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Phenology and Physiology of Canola as Affected by Nitrogen and Sulfur Fertilization

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Abstract: Experiments were conducted at Cereal Crops Research Institute Pirsabak Nowshera, Pakistan, during 2003-04 and 2004-05 to evaluate the impact of nitrogen (N) and sulfur (S) levels, time and methods of application on Canola (*Brassica napus* L. cv. Bulbul-98) under irrigated conditions. Four levels of S (0, 20, 40 and 60 kg S ha^{-1}) and three levels of N (80, 120 and 160 kg N ha^{-1}) and a control treatment with both nutrients at zero level were applied as a sole dose at sowing, or in two split applications (50% at sowing + 50% at leaf rosette stage), or three split applications (1/3rd at sowing + 1/3rd at leaf rosette stage+ 1/3rd at flowering). The experiments were laid out in Randomized Complete Block (RCB) Design with split plot arrangement having four replications. Treatments comprising N and S levels were applied to main plots while time of application treatments were assigned to sub plots. Analysis of the data collected from the experiments indicated that maturity of canola was delayed as N rate was increased. Increasing levels of N had progressively enhanced plant height, leaf area index and CGR up to the highest level of 160 kg N ha^{-1}. However, harvest index, was increased up to 120 kg N ha^{-1}. The influence of S was non-significant on days to maturity while leaf area index and harvest index, were increased significantly when S rate was increased up to the 40 kg S ha^{-1}. However increasing rate of S continuously enhanced plant height and CGR up to the highest level of 60 kg S ha^{-1}. There was no significant influence of the time of application of N and S on plant height, leaf area index and CGR. However, sole application of N and S at sowing resulted in early maturity and three-split applications significantly decreased harvest index of canola.

Key words: Canola, nitrogen, sulfur, phenology and physiology

INTRODUCTION

The supply of protein and oil is becoming scarce especially in the developing countries. Pakistan is facing a widening gap between edible oil requirements and the domestic production. In Pakistan domestic vegetable oil production cannot fulfill the ever-increasing public demand. The total edible oil requirements in 2002-03 were around 2.199 million tonnes. Domestic production was only 0.641 million tones, that is about 29% of the demand. The remaining 71% was made available through imports (Economic Survey Report 2002-03). Fats and oils are essential components of human diet. Most vegetable oils are edible and have been used in food preparation to make it more palatable and nutritious. Vegetable oils are preferred over the solid animal fats because of health benefits (Khalil and Rehman, 1999). Rapeseed or mustard seed was grown about 300 BC in Indus Valley as fodder crop, its oil use started in fifteenth century. Up to the Second World War (1945) the oil was used as lubricant and lamp oil (Weiss, 1983). The crop is a rich source of oil but the presence of erucic acid, which is toxic and has bitter taste and glucosinolate (the sulfur compounds) in the tissues, it could not get an important place as an oil crop (Muhammad *et al*., 1991). Safe limits for these compounds have been described as less than 2% Erucic acid in oil and less than 30 μmol g^{-1} of glucosinolates in oil free meal. (Anonymous, 1999). In 1970s plant-breeding efforts in Canada resulted in improvements in the fatty acid composition of the oil (reduction of erucic acid) and a marked reduction in the level of glucosinolates in the meal. Reduction in the above compounds has made rapeseed the world's third most important vegetable oil, after soybean and palm oil (Downey and Rimmer, 1993). These modifications in the oil and meal of rapeseed led to the development of the name "Canola" as a means of distinguishing the edible oil quality rapeseed from industrial quality oil (high erucic acid). Extraction of seed oil is high, with average oil content of 42% and a protein content of approximately 21% (DeClercq and Daun, 1999). Canola has the lowest saturated fat content of any vegetable oil. Today there is an increasing demand for

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this oil by diet-conscious consumers (Grombacher and Nelson, 1992). The tender leaves of these cultivars serves as vegetable and the seed as a source of cooking oil. The residue left after oil extraction being rich in protein is used in live stock feed (Khalil *et al.*, 1995).

The rapeseed crop has a high requirement for nitrogen, needing considerably more than is provided by most soils and generous use of nitrogen fertilizer is therefore necessary for optimum yield. Canola requires about 25% more N than wheat (Hocking *et al.*, 1997). Nitrogen is a major limiting element of plant growth because of its vulnerability to losses. Nitrogen is closely linked to control the vegetative growth of plant and hence determine the fate of reproductive cycle. An adequate nitrogen supply not only encourages leaf development, it can materially assist in retaining leaves in active photosynthesis over this period and thus assist in the development of flowers and young pods (Weiss, 1983). Choosing the correct rate and timing of nitrogen fertilizer application is therefore one of the most important aspects of successful oilseed rape production (Holmes, 1980).

Sulfur (S) requirements for canola are higher than most crops. The higher protein content of these cultivars compared with cereals, combined with *Brassica's* higher proportion of cysteine and methionine contribute to the larger Sulphur requirement (Durrani and Khalil, 1990). Therefore sulfur nutrition must be seriously considered in a canola fertility program. The current S soil test tends to overestimate available sulfate-S, as field variability is huge. Therefore, at medium to low sulfur soil test levels, 25-35 kg ha^{-1} S is recommended. At high soil sulfur levels, 10-20 kg ha^{-1} S is still recommended (Franzen, 1997). Canola takes up sulfate-S. The form of sulfur fertilizer may be ammonium sulfate (21-0-0-24S) or another available sulfate fertilizer. It is best to provide adequate sulfur before or at planting. Sulfur is probably the most important soil fertility factor to consider when growing canola (Franzen, 1997).

Time and method of application play an important role in proper utilization of the fertilizer. Malhi and Leach (2000) and Malhi and Gill (2002) reported that sole application of S at sowing to canola gave better results than split application. However, Ahmad *et al.* (2005) found that split application of S in canola gave better results than sole application at sowing. Regarding method of N application Barlog and Grzebisz (2004) found that two split application of N half at sowing and half at stem elongation gave greater seed yield than sole or three split applications. While Cheema *et al.* (2001) and Afridi *et al.* (2002) are of the view that time of N application have no significant influence on the performance of canola. Refinement of N and S fertilizer recommendations for canola are needed to ensure optimum productivity, economic vitality and environmental stewardship (Jackson, 2000).

Despite the urgent need of research in sulfur fertility, the research focus on S is not as common as that with major nutrients (NPK). A breakthrough is, thus, essential in this matter to promote S fertilizer use in oilseeds by farmers.

Keeping in view the importance of N and S in canola production, the present study was planned to study the response of the phenological and physiological characteristics of canola to nitrogen and sulfur levels and their methods of application.

MATERIALS AND METHODS

Field experiments were conducted at Cereal Crops Research Institute Pirsabak, Nowshera, Pakistan, located about 1600 km north of Indian Ocean at 34°N latitude, 72°E longitude and have an altitude of 288 m above sea level. The study was conducted over two years period (2003-2005). Soil analysis for nitrogen and sulfur were conducted before sowing of the crop. The soil of the experimental field was sandy loam, moderately calcareous, low in nitrogen (0.15%), low in organic matter (0.31%), low in available sulfur (8.29 mg kg^{-1}) and having a pH of 7.7. The effect of various levels of Sulfur (0, 20, 40 and 60 kg ha^{-1} hereafter called S1, S2, S3 and S4, respectively) and Nitrogen (80, 120 and 160 kg ha^{-1}, hereafter called N1, N2 and N3, respectively). One treatment of both N and S at zero level was kept as check. To study the effect of time of application, S and N were applied at three various times in f ull and split doses i.e., all at sowing (Stage 1) (St1), half at sowing + half at Leaf Rosette (Stage 3) (St2) and 1/3rd at sowing + 1/3rd at leaf rosette + 1/3 at flowering (Stage 6) (St3).

The experiments were laid out in RCB design with split plot arrangement with four replications applying nitrogen and sulfur to main plots and time of application to sub-plots.

The field was prepared well before sowing. Seed of improved canola cultivar Bulbul-98 was obtained from Agricultural Research Institute Tarnab Peshawar. Bulbul-98 is the latest high yielding canola cultivar, approved by provincial seed council, Peshawar, Pakistan. Experiments were planted on 17 October 2003 and 18 October 2004. A uniform seed rate of 5 kg ha^{-1} was seeded in all the plots through hand hoe in straight rows. The size of sub plot was 5×3 m. In each sub plot there were 6 rows 5 m long and 50 cm apart. Fertilizer basic dose of PK at the rate of 60-60 kg ha^{-1} were applied in the form of triple super phosphate and murate of potash. Nitrogen was applied in the form of urea and ammonium sulfate while sulfur was applied in the form of ammonium sulfate. All phosphoric and potash fertilizers were applied at the time of sowing. Nitrogen and sulfur levels were allotted, at random to main plots while the time of application were allotted at random to sub plots. After the completion of germination, seedlings were hand thinned to maintain a uniform plant to plant distance of 5 cm. Weeds were controlled manually. Crop was irrigated when needed. All cultural practices were applied uniformly to all the plots. The experiments were harvested in the month of April during both years. Data were recorded on days to maturity, plant height harvest index, leaf area index and crop growth rate.

Days to maturity were counted from the date of sowing to the date when the colour of the pods turned from green to yellow in each sub plot. Leaf area was measured with the help of a leaf area meter (LICOR Model 3000 A). Leaf area index was determined by dividing leaf area over ground area. Plant height data were recorded by measuring the height of ten randomly selected plants in each sub plot at physiological maturity and then their average was calculated. For total biomass yield, four central rows in each sub-sub plot were harvested, dried and weighed. In order to determine grain yield bundles from the same central four rows were threshed and their grains were weighed and converted to kg per hectare. To calculate harvest index, the grain yield was divided by total biomass yield and multiplied by 100 to express the data as percentage. Crop Growth Rate (CGR) at maturity was calculated by the formula.

$$CGR = \frac{\text{Total biomass yield m}^{-2} \text{ at maturity}}{\text{Days to maturity}}$$

The data recorded were analyzed statistically using analysis of variance techniques appropriate for randomized complete block design. Main and interaction effects were compared using LSD test at 0.05 and 0.01 level of probability, when the F-values were significant (Steel and Torrie, 1984).

RESULTS AND DISCUSSION

Days to maturity: Days to maturity is a measure for the termination of reproductive cycle and completion of life cycle. Data regarding days to maturity as influenced by N and S levels and their time of application are presented in Table 1a and b. Statistical analysis of the data showed that sulfur levels had no significant effect on days to maturity of canola. Nitrogen levels and the time of application of N and S had significantly affected days to maturity during both years. Days to maturity was also

Table 1a: Days to maturity of canola as affected by N and S levels and its time of application under irrigated conditions during 2003-04

Sulfur ($kg\ ha^{-1}$)	Nitrogen ($kg\ ha^{-1}$)	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	171	171	171	171
0	120	172	172	172	172
0	160	174	174	174	174
20	80	171	171	171	171
20	120	171	171	172	171
20	160	172	173	173	173
40	80	171	171	170	170
40	120	172	172	172	172
40	160	172	173	173	172
60	80	170	171	171	170
60	120	171	172	172	172
60	160	172	173	173	172
		S×Stage			
0		172	172	172	172
20		171	171	172	172
40		171	172	172	172
60		171	172	172	172
		N×Stage			
	80	171	171	171	171c
	120	171	172	172	172b
	160	173	173	173	173a
Mean		171b	172a	172a	
Control mean		170b			
Rest mean		172a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Table 1b: Days to maturity of canola as affected by N and S levels and its time of application under irrigated conditions during 2004-05

Sulfur ($kg\ ha^{-1}$)	Nitrogen ($kg\ ha^{-1}$)	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	173	173	173	173
0	120	173	173	174	173
0	160	176	175	176	175
20	80	173	174	174	173
20	120	174	174	174	174
20	160	175	175	175	175
40	80	173	173	174	173
40	120	174	174	175	174
40	160	175	175	175	175
60	80	173	173	173	173
60	120	174	174	175	174
60	160	175	175	175	175
		S×Stage			
0		174	174	174	174
20		174	174	174	174
40		174	174	174	174
60		174	174	174	174
		N×Stage			
	80	173	173	173	173c
	120	174	174	174	174b
	160	175	175	175	175a
Mean		174	174	174	
Control mean		172b			
Rest mean		174a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3 significantly affected by N×S interaction during both years. Increasing N rate progressively delayed maturity and the maximum days to maturity were taken by the plots that received the highest dose of 160 kg N ha^{-1}. Interaction results of N×S indicated that the maximum days to maturity were recorded in those plots in which the highest dose of N was applied with the No. S.

Mean values for time of application showed that two or three split applications of N and S significantly delayed maturity as compared to a sole application at sowing during first year only.

The possible reason for delay in maturity with increasing N rate may be that N promotes vegetative growth and thus the crop continue to grow for a long time. These results are supported by the findings of Sani and Sidhu (1998) and Kutcher *et al.* (2005) who found that days to maturity were increased with increasing N rate.

Plant height (cm): Plant height is a function of genetic as well as environmental conditions. It is considered as vegetative growth potential of a crop. Data regarding plant height of canola as affected by N and S levels and time of application are presented in Table 2a and b. Different levels of N, S significantly affected plant height. Plant height was also significantly affected by N×S interaction. Plant height was increased with increasing N rates and the tallest plants were observed in the plots, which received the maximum dose of 160 kg N ha^{-1}. The response of plant height to N levels was consistent in both years. Increasing sulfur levels also significantly increased plant height. In 2003-04, the maximum plant height was noted in those plots in which 60 kg S ha^{-1} was applied while in 2004-05 the maximum plant height was produced by the plots, which received 40 kg S ha^{-1}.

Table 2a: Plant height (cm) of canola as affected by N and S levels and its time of application under irrigated conditions during 2003-04

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St	S×N		
0	80	172	169	170	170
0	120	173	174	174	174
0	160	175	175	175	175
20	80	174	174	175	174
20	120	180	182	182	181
20	160	182	182	182	182
40	80	174	175	175	175
40	120	184	184	185	184
40	160	186	184	185	185
60	80	176	178	178	177
60	120	184	185	185	185
60	160	185	186	186	186
		S×Stage			
0		173	173	173	173d
20		179	179	179	179c
40		181	181	181	181b
60		182	183	183	182a
		N×Stage			
	80	174	174	174	174c
	120	180	181	181	181b
	160	182	182	182	182a
Mean		177	177	177	
Control mean		156b			
Rest mean		179a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Table 2b: Plant height (cm) of canola as affected by N and S levels and its time of application under irrigated conditions during 2004-05

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St		S×N	
0	80	167	168	168	168
0	120	175	175	176	175
0	160	176	176	176	176
20	80	173	174	174	173
20	120	180	180	181	180
20	160	182	183	183	183
40	80	175	175	175	175
40	120	182	182	181	182
40	160	185	184	184	184
60	80	172	172	172	172
60	120	183	183	184	183
60	160	186	186	186	186
		S×Stage			
0		173	173	173	173c
20		178	179	179	179b
40		180	180	180	180a
60		180	180	180	180a
		N×Stage			
	80	172	172	172	172c
	120	180	180	180	180b
	160	182	182	182	182a
Mean		176	176	176	
Control mean		153b			
Rest mean		178a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

The significant N×S interaction indicated that the maximum plant height was observed in those plots in which 160 kg N ha^{-1} was applied with 40 to 60 kg S ha^{-1} during both years. However, in 2003-04 the plant height produced by 120 kg N ha^{-1} in combination with 40 to 60 kg S ha^{-1} was statistically at par with the plant height produced from 160 kg N ha^{-1} in combination with 40 to 60 kg S ha^{-1}.

The increase in plant height with the increasing rates of N and S indicates the favorable response of canola to both of these nutrients. The increase in plant height with the increasing rates of S and N in our results is consistent with the literature. Holmes (1980) reported that due to S deficiency in rapeseed the growth is checked and the plant height is reduced subsequently. Subhani *et al.* (2003) found that plant height was increased with S application and the maximum plant height was recorded in plots where 30 to 50 kg S ha^{-1} was applied. Ahmed *et al.*

(1999) stated that increasing N rates increased plant height and the maximum plant height was observed in the plots where maximum dose of 120 kg N ha^{-1} was applied. Regarding the time of N and S application our results do not agree with Afridi *et al.* (2002) who reported that sole dose of N produced significantly taller plants than split application.

Leaf area index: Crop production is the practical means of trapping solar energy and converting it into food and other useable materials. Crop production strategies are usually designed to maximize light interception by achieving complete ground cover. Leaf Area Index (LAI) expresses the ratio of leaf area to the ground area occupied by the crop. A LAI of 3-5 is usually necessary for maximum dry matter production of most cultivated crops.

Data regarding LAI of canola as affected by N and S levels and time of application are reported in Table 3a and b. Perusal of the data revealed that N and S levels significantly affected leaf area index of canola, while N and S application times had no significant influence on the leaf area index of canola. Statistical analysis also detected significant interaction among N and S levels. The results were consistent during the two years. Comparing the mean values for N levels, it was found that leaf area index continued to increase with the increasing levels of N and the maximum LAI of 5.47 and 5.63 were exhibited by the plots which received the highest dose of 160 kg N ha^{-1} during the first and second year, respectively.

Table 3a: Leaf area index of canola as affected by N and S levels and its time of application under irrigated conditions during 2003-04

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	3.60	3.58	3.67	3.62
0	120	4.35	4.14	4.67	4.38
0	160	4.71	4.87	5.10	4.90
20	80	3.56	3.78	3.66	3.67
20	120	5.19	5.03	5.16	5.13
20	160	5.74	5.44	5.32	5.50
40	80	3.77	3.84	3.62	3.74
40	120	5.54	5.32	5.29	5.38
40	160	5.86	5.85	5.64	5.78
60	80	3.62	3.47	3.61	3.56
60	120	5.35	5.57	5.20	5.37
60	160	5.85	5.89	5.36	5.70
		S×Stage			
0		4.22	4.20	4.48	4.30c
20		4.83	4.75	4.72	4.76b
40		5.05	5.00	4.85	4.97a
60		4.94	4.98	4.72	4.88ab
		N×Stage			
	80	3.63	3.67	3.64	3.65c
	120	5.11	5.01	5.08	5.07b
	160	5.54	5.51	5.36	5.47a
Mean		4.59	4.56	4.53	
Control mean		2.55b			
Rest mean		4.73a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \le 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Table 3b: Leaf area index of canola as affected by N and S levels and its time of application under irrigated conditions during 2004-05

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	3.84	4.02	3.81	3.89
0	120	4.92	4.74	5.10	4.92
0	160	4.91	5.06	5.14	5.03
20	80	3.92	3.96	3.92	3.93
20	120	5.11	5.47	5.59	5.39
20	160	6.02	5.79	5.77	5.86
40	80	3.91	3.73	3.98	3.87
40	120	5.55	5.65	5.58	5.59
40	160	5.75	5.90	5.84	5.83
60	80	4.38	4.07	4.22	4.22
60	120	5.54	5.81	5.92	5.75
60	160	5.64	5.83	5.94	5.80
		S×Stage			
0		4.55	4.61	4.68	4.61c
20		5.02	5.07	5.09	5.06b
40		5.07	5.09	5.13	5.10b
60		5.18	5.23	5.36	5.26a
		N×Stage			
	80	4.01	3.94	3.98	3.98c
	120	5.28	5.42	5.54	5.41b
	160	5.58	5.64	5.67	5.63a
Mean		4.96	5.00	5.07	
Control mean		3.00b			
Rest mean		5.01A			

Means of the same category followed by the different letters are significantly different from one another using LSD test ($p \le 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

LAI increased with increasing S rates upto 40 kg S ha^{-1} but further increase in S upto 60 kg S ha^{-1} had no significant impact on LAI during both years. Mean values of the interaction among N and S indicated that the LAI was increased with increasing levels of the two nutrients during both years and the higher LAI was recorded in the plots which received 160 kg N ha^{-1} in combination with 40 to 60 kg S ha^{-1} during first year, while during the second year the higher LAI was noted in the plots which received 160 kg N ha^{-1} in combination with 20 to 60 kg S ha^{-1}, however LAI produced by the combination of 120 kg N ha^{-1} and 60 kg S ha^{-1} was at par with the LAI produced by the plots which received N and S in combination of 160 kg N ha^{-1} and 20 to 60 kg S ha^{-1}.

The increase in LAI of canola with increasing levels of N was also reported by Cheema *et al.* (2001) who stated that LAI increased with increase in N rate and the maximum LAI was produced by the highest dose of 120 kg N ha^{-1}.

Crop growth rate (g m^{-2} day^{-1}): Crop growth rate is the gain in weight of a community of plants on a unit of land in a unit of time and is used extensively in growth analysis of field crops. Data regarding mean Crop Growth Rate (CGR) of canola has been summarized in Table 4a and b. Mean values revealed that N, S and interaction of N and S levels had significantly affected mean crop growth rate of canola during both years. Analysis of the data further revealed that the time of application of N and S and the interaction among N×Stage, S×Stage and N×S×Stage had no significant influence on the CGR rate of canola during both years. Increasing N levels significantly increased mean crop growth rate. During first year maximum CGR was observed in the plots, which received the maximum dose of 160 kg N ha^{-1}, while in the subsequent year the CGR produced by the plots supplied with 120 kg N ha^{-1} was at par with the CGR produced by the plots that received 160 kg N ha^{-1}.

Increase in S levels also significantly increased the CGR and the maximum CGR was exhibited by the plots that received 60 kg S ha^{-1} during both years. However, during the second year the CGR produced by 40 kg S ha^{-1} was at par with 60 kg S ha^{-1}. Interaction between N×S indicated that CGR increased with increasing levels of the two nutrients and the maximum CGR was observed in the plots that received 120 to 160 kg N ha^{-1} in combination with 40 to 60 kg S ha^{-1} during both years.

Table 4a: Crop growth rate (g m^{-2} day^{-1}) of canola as affected by N and S levels and its time of application under irrigated conditions during 2003-04

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	4.31	4.33	4.28	4.30
0	120	4.80	4.88	4.80	4.83
0	160	5.19	4.95	4.92	5.02
20	80	4.53	4.46	4.44	4.48
20	120	5.69	5.74	5.71	5.71
20	160	6.22	6.31	6.17	6.23
40	80	4.66	4.69	4.72	4.69
40	120	6.18	6.24	6.26	6.23
40	160	6.70	6.61	6.47	6.59
60	80	4.66	4.63	4.73	4.67
60	120	6.71	6.87	6.37	6.65
60	160	6.72	6.78	6.64	6.71
		S×Stage			
0		4.77	4.72	4.66	4.72d
20		5.48	5.50	5.44	5.47c
40		5.85	5.85	5.82	5.84b
60		6.03	6.09	5.91	6.01a
		N×Stage			80.0
		4.54	4.53	4.54	4.54c
	120	5.85	5.93	5.78	5.85b
	160	6.21	6.16	6.05	6.14a
Mean		5.32	5.33	5.25	
Control mean		2.78b			
Rest mean		5.51a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Table 4b: Crop growth rate (g m^{-2} day^{-1}) of canola as affected by N and S levels and its time of application under irrigated conditions during 2004-05

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	4.0	4.0	4.1	4.0
0	120	4.6	4.6	4.6	4.6
0	160	4.8	4.9	4.9	4.9
20	80	4.3	4.3	4.6	4.4
20	120	5.6	5.7	5.8	5.7
20	160	5.9	5.8	6.0	5.9
40	80	4.5	4.5	4.6	4.5
40	120	6.4	6.3	6.2	6.3
40	160	6.5	6.6	6.4	6.5
60	80	4.7	4.8	4.5	4.7
60	120	6.5	6.5	6.7	6.6
60	160	6.3	6.7	6.5	6.5
		S×Stage			
0		4.5	4.5	4.5	4.5c
20		5.3	5.3	5.5	5.4b
40		5.8	5.8	5.7	5.8ab
60		5.8	6.0	5.9	5.9a
		N×Stage			
	80	4.4	4.4	4.5	4.4b
	120	5.8	5.8	5.8	5.8a
	160	5.9	6.0	6.0	5.9a
Mean		5.3	5.4	5.4	
Control mean		2.7b			
Rest mean		5.4a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

The increase in CGR with the increasing rate of N and S may be due to the positive response of canola to N and S. These results indorsed the views of (Holmes, 1980) who reported that the increasing supply of N increases the amount of protein formatted and therefore the amount of protoplasm. The increase in turn, results in greater cell size and leaf area and thus in greater photosynthetic activity. The overall effect is to increase crop growth dramatically in the absence of other limiting factors and to provide in rapeseed, a large frame on which more flowers and eventually more pods can develop. Similarly Fismes *et al.* (2000) stated that the N and S nutrition during the growth were tightly linked and their interactions were synergistic at optimum rates.

Harvest index (%): Data regarding harvest index (Table 5a and b) showed that N, S and interaction between N and S had significant influence on harvest index of canola. Time of N and S application had no significant impact on harvest index during first year, while in the subsequent year, significant differences were recorded in the values of harvest index for time of application. Analysis of harvest index data detected no significant interaction effects of N×stage, S×stage or N×S×stage in any year.

Table 5a: Harvest index (%) of canola as affected by N and S levels and its time of application under irrigated conditions during 2003-04

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	21.12	21.17	21.48	21.26
0	120	21.48	21.63	21.35	21.49
0	160	19.92	21.15	20.79	20.62
20	80	22.28	23.00	22.15	22.48
20	120	24.60	23.75	23.20	23.85
20	160	21.54	21.38	21.80	21.57
40	80	21.90	22.01	21.84	21.92
40	120	24.35	23.60	23.29	23.75
40	160	22.63	22.81	22.35	22.60
60	80	22.02	22.34	21.36	21.91
60	120	21.83	21.30	22.79	21.97
60	160	21.96	21.84	22.03	21.94
		S×Stage			
0		20.84	21.32	21.20	21.12c
20		22.81	22.71	22.38	22.63a
40		22.96	22.81	22.50	22.75a
60		21.94	21.83	22.06	21.94b
		N×Stage			
	80	21.83	22.13	21.71	21.89b
	120	23.07	22.57	22.66	22.76a
	160	21.51	21.79	21.74	21.68b
Mean		22.06	22.05	21.90	
Control mean		20.66b			
Rest mean		22.11a			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Table 5b: Harvest index (%) of canola as affected by N and S levels and its time of application under irrigated conditions during 2004-05

Sulfur (kg ha^{-1})	Nitrogen (kg ha^{-1})	Stages St-1	St-2	St-3	Mean
		S×N×St			S×N
0	80	22.63	22.74	21.12	22.16
0	120	21.86	21.76	21.52	21.71
0	160	20.67	19.68	20.16	20.17
20	80	22.89	24.13	21.05	22.69
20	120	23.47	23.15	22.69	23.10
20	160	22.28	22.16	21.97	22.14
40	80	22.36	22.58	21.17	22.04
40	120	23.56	23.65	23.83	23.68
40	160	23.08	22.79	23.45	23.11
60	80	21.44	20.87	22.02	21.44
60	120	23.30	23.13	22.26	22.89
60	160	23.80	23.28	22.81	23.30
		S×Stage			
0		21.72	21.39	20.93	21.35b
20		22.88	23.15	21.90	22.64a
40		23.00	23.00	22.82	22.94a
60		22.85	22.43	22.36	22.54a
		N×Stage			
	80	22.33	22.58	21.34	22.08b
	120	23.05	22.92	22.57	22.85a
	160	22.36	21.98	22.10	22.15b
Mean		22.55a	22.44a	21.93b	
Control mean		20.66			
Rest mean		22.11			

Means of the same category followed by the different letter(s) are significantly different from one another using LSD test ($p \leq 0.05$), N = Nitrogen, S = Sulfur, St-1 = Stage-1, St-2 = Stage-2, St-3 = Stage-3

Means for N levels showed that plots treated with different levels of N had significant influence on harvest index and the maximum harvest index was observed in those plots which received 120 kg N ha^{-1} during both years. Comparing different S levels it was observed that plots without S had minimum harvest index during both years, while the plots that received 20 to 40 kg S ha^{-1} had the maximum harvest index. Significant N×S interaction indicated that during first year, the maximum harvest index was recorded in the plots that received 120 kg N ha^{-1} in combination with 20 or 40 kg S ha^{-1}. While during the following year, the higher values of harvest index were recorded in the plots that received 80 to 160 kg N in combination with 20 to 60 kg S ha^{-1}. The lowest value of harvest index was noted in the plots that received the highest dose of 160 kg N with no S application.

Time of N and S application had no significant effect on harvest index during first year, while in the subsequent year three split applications proved inferior in terms of harvest index and exhibited lower harvest index as compared to sole application at sowing or two split applications at sowing + leaf rosette stages.

The maximum harvest index produced by 120 kg N ha^{-1} in this study is in conformity with the findings of Shukla and Kumar (1997) who stated that the harvest index of canola was increased with increasing N rate upto 120 kg N ha^{-1}. Our results appear to be consistent with the views expressed by Reddy (2004) who stated that the harvest index of *Brassica* range from 20 to 30% and is positively correlated with seed yield.

CONCLUSIONS

Increase in N rate to 160 kg ha^{-1} significantly delayed maturity, increased plant height, leaf area index and CGR. However, harvest index, was increased up to 120 kg N ha^{-1}. Sulfur had no significant impact on days to maturity while leaf area index and harvest index, were increased significantly when S rate was increased up to the 40 kg S ha^{-1}. However increasing rate of S continuously enhanced plant height and CGR up to the highest level of 60 kg S ha^{-1}. Time of N and S application had no significant influence on plant height, leaf area index and CGR, however, sole application of N and S at sowing resulted in decreased days to maturity during 1st year while three-split applications significantly decreased harvest index of canola during 2nd year of experiments.

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