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Relationship of Growth Parameters and Nutrients Uptake with Canola (*Brassica napus* L.) Yield and Yield Contribution at Different Nutrients Availability

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Abstract: A field experiment was conducted to evaluate the effect of different nutrients on canola (*Brassica napus* L.) growth parameters, nutrient uptake and ultimately on seed yield. For this purpose a split plot experimental design, with 10 treatments in 4 replications was carried out in 2004-2005, in silt-clay soil at Baiecola Agricultural Research Station, Mazandaran Iran. Canola seed yield, growth parameters (CGR, LAI, RGR and NAR), dry matter accumulation and HI and nutrient content of the leaf were examined. N P K fertilizers together with S and Zn, singly or in combination were applied. The results showed that at treatments T_5 (NP), T_8 (NPK), T_9 (NPKS) and T_{10} (NPKZn) the higher seed yield (> 2600 kg ha^{-1}) coincided with TDM>880 g m^{-2}, the peak CGR ≥ 13.9 g m^{-2} day^{-1} and the maximum LAI ≥ 4.1. The higher seed yield at T_5, T_8, T_9 and T_{10} coincided with higher concentrations of nutrients: N, P, K, S and Zn in leaf at flowering having ≥ 3.40%, ≥ 0.25%, ≥ 1.53%, ≥ 110 ppm and ≥ 22.7 ppm, indicating substantial levels of translocation of nutrients at various stages of plant growth and higher number of pods per plant (≥ 179). Combined application of NPKZn at T_{10} resulted in maximum seed yield (3090 kg ha^{-1}), coinciding with the maximum number of pods per plant (230), maximum TDM (1043 kg ha^{-1}), maximum CGR (20.09 g m^{-2} day^{-1}) and maximum LAI (4.69).

Key words: Canola, yield, Total Dry Matter (TDM), Harvest Index (HI), Crop Growth Rate (CGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR)

INTRODUCTION

Canola (*Brassica napus* L.) growing has been started in Mazandaran Province from the last 10 years only. Agronomically, the greatest challenge in growing a crop like canola is getting adequate nutrient since canola plant is well known to be a voracious scavenger of nutrients, normally rendering the soil impoverished. The seed yield of canola 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 nutrients availability. The seed yield, total dry matter and harvest index in some genotypes of *Brassica napus* and *Brassica juncea* has been found to improve with higher rate of N (Kumar *et al*., 2001; Cheema *et al*., 2001; Khanna *et al*., 2003; Miller *et al*., 2003). 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). The application of P also significantly increases the seed yield, Leaf Area Index (LAI) and Total Dry Matter (TDM) as well as increases the P uptake in canola and some other *Brassica* species (Thakur and Jagdish, 1998; Lickfett *et al*., 1999). 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.

The imperfect and inadequate integration of nutrients and bad management practices limit the productivity of canola (*Brassica* sp.) as well as rape seed. 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 application and their influence on the physiological parameters comprising: Total Dry Matter (TDM), Crop Growth Rate (CGR), Relative Growth Rate (RGR), Leaf Area Index (LAI) and Net Assimilation Rate (NAR) at different intervals, denoting important growth stages and nutrient uptake and ultimately the seed yield.

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MATERIALS AND METHODS

A field experiment was conducted to evaluate the effect of different nutrients on canola growth parameters, nutrient uptake at flowering stage and ultimately on seed yield. For this purpose a split plot experimental design, with 10 treatments in 4 replications was carried out in 2004-2005, in silt-clay soil at Baiecola Agricultural Research Station, Mazandaran Iran. 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. 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 were taken and analyzed. The plantation was done in 30 cm row spacing with a 5 cm interplant distance in each row.

The experimental soil has 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, 1995; 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 (T_2), P (T_3), K (T_4), NP (T_5), NK (T_6), PK (T_7), NPK (T_8), NPK S (T_9) and NPK Zn (T_{10}) 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. The growth parameters comprising TDM (Total Dry Matter), Leaf Area Index (LAI), Crop Growth Rate (CGR), RGR (Relative Growth Rate) and NAR (Net Assimilating Rate) were determined following Acuqaah (2002) and Gupta and Sumita (2005). The concentration of different nutrients in leaf at flowering (112-133 DAS) was also determined following dry oxidation and digestion in HCI (Eamami, 1996) method.

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 AND DISCUSSION

Total Dry Matter (TDM): The application of different chemical fertilizers (Table 1) improved significantly the fodder resulting in TDM. The TDM increased during the plant growth, reached to a maximum level at 134-153 DAS, then showed a declining trend at maturity. A significantly high TDM was obtained during (68 to 82 DAS) period at treatments T_8 (NPK), T_9 (NPKS) and T_{10} (NPKZn). A threshold value of 95 g m^{-2} obtained at these three treatments was significantly different from the results at other treatments. The TDM showed exuberant increase till 134-153 DAS, with a threshold of 1035 g m^{-2} for these three treatments. At maturity (154-182 DAS), the TDM gets lowered in all the treatments, may be on account of dropping of senescent leaves and pods. Wysocki *et al.* (2005) have also reported such a decline in TDM after reaching a climax in full bloom. The TDM at the treatments T_8 (NPK), T_9 (NPKS) and T_{10} (NPKZn) remained more than that at others treatments with a threshold of 1014 g m^{-2} at maturity.

Crop Growth Rate (CGR): The rate of increase in the dry matter per unit of land and unit of time shows the Crop Growth Rate (CGR). It increases with the crop growth and after reaching a climax, declines, showing a decrease in the rate of dry matter accumulation (Table 2). During 68 to 82 DAS the CGR was low at each treatment except at treatments T_5 (NP), T_8 (NPK), T_9 (NPKS) and T_{10} (NPKZn) with a threshold value of 4 g m^{-2} day^{-1}. The CGR increased steeply till 112 to 133 DAS (at flowering). During flowering a much higher CGR was obtained at the treatments T_9 and T_{10} (~ 20 g m^{-2} day^{-1}) compared to other treatments. Shukla *et al.* (2002) reported that using sulphur and zinc as supplementary nutrients resulted in 20.5 and 23% increase in CGR in Indian mustard. In the present case also it was very high at T_8, T_9, T_{10} till 153 DAS, where K, S and Zn where supplementary nutrients to NP. Unlike the TDM, the CGR was higher during the flowering period. Even when the CGR declined (134-153 DAS), the TDM showed improvement at all the treatments (T_2-T_{10}). It is perhaps related to the new and actively photosynthesizing tissues of pods which grow

Table 1: 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	15.00	41.00	165.00	278.00	315.00	285.00
T_2 = N	2.68	26.00	67.00	285.00	543.00	740.00	670.00
T_3 = P	2.42	22.00	61.00	242.00	481.00	615.00	572.00
T_4 = K	2.22	19.00	50.00	217.00	442.00	525.00	497.00
T_5 = NP	3.14	30.00	86.00	367.00	659.00	889.00	883.00
T_6 = NK	2.88	29.00	74.00	314.00	586.00	779.00	728.00
T_7 = PK	2.46	24.00	63.00	256.00	491.00	634.00	573.00
T_8 = NPK	2.98	33.00	95.00	408.00	745.00	1035.00	1014.00
T_9 = NPKS	3.23	35.00	101.00	419.00	832.00	1127.00	1036.00
T_{10} = NPKZn	3.65	37.00	107.00	427.00	849.00	1160.00	1043.00
LSD (0.05)	0.117	2.985	3.863	12.17	21.09	21.39	23.05

Table 2: Effect of chemical fertilizer on CGR at different stages of plant growth

Treatments (g m^{-2} day^{-1})	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	0.050	0.415	1.85	4.42	5.38	1.94	-1.070
T_2 = N	0.078	0.727	2.93	7.78	12.28	10.36	-2.480
T_3 = P	0.071	0.611	2.78	6.46	11.38	7.05	-1.530
T_4 = K	0.064	0.524	2.21	5.96	10.71	4.36	-0.990
T_5 = NP	0.092	0.839	4.00	10.03	13.90	12.10	-0.214
T_6 = NK	0.084	0.816	3.21	8.57	12.95	10.15	-1.821
T_7 = PK	0.072	0.673	2.78	6.89	11.19	7.52	-2.176
T_8 = NPK	0.087	0.937	4.43	11.17	16.04	15.26	-0.750
T_9 = NPKS	0.095	0.992	4.71	11.35	19.66	15.52	-3.247
T_{10} = NPKZn	0.107	1.042	5.00	11.42	20.09	16.36	-4.175
LSD (0.05)	0.01656	0.0907	0.327	0.462	0.929	1.57	1.030

Table 3: Effect of Chemical fertilizer on RGR at different stages of plant growth

Treatments (g g^{-1} dry wt.)	RGR 1-34	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = Control	0.015	0.066	0.074	0.049	0.024	0.0064	-0.0035
T_2 = N	0.028	0.070	0.068	0.051	0.030	0.0162	-0.0035
T_3 = P	0.026	0.068	0.073	0.048	0.032	0.0129	-0.0025
T_4 = K	0.023	0.066	0.070	0.052	0.033	0.0091	-0.0019
T_5 = NP	0.033	0.069	0.078	0.051	0.027	0.0156	-0.0002
T_6 = NK	0.030	0.071	0.067	0.051	0.029	0.0149	-0.0024
T_7 = PK	0.026	0.070	0.069	0.050	0.030	0.0134	-0.0036
T_8 = NPK	0.032	0.074	0.075	0.052	0.028	0.0173	-0.0007
T_9 = NPKS	0.034	0.074	0.076	0.051	0.032	0.0158	-0.0030
T_{10} = NPKZn	0.038	0.072	0.075	0.049	0.032	0.0165	-0.0037
LSD (0.05)	0.01656	0.01656	0.01656	0.01656	0.01656	0.01656	ns

during this period of growth. Similar observation was also made by Clarke and Simpson (1978) and Mathur and Wattal (1996). The decrease in CGR between the period 134-153 DAS eventually becomes negative at the physiological maturity (after 153 DAS) of the canola plants. The steep decline in CGR in the last four weeks is on account of the corresponding decrease in TDM observed at all the treatments.

Relative Growth Rate (RGR): Application of chemical fertilizers resulted in initially higher value of the RGR especially at the treatments T_{10}, T_9 and T_5 with NP and supplementary S and Zn followed by T_8 (Table 3) with supplementary K in the first five weeks of growth. The RGR at 68-82 DAS remained almost steady in which it was also higher at these four treatments. The subsequent senescence of some tissues resulted in a steady decrease of the RGR during 83-111 DAS and 112-133 DAS (flowering) at all the treatments. The RGR decreased further during the period 134-153 DAS. Eventually, in the final 4 weeks the RGR 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 on account of an increase in the dead and woody tissues and textures compared to the alive and active textures. Similar observations were made by Shukla *et al*. (2002) on Indian mustard.

Leaf Area Index (LAI): The rate of increase in the leaf area determines the photosynthetic capacity of the canola plant. The application of different combinations of chemical fertilizers influenced the LAI (Table 4) significantly. The canola plant growth is critical before winter commencement and if it is able to produce enough leaves prior to severe season, the plant spends a healthy winter. The LAI during 68 to 82 DAS was higher at T_8, T_9

Table 4: 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	0.10	0.59	0.99	1.25	1.64	1.35	0.46
T_2 = N	0.15	1.51	2.55	2.70	2.86	2.77	1.09
T_3 = P	0.13	1.33	2.20	2.52	2.49	2.17	0.92
T_4 = K	0.11	1.10	1.96	2.04	2.00	1.74	0.77
T_5 = NP	0.16	1.89	3.66	3.86	4.10	3.40	1.42
T_6 = NK	0.15	1.51	2.71	2.86	3.03	2.85	1.18
T_7 = PK	0.13	1.33	2.22	2.62	2.58	2.27	0.95
T_8 = NPK	0.16	1.99	4.19	4.51	4.49	3.60	1.65
T_9 = NPKS	0.18	2.13	4.33	4.69	4.58	3.80	1.78
T_{10} = NPKZn	0.19	2.20	4.39	4.62	4.69	3.90	1.82
LSD (0.05)	0.016	0.117	0.117	0.148	0.090	0.148	0.090

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

Treatment ($g\ m^{-2}$ leaf area day^{-1})	NAR 0-34	35-67 DAS	68-82 DAS rosette	83-111 DAS	112-133 DAS flowering	134-153 DAS	154-182 DAS maturity
T_1 = Control	0.50	0.69	1.88	3.54	3.30	1.44	-2.40
T_2 = N	0.52	0.47	1.15	2.88	4.29	3.74	-2.26
T_3 = P	0.54	0.46	1.27	2.56	4.57	3.26	-1.66
T_4 = K	0.59	0.47	1.13	2.92	5.38	2.51	-0.31
T_5 = NP	0.57	0.44	1.09	2.60	3.39	3.59	0.151
T_6 = NK	0.56	0.53	1.18	2.99	4.27	3.56	-1.68
T_7 = PK	0.55	0.51	1.25	2.63	4.33	3.31	-2.31
T_8 = NPK	0.54	0.47	1.05	2.48	3.57	4.23	-0.42
T_9 = NPKS	0.52	0.46	1.09	2.42	4.29	4.10	-1.83
T_{10} = NPKZn	0.56	0.47	1.14	2.47	4.28	4.19	-2.29
LSD (0.05)	0.09	0.104	0.14	0.335	0.366	0.491	1.127

and T_{10}, a threshold value of 4.19 observed in these treatments. Thus the presence of K, S and Zn as supplementary nutrients of NP was very useful. Like CGR, the LAI increased further till flowering (112-133 DAS) and reached a climax during this stage. At this stage the maximum LAI was recorded at T_{10} resulting in LAI 4.69 followed by T_9 (4.58) and T_8 (4.49) i.e., NP with Zn, S and K. Increase in the LAI in rapeseed and mustard plant by application of N, P, K, S and Zn have also been reported (Lallu and Saxena, 1995; Pasricha and Bahl, 1996; Tomar *et al*., 1997; Krishna *et al*., 1999).

The LAI at flowering is considered crucial for getting better seed yield. In the present case the maximum LAI at treatments T_1, T_2, T_3, T_4, T_6 and T_7 remained ≤ 3, while at treatments T_5, T_8, T_9 and T_{10} it enhanced up to > 4, thus it is expected that the treatments T_5, T_8, T_9 and T_{10} are more efficient than the treatments T_1, T_2, T_3, T_4, T_6 and T_7 for getting enhanced yield.

The LAI of the canola plants thereafter declined at the flowering and even more at maturity. The decrease in LAI at the final stages of the canola growth is quit normal and can be on account of senescence and dropping of leaves, especially the old ones and those which were present at the lower horizons of the canopy.

Net Assimilation Rate (NAR): The TDM per unit of leaf area is termed as net assimilation rate (NAR) or unit leaf rate. It is giving by the ratio of CGR to LAI. In the initial stages up to 67 DAS there were statistically no differences in NAR at treatments (Table 5). The NAR remained subdued right up to 111 DAS where the control plot showed better results than those with chemical fertilizers. At flowering the NAR was greater at treatments other than T_5 and T_8 with NP and NPK. It was maximum at T_4 (5.38 g m leaf area^{-2} day^{-1}) showing the minimum LAI compared to CGR in presence of K, at the remaining treatments NAR was >4 and <5 but higher than at control.

The application of the chemical fertilizers resulted in delaying NAR to its maximum level (111 to 133 DAS). At T_8, T_9 and T_{10} during early stages of the growth NAR was less, which showed the lower ratio of CGR to LAI in these treatments compared to the others. During flowering (112 to 133 DAS) NAR rose distinctly, at some treatments having >4.5 g (m leaf area day^{-1}). During 134-153 DAS, although the NAR was higher at treatments T_8, T_9 and T_{10} ($\geq$ 4.1), but it showed more increasing trend at T_5 and T_8 from 112-133 DAS to 134-153 DAS. This increase ensured plant growth and subsequently a higher seed yield in these treatments compared to the rest of the treatments. It was because of more increase in the CGR relative to LAI. 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.

Nitrogen: The application of N fertilizer resulted in a substantial increase in N content of the leaf. The N concentration of leaf observed in the present study

Table 6: Effect of chemical fertilizers and biofertilizers on the concentration of N, P, K, S and Zn in leaf

Treatments	N contents of leaf (%)	P contents of leaf (%)	K contents of leaf (%)	S contents of leaf (ppm)	Zn contents of leaf (ppm)
T_1 = Control	2.91	0.15	1.23	92	21.50
T_2 = N	3.39	0.19	1.37	96	22.40
T_3 = P	3.12	0.24	1.35	98	21.90
T_4 = K	2.97	0.17	1.80	94	21.30
T_5 = NP	3.47	0.25	1.53	110	22.70
T_6 = NK	3.42	0.22	1.91	107	22.20
T_7 = PK	3.18	0.25	1.86	102	22.50
T_8 = NPK	3.46	0.25	1.93	112	23.00
T_9 = NPKS	3.43	0.26	1.93	145	23.10
T_{10} = NPKZn	3.40	0.25	1.94	117	27.20
LSD (0.05)	0.104	0.016	0.117	6.069	1.547

(Table 6) was within the range 2.91-3.47%. Application of N fertilizer alone at T_2 resulted in 3.39% N in leaf showing an 16.5% enhancement. The maximum N content among the treatments T_1 to T_{10} however, was observed at T_5 (3.47%) showing 19.24% increase which was followed by T_8 (3.46%) where N was supplemented with P and K. At T_6, T_9 and T_{10} also the N concentration was $\geq$ 3.4% but less than at T_5 and T_8. An increase in N concentration with the application of N in Indian mustard has been reported (Kakati and Kalita, 1996) which was reflected in increased seed yield and yield attributing characters. A higher nitrogen uptake in the grain and straw of rice with the application of N fertilizer is also reported (Roul and Sarwagi, 2005).

Correlating leaf N content with LAI, it was observed that the higher leaf N content at treatments T_5, T_8, T_9 and T_{10} ($\geq$ 3.4%) coincided with the higher LAI ($\geq$ 4.10) at flowering stage. It indicates conductive conditions for efficient translocation of N. However, it is not a limiting factor for obtaining higher LAI, as seen at T_2 and T_6.

Correlating leaf N content with NAR, it was observed that the higher N content at treatments T_8, T_9 and T_{10} ($\geq$ 3.4%) coincided with NAR $\geq$ 4.1 g m leaf area^{-2} day^{-1}, at 134-153 DAS. The increasing trend of NAR from 112-133 to 134-153 DAS was maximum at T_5 and T_8 among all the treatments which coincided with leaf N of 3.47 and 3.43%, respectively.

Phosphorus: The P fertilizer increased its concentration in the leaf (Table 6). Application of P at T_3 did enhance the P concentration to 0.24%. The N and K fertilizers at T_2 and T_4 also resulted in mobilization of P by 26 and 13% increase into the leaf, respectively. The maximum content of P in leaf was however observed at T_9 (0.26%) showing 73.33% increase over control. At this treatment (T_9) NPK was supplemented by S which should have reduced the soil pH and facilitated the mobilization of P. At treatments without S like at T_5, T_7, T_8 and T_{10} also the P uptake was substantial (0.25%) but slightly lower than at T_9. The results are similar to the findings of Kakati and Kalita (1996) in Indian mustard.

Correlating the leaf P content with LAI, it was observed that higher leaf P content at treatments T_5, T_8, T_9 and T_{10} ($\geq$ 0.25%) coincided with higher LAI ($\geq$ 4.1) at flowering stage. It indicates conductive condition of efficient translocation of P. However, it is not a limiting factor for obtaining higher LAI, as seen at T_7, which is without N. Correlating the leaf P content with NAR, it was observed that higher leaf P contents at treatments T_8, T_9 and T_{10} ($\geq$ 0.25%) coincided with NAR ($\geq$ 4.10 g m leaf area^{-2} day $^{-1}$).

Potassium: The application of K fertilizer individually or in combination with N, P, S and Zn showed an overall increase in the concentration K in leaf (Table 6). Applying K fertilizer at T_4 (1.8%) showed an increase of 46.34% in its concentration in leaf but the highest K concentration was obtained at T_{10} (1.94%) which was close to those obtained at T_8 and T_9 (1.93%). Increase in K concentration of leaf by application of K fertilizer have also been reported by Kopsell *et al.* (2004) in Leafy (*Brassica oleracea*) cultivars, suggesting a range between 2.1 and 3.5%. In the present study however, leaf K levels ranged from 1.23 to 1.94%. The P content at T_6 (NK) and T_7 (PK) was 1.91 and 1.86% showing 55 and 51% increase over control, respectively.

Correlating the leaf K content with LAI, it was observed that higher leaf K content at treatments T_8, T_9 and T_{10} ($\geq$ 1.93%) coincided with higher LAI ($\geq$ 4.49) at flowering stage. It indicates conductive condition of efficient translocation of K. Correlating the leaf K content with NAR, it was observed that higher leaf K contents at treatments T_8, T_9 and T_{10} ($\geq$ 1.93%) coincided with NAR ($\geq$ 3.57).

Sulphur: The maximum concentration of S in leaf (Table 6) was obtained at T_9 (145 ppm) where S fertilizer was applied. Application of sulphur was reported to be beneficial to yield of *Brassica* family (Tadon, 1991; Sharma and Debnath, 1999) might be due to better availability of N, K and S and their translocation which reflects in terms of increased yield attributes of canola.

Zinc: Application of Zn fertilizer at treatment T_{10} resulted in higher Zn concentration (27.2 ppm) which showed 26.5% increase over control (Table 6). Applying Zn has been reported to increase the Zn concentration in leaf, seed and straw of rapeseed and canola (Rashid *et al.*, 1994; Grawel and Graham, 1999; Morshedi *et al.*, 2004).

Seed yield and yield attribution

Seed yield: The seed yield improved significantly by the application of different nutrients at $p<0.01$ (Table 7). The maximum seed yield was obtained at T_{10} (3090 kg ha^{-1}), showed an increase of 319% over the control. At T_8 (2975 kg ha^{-1}) and T_9 (3025 kg ha^{-1}), the seed yield showed 304 and 310% increase, respectively. These three treatments though ranked statistically in the same group, the seed yield shot above 3000 kg ha^{-1} by application of additional S and Zn, especially the latter. Haneklaus *et al.* (1999) reported an 88% rise in the canola yield by applying S-fertilizers (gypsum) alone. Using a judicious combination of S with N P K fertilizers the seed yield has increased more than four times in the present experiment.

An increase of 105% in canola yield has already been reported (Mirzashahi *et al.*, 2004) by applying K fertilizer alone in northern Khuzestan, Iran. In the present experiment K (1266 kg ha^{-1}) increased the seed yield around 72% over the control. An increase of 42.5% was also reported (Aulakh and Pasricha, (1997) by application of P fertilizer, in the present study however, the seed yield enhanced 124% owing to the applying P fertilizer. Between N (T_2), P (T_3) and K (T_4), the application of N (urea) on the seed yield was the most effective (1997 kg ha^{-1}), but combination of NP (T_5) was more effective than using N, P, K singly or even NK (T_6) and PK (T_7).

The results obtained in the present study are reported by Cheema *et al.* (2001) suggesting that increase in the rate of N and P separately resulted in a higher seed yield; Mainly because of more number of pods per plant. Similar observations were also reported by Santonoceto *et al.* (2002) and Hocking *et al.* (2003) for canola and by Jayan *et al.* (1997) and Zhaohui and Shengxiu (2004) for mustard.

Correlating the LAI with the seed yield (0.988**), it was observed that the canola yield suffered at treatments whenever the LAI is<4 at the flowering stage. Similar observation was also made by Mendham *et al.* (1990) reporting that the LAI<4 resulted in decrease in the growth and yield of canola.

Number of pods per plant: The number of pods per plant was improved ($p<0.01$) by the application of chemical fertilizers (Table 7). At T_1 (control) and T_4 (K) the number remained subdued (< 95), while at T_3 (P) and T_7 (PK) it increased up to 122 and 126, respectively. The application of N alone (T_2) and NK (T_6) enhanced the number further up to 137 and 141, respectively and at T_5 (NP) it shot to 179. The number of pods improved even more at T_8 (216), T_9 (224) and reached a maximum at T_{10} (230). Correlating the number of pods with TDM (Table 1) at maturity, the maximum CGR (Table 2) and the maximum LAI (Table 4) both at flowering, it is observed that the number of pods $\geq$179 coincided with TDM>880 g m^{-2} (0.983**), the maximum CGR $\geq$13.9 g $m^{-2}day^{-1}$ (0.945**) and the maximum LAI > 4.1 (0.992**), observed at T_5, T_8, T_9 and T_{10}. It was further noticed that the attainment of the number of pods $\geq$179 coincided with higher concentrations of the nutrients: N, P, K, S and Zn in leaf at flowering having $\geq$3.4%, $\geq$0.25%, $\geq$1.53%, $\geq$110 and $\geq$22.7 ppm (Table 6).

Table 7: Effect of different nutrients on yield, harvest index and pods/plant

Treatments	Yield (kg h^{-1})	HI (%)	Pods/plant
T_1 = Control	736.3f	20.56bc	75e
T_2 = N	1997cd	22.95a	137c
T_3 = P	1650d	22.30abc	122c
T_4 = K	1266e	20.28c	94de
T_5 = NP	2622b	22.86ab	179b
T_6 = NK	2107c	22.42abc	141c
T_7 = PK	1690d	22.76ab	126c
T_8 = NPK	2975a	22.68ab	216a
T_9 = NPKS	3025a	22.66ab	224a
T_{10} = NPKZn	3090a	22.87ab	230a
LSD (0.01)	346.7	2.002	20.15

Mean values with the same letter(s) are not significantly different

Harvest index: The Harvest Index (HI) is the ratio of economical yield (seed yield) to total plant biological yield, which usually expresses as%. The HI showed an improvement by the application of chemical fertilizers at $p<0.05$ (Table 7). The highest harvest index (22.95%) among the treatments T_1 to T_{10} was observed at treatments T_2 ensuring the higher allocation of assimilates from vegetative parts to grain (Kumar *et al.*, 2001). The higher HI indicates a corresponding increase in seed yield rather than stover yield (Kumar and Gangwar, 1985). At T_5 and T_{10} the HI was also high ($\geq$22.86%), followed by T_7 (22.76%), T_8 (22.68%) and T_9 (22.66%), which showed the effect of N, P, K, S and Zn in higher increase in the seed yield rather than fodder.

The lowest HI however, was recorded at T_4 (20.28%) showing the least effect of K fertilizer in the present study, related to lower seed yield and higher fodder. Kumar *et al.* (2001) reported that seed yield and harvest index in some genotype of *Brassica napus* and *Brassica juncea* increased with higher rates of N, which is also observed at the present study. The application of N, K and S was reported to increase the yield as well as HI of rapeseed and Indian mustard (Khanpara *et al.*, 1993; Pasricha and Bahl, 1996; Singh and Kumar, 1996; Kachroo and Kumar, 1997).

CONCLUSIONS

The present study showed that application of N and P fertilizers singly enhanced the seed yield only up to <2000 kg ha^{-1}. K fertilizer has the least effect in promoting the seed yield (<1270 kg ha^{-1}) at T_4 and (<1700 kg ha^{-1}) at T_7. Combined application of NP (T_5) has a better effect in enhancing the yield beyond 2600 kg ha^{-1}, which is more than that at T_6 using NK (2100 kg ha^{-1}). Application of NPK alone (T_8), with S (T_9) and with Zn (T_{10}) did enhance the seed yield ~ 3000 kg ha^{-1}. At treatments (T_5, T_8, T_9 and T_{10}) the higher seed yield (> 2600 kg ha^{-1}) coincided with TDM>880 g m^{-2}, the peak CGR ≥ 13.9 (g m^{-2} day^{-1}) and the maximum LAI ≥4.1.

The higher seed yield at T_5, T_8, T_9 and T_{10} coincided also with higher concentrations of nutrients: N, P, K, S and Zn in leaf at flowering having ≥ 3.40%, ≥ 0.25%, ≥1.53%, ≥ 110 ppm and ≥ 22.7 ppm, indicating substantial levels of translocation of nutrients at various stages of plant growth. Above mentioned levels of nutrient concentrations coincided with increased number of pods per plant (≥ 179) and the >2600 kg ha^{-1} yield.

The higher seed yield in the treatments comprising NPK, with S or Zn was an account of higher value of TDM at ripening stage. 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 (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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