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Physiological Analysis of the Growth and Development of Canola (*Brassica napus* L.) Under Different Chemical Fertilizers Application

Esmaeil Yasari and A.M. Patwardhan
Department of Environmental Science, University of Pune, Pune 411 007, India

Abstract: A split-plot experimental design with nine treatments and a non-fertilizer application control plot in 4 replications was carried out during the 2004-2005 growing season, at the Baiecola Agricultural Research Station in the Mazandaran province of Iran. Canola (*Brassica napus* L.) was grown as a second crop in rotation after wheat and its seed yield, growth parameters (CGR, LAI, RGR and NAR), dry matter accumulation and HI was examined. N P K fertilizers together with S and Zn, singly or in combination were applied, before the sowing and after examining the soil requirement. The maximum yield (3141.250 kg h^{-1}) and TDM (6498 kg h^{-1}) and seed oil content (45.83%) were obtained at T_{10} (NPK Zn), coinciding with 203 pods/plant and 120.53 cm plant height. The application of NPKS at T_9 resulted in the maximum seed protein (24.25%). Maximum LAI was recorded during 83 to 111 DAS period for all the treatments coinciding with the highest LAI value at T_{10} (4.8) which was followed up by the T_9 and T_8 having 4.61 and 4.56, respectively. The maximum value of CGR resulted at flowering (112-133 DAS) in which the T_{10}, T_9 and T_8 showed the maximum value of CGR having 16.313, 15.770 and 15.373 (g m^{-2} day^{-1}), respectively. The optimum LAI of canola plantation for the area in the study year was 4.26 which obtained at T_{10} during flowering. The RGR and NAR also were affected by the treatments, though not so much effective for RGR, the maximum NAR resulted at T_9 quite resemble to those of T_8 and T_{10} during the flowering stage.

Key words: Canola, yield, TDM, HI, CGR, RGR, NAR

INTRODUCTION

The seed yield of canola (*Brassica napus* L.) is related to certain plant characters, such as yield components as well as growth parameters. It is important to understand how the component unit of crop stands, accumulate biomass as well as how they perform in a group under different situations of soil fertility. Farmers in Mazandaran (the Northern Province) venturing canola growing apply the traditional N (Urea), P (Triple phosphate) fertilizers irrespective of the soil requirement, as they do usually for other crops like rice and wheat.

The seed yield, total dry matter and harvest index in some genotype of *Brassica napus* and *Brassica juncea* has been found to improve with higher rate of N (Kumar *et al*., 2001; Cheema *et al*., 2001). It is because N input generally increases the rate of conversion of carbohydrates into protein which in turn is important in the structure of the protoplasm. It increases the cell size, which is manifested morphologically in the increased leaf area index and crop growth rate (Bharadwai, 1991). A similar effect has also been noted by the application of sulphur (Chandel *et al*., 2002) in augmenting the cell-division; cell-elongation besides chlorophyll synthesis. These fertilizers also help in accelerating the photosynthetic activity (Chongo and McVetty, 2001) seen in the healthy green leaf number and also in dry-matter production (Singh and Singh, 1983; Diepenbrock, 2000) as observed in Indian mustard.

Lately it has been realized in Iran that imperfect and inadequate integration of nutrients and bad management practices limit the productivity of canola (*Brassica* sp.) as well as rapeseed. Also a total ignorance about the nutrient requirement of the soil spoils the canola crops in most cases and result in either lack or excess of these nutrients. Hence the present experiment was planned to establish a correlation between the different nutrients applications and their influence on the physiological parameters.

MATERIALS AND METHODS

The canola (cv. Hyola 401 hybrid), a high yielding early maturity canola hybrid, was grown during the months October to May, which is generally a humid season in Northern Iran. A split-plot experimental design,

Corresponding Author: Esmaeil Yasari, Department of Environmental Science, University of Pune, Pune 411 007, India
Tel: 91-9881414547

with 9 treatments in 4 replications with one control plot in each replication, was carried out in 2004-2005, in Baiecola Agricultural Research Station, Mazandaran (Lat. 36°37'N and Long 53°11'E) with an elevation of 16 m above the sea level. The area receives an average of 700-800 mm rain fall and has a relative humidity of 77% (Iranian Meteorological Organization, 2005). Prior to sowing, the field was prepared and sprayed with herbicide EK Trifluralin. The field was divided into plots of 2.5 × 4 m from which soil samples was taken and analyzed. The plantation was done in 30 cm row spacing with a 5 cm interplant distance in each row.

The experimental soil was texturally silt-clay, with pH 7.6, 1.3% O.C, 180 ppm of available K, 7 ppm of available P, 18 ppm Mn, 11 ppm Fe, 1.1 ppm B and 0.96 ppm of Zn. These characteristics formed the basis for the scheme of fertilizer application chosen for the experiment. The soil being adequately rich in Fe (>10 ppm), Mn (>15 ppm) and B (>1 ppm) these fertilizers were not added (Kimber and McGregor, 1999; Malakouti and Sepehr, 2004). The fertilizers of N as Urea (250 kg h^{-1}) applied in three split doses (1/3 before cultivation along with the other fertilizers as basal at final land preparation, 1/3 after rosette and 1/3 at stem elongation), P as triple super phosphate (150 kg h^{-1}), K as potassium sulfate (100 kg h^{-1}), S as sulfur powder (100 kg h^{-1}) and Zn as zinc sulfate (40 kg h^{-1}) were applied. Canola was grown under rain fed conditions and the chemical fertilizers used were compounds of N, P, K, NP, NK, PK, NPK, NPK S, NPK Zn applied as sub plots.

Five plants were sampled randomly in each treatments and averaged for recording the change in dry weight in shoots (above ground), interval at different stages of the canola growth 34, 67, 82, 111, 133, 153 and 182 DAS (Days After Sowing). The samples were first sun dried and thereafter in oven at 70°C till a constant weight was recorded. At maturity, the HI was estimated by dividing the seed yield to biological yield (seed + dry matter) and multiplying with 100. The leaf area (only one side) was determined by estimating the leaf weight and weight and surface of standard papers with the similar surface of the leaves. The dry matter accumulation rate per unit of land area (CGR) expressed as g m^{-2} day^{-1} and was calculated as: $CGR = (W_2-W_1)/\ \{SA\ (t_2-t_1)\}$. W_1 and W_2 are crop dry weight at the beginning and end of the interval t_1 and t_2 and SA is the soil area occupied by the plants at each sampling. The Relative Growth Rate (RGR) of plant at an instant in time (t) is defined as the increase of plant material per unit of material present per unit of time. It is expressed as g (g dry wt^{-1}) day^{-1} and was calculated as: $RGR = 1/w.\ dw / dt = d/dt\ (\log_e w)$ W is the dry weight and dw/dt is the change in dry weight per unit time.

The dry matter accumulation per unit of leaf area is termed as net assimilation rate (NAR). It is expressed as g (m leaf $area)^{-2}$ day^{-1} and calculated as: $NAR = 1/A.\ dw/dt$ Here, A is the leaf area and dw/dt is the change in plant dry matter per unit time (Acuqaah, 2002; Gupta and Gupta, 2005).

The seed oil and protein content were measured using Nuclear Magnetic Resonance (NMR) spectrophotometry (Madsen, 1976) and Micro Kjeldahl digestion followed by automated colorimetric analysis (Stringam *et al*., 1974), respectively. The data were analyzed following the Analysis of Variance Technique (ANOVA) and the mean differences were adjudged by the Duncan's Multiple Range Test (Gomez and Gomez, 1984).

RESULTS

Seed yield and yield attribution: The seed yield, HI, number of pods per plant, height of plant all were influenced significantly by the treatments. The effect on seed yield has been statistically significant ($p<0.01$), the best results obtained at T_{10} (NPK Zn), as the yield (3141.250 kg h^{-1}) by 326.61% increase over the control (Table 1). At T_5 (2621.500 kg h^{-1}), T_8 (2997.750 kg h^{-1}) and T_9 (3095.513 kg h^{-1}), the yield showed an increase of 256, 307 and 320% increase over the control, respectively. These three treatments though rank statistically in the same group, the yield shot above 3000 kg h^{-1} by application of additional S and Zn (as Zn sulfate), especially the latter. Haneklaus *et al.* (1999) reported an 88% rise in the canola yield by applying S-fertilizers (gypsum) alone. Mohan and Sharma (1992) also reported that application of N up to 75 kg h^{-1} as well as S increased the seed yield of Indian mustard. Jayan *et al.* (1997) reported an increase of 33% over the control, in the yield of Indian mustard by applying sulphur (50 kg ha^{-1}). Using a judicious combination of S (powder) with NPK fertilizers the yield has increased almost three times in the present experiment.

The HI also showed significant improvement ($p<0.05$), the best result at T_8 (33.57%) showing a 123% increase over the control. The lowest HI obtained at T_1 (Table 1). The high values of Harvest Index showed the more allocation of assimilate to the seed comparing to stove in the corresponding treatments.

The effect on the number of pods/plant was also statistically significant ($p<0.01$), the best result was at T_{10} with 203.35 pods, showing a 91.16% increase over the control, which coincided also with the highest seed yield (Table 1). Similar observation was made by Ozer (2003) and Hocking *et al.* (1997) suggesting seed yield increase with enhancement in N rate was mostly due to increase in

Table 1: Effects of chemical fertilizers on yield, harvest index, pods/ plant, plant height, seed oil and protein content

Treatments	Yield (kg h^{-1})	HI (%)	Pods/plant	Plant height (cm)	Oil content (%)	Protein content (%)
T_1 = control	736.313	15.03	106.40c	97.68b	41.84b	21.20d
T_2 = N	1827.438	28.18	131.38bc	107.18ab	43.69ab	23.43a-d
T_3 = P	1718.938	28.96	120.30bc	103.60ab	44.00ab	22.95a-d
T_4 = K	1266.125	24.36	124.40bc	98.00b	44.35ab	22.75b-d
T_5 = NP	2621.500	32.73	156.18a-c	112.70ab	45.42a	23.83a-c
T_6 = NK	1936.813	28.58	157.60a-c	108.83ab	43.99ab	23.18a-d
T_7 = PK	1520.750	23.35	134.6bc	102.80b	45.23a	22.50cd
T_8 = NPK	2997.750	33.57	168.68ab	110.10ab	45.68a	23.50a-c
T_9 = NPKS	3095.313	32.91	189.78a	112.88ab	44.38ab	24.25a-c
T_{10} = NPK Zn	3141.250	31.79	203.35a	120.53a	45.83a	24.03a-c
LSD (0.05)	784.3	8.954	34.73	11.39	1.987	1.919

Canola Growth Analysis: Values followed by different letter (s) differ significantly at $p<0.05$

pods number. The present experiment has shown that applying NP (T_5) increased the yield by 256.03%, the pods per plant increased by 46.78%, which was double the number of pods obtained by only N (T_2). The yield of ~3000 kg h^{-1} at T_9 and T_{10}, correspond to >189 pods/plant, indicating the usefulness of S and Zn as additions.

The effect on plant height was also statistically significant ($p<0.01$). The maximum height was attained at T_{10} (120.53 cm) but statistically it was not so different at all other treatments except at T_4 and T_7 where the height remained low (Table 1). The yield of ~ 3000 kg h^{-1} (T_5, T_8, T_9 and T_{10}) coincided with the plant height of 112 cm and pods/plant 160.

Oil and protein: Seed oil and protein content were influenced significantly by the treatments. The effect on canola seed oil was statistically significant ($p<0.05$), the maximum obtained at T_{10} (45.83%) showed a 9.53% increase over the control. The oil content improved at each treatment but remained within a narrow range of 43.7 to 45.8%. The seed oil content seemed somewhat NP dependent; the results at T_5, T_8 and T_{10} were quite similar, recording >8% gain over the control (Table 1). An improvement over the control was not treatment specific as even the depressed response at T_2 (N) and T_6 (NK) showed a rise. In an experiment carried out in Kerman, Iran (Morshedi *et al*., 2004; Malakoti and Sepehr, 2004), reported an improvement in the canola seed yield and oil content by applying Zn and Fe fertilizers (foliar sprays) along with N and K. An 1.5% increase in oil content of seeds of rapeseed was observed by Lääniste *et al.* (2004) due to additional application of sulfur. In the present experiment a remarkable improvement was achieved by the combined use of N, P and K with S/Zn-fertilizers. A similar observation was made earlier (Hocking *et al*., 1997) in experiments using N fertilizer in canola growing.

The effects of fertilizers on seed protein was also significant ($p<0.05$), the highest obtained with NPKS at T_9 (24.25%) but it was statistically similar to that of at all other treatments, except at T_4 (only K) and T_7 (PK). An increase in oil and protein content of seed due to application of nitrogen fertilizer was reported by Brennan *et al.* (2000), Ramsey and Callinan (1994) in canola and Mohan and Sharma (1992) in Indian mustard. Protein content enhancement in seeds of Indian mustard was observed by Chandel *et al.* (2002), Kumar *et al.* (2001), Singh *et al.* (1998), due to application of sulfur.

Dry- matter accumulation: The dry-matter accumulation was quite significantly improved by the treatments of different combinations of chemical fertilizers (Table 2) and can be seen at every stage of the plant growth. Generally a healthy plant growth achieved before rosette ensures a better tolerance of the winter in northern Iran. The application of N, P with or without K, S and Zn is found useful as it promoted a much healthier growth before the commencement of winter. A significantly higher TDM at rosette (35 to 67 DAS) was obtained at T_5, T_8, T_9 and T_{10} and a threshold value of 84 g m^{-2} was observed. At flowering (112 to 133 DAS) the TDM increased almost 7 times at these four treatments and a threshold value of 621 g m^{-2} was observed. The treatments T_8, T_9 and T_{10} resulted in a higher TDM than at T_5. This increase in TDM continued till reaching (134-153 DAS), with a threshold value of 820 g m^{-2}. At maturity (154-182 DAS), the TDM lowered in each of these four treatments almost returning to the level at the rosette stage or a little lower (with a threshold of 554 g m^{-2}). The exuberant growth rate between 134-153 DAS and a subsequent retardation is correlated with the stages of pod and seed initiation in canola plant. Wysocki *et al.* (2005) reported that after reaching a climax in full bloom, the canola dry matter declined due to flower drop and leaf senescence. A similar trend was found in seed yield as well as HI which was highest at treatments, T_5, T_8, T_9 and T_{10}. The higher HI indicates a corresponding increase in seed yield rather than stover yield (Kumar and Gangwar, 1985). Similar observation were made by Khanpara *et al.* (1993) and Kachroo and Kumar (1997) for Indian mustard.

Leaf Area Index (LAI): The rate of increase of leaf area determines the rate of increase in the photosynthetic

Table 2: Effects of chemical fertilizers on dry matter accumulation

Treatments TDM (g m^{-2})	0-34 DAS	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = control	1.72	15.84	42.72	182	357	512	428.05
T_2 = N	2.68	26.316	66	257.4	527.8	716.8	487.2
T_3 = P	2.6	26.52	59.4	226.2	485.8	658	412.65
T_4 = K	2.42	27.42	48.96	241.8	427	603	430.5
T_5 = NP	3.14	32.4	84.24	330.2	621.6	820.4	544.6
T_6 = NK	2.88	28.8	72.36	283.4	469	601	488.6
T_7 = PK	2.46	23.04	53.16	224.9	476	594	483.35
T_8 = NPK	2.98	32.64	89.88	357.5	695.8	862.4	605.85
T_9 = NPKS	3.23	35.22	94.8	362.7	709.8	914.2	635.95
T_{10} = NPK Zn	3.85	32.952	96.6	353.6	712.6	921.2	649.8
LSD (0.05)	0.1656	3.795	5.436	25.62	46.16	38.59	22.73

Table 3: Effect of chemical fertilizer on LAI at different stages of plant growth

Treatments	0-34 DAS	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = control	0.102	0.38	1.04	2.80	2.65	2.38	1.78
T_2 = N	0.138	0.75	2.60	3.90	3.49	3.14	2.39
T_3 = P	0.156	0.71	2.36	3.88	3.44	3.09	2.03
T_4 = K	0.158	0.52	2.24	3.36	3.58	3.22	2.31
T_5 = NP	0.144	0.76	3.52	3.95	3.90	3.51	3.12
T_6 = NK	0.144	0.71	2.84	3.80	3.70	3.33	2.86
T_7 = PK	0.144	0.56	2.00	3.50	3.80	3.42	3.13
T_8 = NPK	0.136	0.78	3.44	4.56	4.02	3.61	3.17
T_9 = NPKS	0.180	0.93	3.40	4.61	3.98	3.58	3.40
T_{10} = NPK Zn	0.198	0.87	3.58	4.80	4.26	3.83	3.66
LSD (0.05)	0.1656	0.1656	0.1481	0.3312	0.1656	0.1047	0.4056

capacity of plant. The application of different combination treatments did influence the LAI (Table 3) significantly. As mentioned earlier, the canola plant growth is critical at the rosette stage and if it is able to produce enough leaves before rosette the plant may spend a healthy winter. The LAI at rosette stage was higher at T_5, T_8, T_9 and T_{10} with a threshold value of 3.4. It increased further till 111 DAS in each of these four treatments but retards somewhat at the flowering stage. The application of NP with or without K, S and Zn resulted in higher LAI with a threshold value of 3.9-4 at the flowering stage. Correlating it with the yield, it can be concluded that the canola yield suffered at treatments where the LAI is <4, as observed also by Mendham *et al.* (1990). The optimum LAI of canola plantation (The LAI which resulted in the maximum value of CGR) for the area in the year of the study was understood to be 4.26 which obtained at T_{10} at flowering. The decrease in the LAI between 112-133 DAS and even further during the maturity is significant, as it relates to the broadening of the leaves, when compared to the exuberant increase in TDM in the corresponding period up to 153 DAS. Overall it can be concluded that successive increase in leaf area by application of NPK together either with or without S and Zn at different growth stages sufficiently indicated the beneficial effects of these nutrients, especially Zn and S, in increasing in the number and size of leaves of the canola plant. Sulphur is requires for *Brassica* to use nitrogen efficiently and plays important role in protein formation (Shulka *et al.*, 2002; Havlin *et al.*, 2003). Zinc closely involves in the N metabolism of the plant (Grant and Bailey, 1990).

Crop Growth Rate (CGR): The different treatments helped in an increasing the CGR compared to the control (Table 4). During rosette the CGR was low for each of the treatments but at T_5, T_8, T_9 and T_{10} it was higher. Plants resumed growth rapidly after rosette, the highest growth rate showed at T_{10} followed by T_5, T_8 and T_9. Unlike the TDM, the CGR calculated for the flowering period (112 to 134 DAS) was the highest, almost 16 to 18 times its value at rosette, it is more likely that new and actively photosynthesizing tissues of pods might be responsible for increase in dry weight during this phase (Clarke and Simpson, 1978). CGR then decreased eventually between the period 134-153 DAS and to even a negative value at final maturity (after 153 DAS). The steep decline in CGR in the last four weeks is an account of senescence of older leaves.

The CGR for all the treatments was low in the beginning, increased thereafter considerably up to 135 days with a peak during 112 to 135 days (Table 4). Thereafter the sharp reduction in CGR was recorded up to maturity. The decrease in leaf area index and crop growth rate towards maturity was due to senescence of lower leaves. Similar observation was made by Kumar *et al.* (1999). Shukla *et al.* (2002) reported that sulphur and zinc as supplementary nutrients application resulted in 23% and 20.5% increase in CGR value of Indian mustard although the effects were not statistically different.

Relative Growth Rate (RGR): The RGR of crop plants generally begins slowly just after germination, peaks rapidly soon afterward and then falls off. In the initial stages of the plant growth the ratio between active (alive) and dead tissues is high and almost the entire cells of productive organs are actively engaged in vegetative matter production. This is distinctly visible in the treatments T_5, T_8, T_9 and T_{10} which resulted initially in a higher RGR (Table 5) in the first five weeks of growth but subsequent senescence of some tissues, resulted in a steady decrease at the rosette and flowering stages. The further decrease in the RGR in the period 134-153 DAS was somehow similar, irrespective of the treatment and even reached a lower value in the above four treatments compared to others which might be due to more initial dry weight in these treatments compare to the other treatments. Eventually, in the final 4 weeks it reached a negative value for all the treatments. The reason of such negative value in RGR at the finial stage of the canola growth period can be an account of increase of the dead and woody tissues and textures comparing to the alive and active texture. Similar observations were made by Shukla *et al*. (2002) in Indian mustard.

Net Assimilation Rate (NAR): When all leaves are exposed to full sunlight, NAR remains to be highest. It also remains highest when plants are small and leaves are few to get maximum sunlight without shading effects. The NAR decreases with crop growth due to mutual shading of leaves and reduced photosynthetic efficiency of older leaves (Table 6).

When all leaves are exposed to full sunlight, NAR remains highest. It also remains highest when plants are small and leaves are few to get maximum sunlight without shading effects. The NAR decreases with crop growth due to mutual shading of leaves and reduced photosynthetic efficiency of older leaves (Kimber and McGregor, 1999).

Table 4: Effect of chemical fertilizer on CGR at different stages of plant growth

Treatments	0-34 DAS ($g\ m^{-2}\ day^{-1}$)	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = control	0.049	0.428	1.792	4.799	7.950	7.75	-2.79
T_2 = N	0.078	0.717	2.643	6.597	12.287	9.45	-7.65
T_3 = P	0.075	0.724	2.192	5.750	11.797	8.61	-8.17
T_4 = K	0.070	0.757	1.435	6.647	8.413	8.80	-5.74
T_5 = NP	0.091	0.886	3.456	8.477	13.240	9.94	-9.19
T_6 = NK	0.083	0.785	2.904	7.275	8.435	6.60	-3.74
T_7 = PK	0.070	0.625	2.008	5.919	11.410	5.90	-3.68
T_8 = NPK	0.085	0.898	3.816	9.223	15.373	8.39	-8.54
T_9 = NPKS	0.094	0.969	3.969	9.236	15.770	10.22	-9.18
T_{10} = NPK Zn	0.113	0.879	4.240	8.857	16.313	10.43	-9.04
LSD (0.05)	0.1656	0.1171	0.3703	0.9024	2.289	3.073	1.492

Table 5: Effect of chemical fertilizer on RGR at different stages of plant growth

Treatments	RGR 1-34 g (g drywt^{-1})	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = control	0.081	0.066	0.065	0.050	0.030	0.015	-0.005
T_2 = N	0.094	0.068	0.060	0.047	0.032	0.015	-0.012
T_3 = P	0.095	0.070	0.053	0.046	0.033	0.015	-0.015
T_4 = K	0.097	0.073	0.038	0.053	0.028	0.017	-0.011
T_5 = NP	0.101	0.070	0.064	0.046	0.027	0.012	-0.013
T_6 = NK	0.096	0.068	0.063	0.047	0.025	0.010	-0.006
T_7 = PK	0.094	0.067	0.056	0.049	0.028	0.010	-0.006
T_8 = NPK	0.103	0.071	0.067	0.047	0.028	0.013	-0.011
T_9 = NPKS	0.100	0.071	0.066	0.045	0.033	0.013	-0.012
T_{10} = NPK Zn	0.098	0.065	0.071	0.048	0.031	0.011	-0.011
LSD (0.05)	0.01656	0.01656	0.01656	0.01656	NS	NS	NS

Table 6: Effect of chemical fertilizer on NAR at different stages of plant growth

Treatments	NAR 0-34 g (m leaf area)$^{-2}$ day^{-1}	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = control	0.493	1.125	1.720	1.717	3.010	3.230	-1.57
T_2 = N	0.563	0.952	1.017	1.683	3.520	2.990	-3.20
T_3 = P	0.487	1.015	0.923	1.477	3.423	3.140	-4.33
T_4 = K	0.447	1.446	0.637	1.977	2.347	2.723	-2.55
T_5 = NP	0.637	1.163	0.980	2.147	3.393	2.827	-2.96
T_6 = NK	0.587	1.094	1.017	1.920	2.327	1.973	-1.28
T_7 = PK	0.503	1.123	1.013	1.680	3.000	1.733	-1.19
T_8 = NPK	0.643	1.147	1.107	2.020	3.813	2.300	-2.70
T_9 = NPKS	0.527	1.032	1.167	1.997	3.963	2.850	-2.72
T_{10} = NPK Zn	0.570	1.002	1.177	1.843	3.827	2.717	-2.47
LSD (0.05)	0.05237	0.1571	0.1888	0.240	0.6767	0.8871	0.8296

At the rosette stage, it is surprising to find that the NAR at all the treatments was fairly lower than in the control plants (Table 6). In the interval 83-111 DAS, the NAR at most treatments showed a rise and became marginally higher than at the control. The NAR at the control remained unchanged. At the flowering stage (112 to 133 DAS) the NAR rose distinctly, nearly doubled at some treatments as well as at the control, indicating that this factor was not so dependent on any specific kind of treatment. On the other hand it also shows that the CGR increased and the LAI decreased during this period. It is further proved by the fact that while at the control it raised further in the subsequent period (134-153 DAS), it declined in all the treatments significantly, except at T_4. This indicates a larger increase in the LAI as compared to the CGR in practically all the treatments. A rise in the NAR would also mean a resultant gain in photosynthesis over respiration and the reverse would be the case in case of declining NAR in the respective stages of plant growth.

CONCLUSIONS AND DISCUSSION

The yield of ~3000 kg h^{-1} (T_8, T_9 and T_{10}) was obtained when the plant height reached ≥111 cm and the pods/plant were ≥ 160. Similarly, the yield range of ~2700-3000 kg h^{-1} reached only at treatments in which the LAI (at flowering stage) was ≥ 3.90. The yield of ~ 3000 kg h^{-1} at T_9 and T_{10}, correspond to >189 pods/plant and LAI value ~4, indicating the usefulness of S and Zn as additions. The canola growth and yield suffered at treatments where the LAI is <4, as observed also by Mendham *et al*. (1990).

Increasing trend of LAI during the growth periods continued to 83-111 DAS which was synchronized with increase in CGR and dry-matter accumulation. After this period a gently decrease in LAI was observed in spite of continuity increase in the two values (CGR and dry-matter accumulation) up to 112-133 and 134-153 DAS for CGR and TDM, respectively. The result showed that increase in CGR and dry-matter accumulation irrespective to decrease in LAI in the corresponding phase is more likely because of the new actively phosynthesizing tissues of pods which might be responsible for increase in dry weight as well as CGR during these phase. Similar observation was made by Clarke and Simpson (1978) in Indian mustard.

Jain *et al*. (1995) reported that leaf area index and dry matter increased significantly by providing S fertilizer. The increase in LAI was attributed to the increase in leaf number and total leaf area/plant. Singh and Kumar (1996) reported that application of N and S resulted in the increase in yield as well as in HI of Indian mustard. An increase in HI for *Brassicas* through fertilizer use can also be achieved by greater allocation of assimilates from vegetative plant parts to grain (Singh *et al*., 2001).

The higher seed yield in the treatments comprising NPK, with S or Zn was an account of higher value of TDM at ripening stage, which coincided with the higher value of HI (>31%). This fact showed that the canola crop adopt themselves to use the available nutrients for the healthy growth during different stages and transfer these nutrients as well as assimilates to the most important sinks which is called seed. This transference was proved to be more effective for the treatments including NPK, NPKS and NPK Zn since they showed more HI as well TDM.

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