before the roots have developed, sufficiently to take up significant amount of P from the soil. Phosphorus is needed during the earliest stage of plant growth. Any P deficiency during early growth can greatly reduce yield potential of tops and seeds. Therefore, the amount of P in canola seed could be important to help seedling establishment and in determining final seed yield.

Table 4. Effect of phosphorus, sulphur and zinc application on seed and straw yields of canola.

Treat-meant	S_0			S_{150}			S_{300}			Mean values		
	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}
Seed yield (kg/fed)												
P_0	**345**	**361**	383	390	400	411	412	419	421	395	405	482
P_{30}	**415**	**418**	420	435	461	464	473	485	495	416	457	444
P_{60}	**424**	**443**	428	475	501	508	511	519	530	489	474	459
Straw yield (kg/fed)												
P_0	**510**	**542**	580	585	593	620	629	632	636	582	598	650
P_{30}	**622**	**627**	630	650	694	700	710	731	740	620	686	657
P_{60}	**636**	**665**	645	710	755	763	769	783	800	735	707	690

L.S.D. at 0.05

Plant character	P	S	Zn	P x S	P x Zn	S x Zn	P x S x Zn
Seed yield	19.1	10.4	5.7	23.1	16.0	11.0	21.5
Straw yield	26.8	13.0	9.0	33.0	24.6	17.1	28.9

The positive response of canola yield to sulphur fertilization was associated with the applied rate of 300 kg S/fed. The corresponding seed yields were 390 and 412 kg/fed for the applied rates of 150 and 300 kg S/fed, in the absence of applied P and Zn, with relative increases of 13.04 and 19.40% over the control treatment, respectively. Similar results are observed by **Haneklaus *et al.* (1999), Zhao *et al.* (1999) and Malhi *et al.* (2002, 2006 and 2007)**. **Grant *et al.* (2000 and 2003), Pioter *et al.* (2003), Malhi and Leach (2002), Malhi and Gill (2002 and 2006) and Malhi *et al.* (2007)** reported that all Brassica oilseed species/cultivars responded positively for seed yield and most other parameters to S fertilizer application. The effect of S deficiency and applied S were more pronounced on seed than straw. They also suggest that S fertilizer application rates for all seed yield should be similar for the B-oilseed species/cultivars used on S-deficient soil, but higher yielding types would produce greater seed yield by using S more efficiently.

Data presented in Table 4 showed a positive response for each of all yield components, seed and straw yields of canola plants to soil application of Zn at the applied rate of 20 kg/fed as $ZnSO_4.7H_2O$, in the absence of P and S. The corresponding relative increase percentages in seed and straw yields were 11.01 and 13.70 % over the control treatment, respectively. These results are confirmed by those obtained by **Grewal *et al.* (1997**) and **Dingiin *et al.* (1996)**. Also, the results showed that the yield of canola seed has been found to be significantly increased due to solely and combined treatments of S and Zn, being recorded the greatest yield at the combined treatment of (S_{300} and Zn_{20}), in the absence of P, over that absolute control (S_0 and Zn_0). Such greater increase in seed yield due to the applied previous combined treatment might be due to higher availability of S and Zn in the soil with the simultaneous greater absorption imparting growth and seed yield. Similar results also reported by Sharma *et al.* (1990) and Das *et al.* (2004). Although the sole application of both S and Zn gave higher yields, but their combined treatments showed further more yield. The results also showed that the maximum increase percentage in canola seed yield of 22.03 % was recorded with the combined treatment of (S_{300} and Zn_{20}), in the absence of P, over the absolute control.

Regarding the interaction between P and S application, there was a significant effect at both rates of 30 and 60 kg P_2O_5/fed in combination with S at a rate of 300 kg/fed in the absence of applied Zn. These applied treatments enhance dry matter, seed yield and yield components of canola. The maximum dry matter yield at flowering stage, seed yield and yield components were achieved at 60 kg P_2O_5/fed in combination with 300 kg S/fed. The greatest seed yield of 511 kg/fed, which was obtained under the abovementioned P and S rates, achieved a relative increase percentage of 48.1 % over the control treatment. This was more related to largely greater numbers of pods and branches/plant.

The interaction effect of P and Zn was significant for yield and its components of canola plants. Maximum seed yield was recorded at the combined treatment of (60 kg P_2O_5/fed + 20 kg $ZnSO_4.7H_2O$/fed) in the absence of applied S. This favourable effect of P and Zn combination may be due to maintaining a best balance between P and Zn in the canola plant for optimum growth. These results are in agreement with those obtained by **Lu-Zhong *et al.* (1998)** who noted a significant increase in straw of canola plant with application of Zn and P**.**

Growth parameters, seed and straw yields as well as yield attributes were favourably affected by combined application of S and Zn fertilizers, mainly due to the higher biomass production, as discussed earlier. Meanwhile, the improvement in canola yield attributes alone resulted in higher seed yield. Application of (S + Zn) fertilizers resulted in proportionately similar increase in seed and straw yields. These results confirm those obtained by **Das *et al.* (2004)**.

The P and S applications influenced the yield of canola components as a result of changes in the growth and development patter of the crop. The importance of P and S in improving seed yield was demonstrated by **Malhi (2006) and Malhi *et al.* (2007)**. So, it was concluded that seed yield of canola could be enhanced significantly by the application of P at a higher rate of 60 kg P_2O_5/fed than the recommended dose of 45 kg P_2O_5/fed, with S and Zn in such deficient experimental sandy soil. In this connection, **Dingiin *et al.* (1996)** reported that both P and Zn fertilizers enhanced growth and yield of oilseed rape.

II. *Nutrient contents of canola plants:*

a. Nitrogen content:

Data presented in Table 5 revealed that a significant increase in N content of canola plant tissues at 90 days from sowing was observed with the application of P, s and Zn. However, successive additions of S rates with and without Zn increased N content, may be attributed to the application of S could be enhanced root activity. Meanwhile, the increase of N content by Zn application may be due to the fact that Zn has an ability to form complexes with N, O and particularly S, and then performs catalytic and structural roles in enzymes. Many enzymes contain Zn as structural, catalytic or cofactor components.

Table 5. Effect of phosphorus, sulphur and zinc application on nutrient contents in plant tissues of canola plants at flowering stage.

Treat-meant	S_0			S_{150}			S_{300}			Mean values		
	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}
Nitrogen content %												
P_0	3.82	3.89	3.92	3.94	3.97	4.02	4.05	4.10	4.19	3.99	4.05	4.16
P_{30}	4.00	4.04	4.06	4.11	4.20	4.27	4.30	4.33	4.39	4.18	4.20	4.20
P_{60}	4.20	4.25	4.30	4.35	4.45	4.49	4.55	4.63	4.70	4.49	4.35	4.24
Phosphorus content %												
P_0	0.52	0.53	0.55	0.55	0.56	0.58	0.58	0.59	0.61	0.56	0.59	0.61
P_{30}	0.60	0.61	0.61	0.62	0.64	0.66	0.66	0.68	0.70	0.64	0.63	0.63
P_{60}	0.61	0.63	0.65	0.66	0.68	0.70	0.70	0.72	0.71	0.67	0.66	0.74
Sulphur content &												
P_0	0.14	0.16	0.17	0.22	0.24	0.26	0.27	0.27	0.28	0.23	0.22	0.22
P_{30}	0.16	0.18	0.19	0.23	0.25	0.27	0.27	0.29	0.31	0.26	0.27	0.26
P_{60}	0.18	0.20	0.21	0.26	0.25	0.30	0.33	0.35	0.36	0.28	0.28	0.27
Zinc content (mg/kg plant)												
P_0	65	70	72	70	73	78	71	78	79	73	77	79
P_{30}	64	69	70	70	75	80	71	78	77	72	75	74
P_{60}	64	65	67	72	76	80	72	76	77	72	75	76

L.S.D. at 0.05

Plant character	P	S	Zn	P x S	P x Zn	S x Zn	P x S x Zn
N content	0.040	0.010	0.010	0.030	0.050	0.020	0.050
P content	0.018	0.019	0.008	0.010	n.s.	n.s.	n.s.
S content	0.010	0.006	0.006	0.010	n.s.	n.s.	n.s.
Zn content	n.s.	0.150	0.590	0.500	1.030	1.030	n.s.

Protein synthesis, hormone (axin), indole acetic acid (IAA) and carbohydrate metabolism also require Zn. Consequently, N content and some nutrients tended to increase **(Marschner, 1986)**. A significant increase in N content of shoot plant tissues was observed with increased the applied P rates up to 60 kg P_2O_5/fed. These results are supported by the findings of **Kasturikrishan and Ahlawat (1999)**. A significant interaction effect of (P x Zn) and (S x Zn) were observed for N content in the canola plant tissues.

b. Phosphorus content:

Data of application of P, S and Zn showed a significant increase in P content of canola plant tissues with increasing their added rates, as shown in Table 5. Also, the successive additions of elemental sulphur up to 300 kg/fed showed a progressive increase in P content of canola tissues. This effect may be due to the influence of H_2SO_4, formed by oxidation of S in the soil on solubilization and mobilization of P in the presence of sulphate ions. The interaction between P and S was significant and the best combination dose was (P_{60} S_{300}), which gave the maximum P content. This confirms the synergism between P and S **(Patel and Sheleke, 1998; Varavipur *et al.*, 1999)**.

c. Sulphur content:

Sulphur content of canola plant tissues increased significantly with application of P, S and Zn. The sulphur content increased significantly with every applied successive addition of S over the control. Similar results were recorded by **Ceccotti (1996), Zhao *et al.* (1999), Haneklaus *et al.* (1999) and**

Messick *et al.* (1999). Similarly, P fertilization also helped in increasing S content. The interaction of S and P was significant. The significant increase in S content by P application confirmed the synergistic relationship of S and P, which may be attributed to the promotion of root development by P that has been found to induce higher uptake of native applied sulphur.

d. Zinc content:

Data in Table 5 showed that the successive increases in applied P rates resulted in a significant decrease in Zn content of canola plant tissues. A similar observation was obtained by **Dingiin *et al.* (1996)**, who reported that P_2 depressed Zn content in oilseed rape leaves as compared to P_1. This could be attributed to dilution of the extra dry matter produced. The antagonistic effect of P on Zn content may be due to P slowing Zn-absorption by plant roots and the subsequent retardation in Zn translocation from roots to shoots. Meanwhile, Zn content in canola plant tissues increased significantly with the application of S and soil application of Zn.

The increases in S and Zn contents were probably due to easy and greater availability of these nutrients with extended root system as a result of external supply of S and Zn.

III. *Seed quality of canola:*

As seen in Table 6, protein and oil contents in seed were increased significantly with increasing P rates up to 60 kg P_2O_5/fed. Synthesis of fatty acids in plant occurs through conversion of acetyl Co-A to maloney Co-A in presence of ATP and phosphate **(Bonner and Varner, 1965)**. Similarly fertilization of P elevated protein content in seed may be due to more protein synthesis in the presence of P and the formation of some stable phospho-protein compounds. These results are in harmony with those obtained by **Patel and Shelk (1998)**. The obtained data also revealed that the amount of protein content was gradually increased as a function of successive additions of elemental sulphur.

Table 6. Effect of phosphorus, sulphur and zinc application on protein and oil contents of canola plants.

Treat-ment	S_0			S_{150}			S_{300}			Mean values		
	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}	Zn_0	Zn_{10}	Zn_{20}
Protein content %												
P_0	32.1	34.3	34.5	34.6	34.9	35.1	35.4	35.7	36.1	34.7	35.2	36.0
P_{30}	35.0	35.3	35.3	35.9	36.3	36.5	36.8	37.0	37.2	36.1	36.2	36.3
P_{60}	36.8	36.6	36.9	37.3	37.7	38.1	38.6	38.9	39.5	37.8	37.2	36.5
Oil content %												
P_0	39.3	40.0	40.5	40.7	40.8	41.2	40.6	41.0	41.7	40.6	41.1	41.4
P_{30}	41.0	41.4	41.6	41.8	41.8	41.9	41.8	42.3	42.8	41.8	41.9	41.8
P_{60}	41.8	42.1	42.3	42.5	43.0	43.7	42.9	43.5	44.1	42.9	42.3	42.2

L.S.D. at 0.05							
Seed character	P	S	Zn	P x S	P x Zn	S x Zn	P x S x Zn
Protein content	0.11	0.12	0.06	0.06	0.05	0.05	0.07
Oil content	0.32	0.26	0.24	0.29	0.29	0.29	0.32

The response of seed oil content to S application is presented in Table 6, however, there was an increase in content of oil in canola seeds. The increase was particularly significant at the applied S-rates 150 and 300 kg/fed, with the increase averages of 4.1 and 5.3, respectively. In this connection, **Lal *et al.* (1995)** showed that S application resulted in significant increase in seed oil content, since S is an integral part of acyl-Co-enzyme A that helps synthesis of more fatty acids. The highly significant enhancement of S on the oil content of canola seed due to it represents an essential component in some amino acids **(Malhi, 2007)**.

Data also revealed that the amount of protein content was gradually increased as a function of successive additions of elemental sulphur, where the highest rate of applied S (300 kg S/fed) produced the greatest protein content percentage. These increases may be due to the very important role of S in protein content of canola plant. Sulphur is a component of the amino acids such as cystein and methionine as essential amino acids for protein synthesis **(Anderson, 1990)**. Also, **Patel and Shelke (1998)** reported that the possible explanation in increased oil and protein contents in seed was that, S is directly, involved in oil synthesis and protein metabolism. Sulphur fertilization does not only improved the quality of oil crop product and increase its market value, particularly in the case of rapeseed, but also it plays an important role in protein synthesis, and thus affected N-use and metabolism in plant **(Messick and Fan, 1999)**.

Depending upon the presented Data in Table 6, protein and oil contents of canola seed have been found to be significantly increases due to the solely treatment of Zn application, where the greatest values were associated with the highest Zn-rate of 20 kg $ZnSO_4.7H_2O$/fed. As for the combinations of P, S and Zn, the obtained data in Table 6 showed a significantly increase in the amount of oil content of canola seeds as compared to either applied solely treatments or the control one. The maximum increase in seed oil content of 44.1 % was recorded at the combined treatment of (P_{60} x S_{300} x Zn_{20}) than those other treatments. Similar results were observed by **Das *et al.* (2004)**.

Data in Table 6, also revealed that the amount of protein recorded an increase significantly of 7.5 at the applied solely treatment of Zn_{20}. The corresponding increase percentages for S_{300} and P_{60} were 10.3 and 14.6 %, respectively. Being greater magnitude of 23.0 % was occurred at the combined treatment of (P_{60} x S_{300} x Zn_{20}), mainly due to greater stimulating action of Zn in the synthesis of S containing protein and also localization of Zn in protein bodies as discrete particularly in seed as well as higher rate of translocation of Zn in presence of S from the root to seed via shoot meristem resulting increased tranciption and transaction with reduced rate of RNA degradation **(Sharma *et al.*, 1990)**.

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التأثير المتكامل للفوسفور والكبريت والزنك على إنتاجية نباتات الكانولا المنزرعة فى تربة رملية حديثة الإستصلاح

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أجريت تجربة حقلية على تربة رملية بمحطة البحوث الزراعية خلال الموسم الشتوى ٢٠٠٩/٢٠١٠ لدراسة تأثير إضافة الفوسفور بمعدلات (0, 30 and 60 kg P_2O_5/fed)، الكبريت (0, 150 and 300 kg S/fed)، الزنك بمعدلات (0, 10 and 20 kg $ZnSO_4.7H_2O$/fed) وكذلك تأثيراتها المتداخلة على محصول الكانولا (صنف سرو ٤)، ومكوناته (طول النبات، عدد التفريعات/نبات، وزن المادة الجافة للسيقان/نبات فى بداية مرحلة التزهير، عدد القرون/نبات، وزن ١٠٠٠ حبة)، قياسات جودة الحبوب من حيث محتواها من الزيت والبروتين.

وبصفة عامة، فان النتائج المتحصل عليها تشير إلى أن إضافة الفوسفور، الكبريت، الزنك كمعاملات منفردة باختلاف معدلاتها أظهر الدور الفعال على زيادة وزن المادة الجافة للسيقان فى بداية مرحلة التزهير، محتوى أنسجة النبات من المغذيات بعد ٩٠ يوما من الزراعة، محصول الحبوب وجودته. حيث أن إضافة تلك المعاملات العنصرية (Nutrients of P, S and Zn) قد أظهرت زيادات معنوية فى محصول الكانولا ومكوناته، والتى تعاظمت قيمها بزيادة معدلات الإضافة حتى المعدل الأعلى لكل عنصر، وبأفضلية لإضافة معاملة الفوسفور مقارنة بكلا الكبريت أو الزنك المضاف بصورة منفردة .

ولقد أظهرت معاملات الإضافات المشتركة للمغذيات (P x S), (P x Zn) and (S x Zn) زيادات أكثر وضوحا فى محصول حبوب الكانولا ومكوناته النباتية، وبفروق أكثر معنوية مقارنة بتلك الإضافات المنفردة للمغذيات. وقد تعاظمت هذه الزيادات فى حالة المعاملة الثلاثية المشركة لعناصر P, S and Zn مقارنة بالمعاملات الثنائية المشتركة. وأيضا، زيادة المعدلات المضافة من عناصر P, S and Zn قد أدت إلى زيادات معنوية فى محتوى الأنسجة النباتية للكانولا من مغذيات N, P and S بعد ٩٠ يوما من الزراعة، بينما محتواها من الزنك قد تناقص باضافة الفوسفور، والعكس صحيحا عند إضافة كلا عنصرى الكبريت والزنك واللذان أحدثا زيادة معنوية فى محتوى الأنسجة النباتية من الزنك. وأوضحت النتائج أن المعاملة الثلاثية المشتركة لعناصر P, S and Zn قد أظهرت علاقة تشجيعية فيما بينهم، كما تشير النتائج إلى أن المعاملة الثلاثية المشتركة للمغذيات الثلاث بمعدلات ٦٠، ٣٠٠، ٢٠ كجم/فدان من الفوسفور، الكبريت، الزنك على الترتيب كانت الأكثر ملائمة من حيث الحالة الغذائية للكانولا.

تحت ظروف هذه التجربة، يمكن إستخلاص أن إضافة عناصر P, S and Zn كممعاملات منفردة كانت ذات تأثير مفيد على قياسات جودة حبوب الكانولا، حيث محتوى الحبوب من الزيت والبروتين قد اظهر زيادات معنوية، ومن ثم فى المعاملات المشتركة، وطبقا للواقع، فان المعاملة الثلاثية المشتركة (P_{60} S_{300} Zn_{20}) كانت الأفضل فى الحصول على أعلى القيم لقياسات جودة حبوب الكانولا ممثلة فى أعلى محتوى للزيت والبروتين فى الحبوب.