THE EFFECT OF NITROGEN LIMITATION ON INTERCEPTION AND USING OF RADIATION IN SPRING CANOLA CULTIVARS

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Abstract

In order to estimate extinction coefficient (EC or K), radiation use efficiency (RUE) and dry matter accumulation (DMA) in canola (Brassica napus L.), a factorial experiment was conducted based on randomize complete block design (RCBD) with four replications in 2013-2015, at Gonbad Kavous University, Iran. Treatments consisted of four canola cultivars (Hyola 401, Zarfam, Hyola 308 and RGS003) and three levels of nitrogen fertilizer (0, 50% (75 kg/ha urea) and 100% (150 kg/ha urea) of N fertilizer recommendation). Results showed that nitrogen fertilizer had a significant impact on light extinction coefficient, especially in the second year. The obtained figures of extinction coefficient for the cultivars ranged from 0.4 to 0.8, with the lowest at 100% recommended nitrogen for RGS003 in the second year. The amount of RUE was different during the two years in terms of nitrogen fertilizer for cultivars. The highest RUE (1.2 g MJ^{-1}) was obtained at 100% nitrogen fertilizer for RGS003 in the second year. There was a significant effect of treatments on dry matter ($P<0.05$). The highest and lowest dry matter production were 1032.4 and 371.9 g m^{-2} day^{-1} at zero and 100 percent of N fertilizer recommendation and for Hyola 308 and RGS003, respectively.

Keywords: *Brassica napus L., Fertilizer, Leaf area index, Radiation use efficiency*

1. INTRODUCTION

Colza is grown on an area of 33708547 ha with an annual production of 68855446 tones given an average yield of 2467 kg/ha in the world and it is grown on an area of 75431 ha with an annual production of 138489 tones given an average yield of 1836 kg/ ha in Iran (FAO/STAT, 2017). Interception of solar energy and its use efficiency are two major factors that affect the production of dry matter in plants (*Li* et al., 2009; *Sun* et al., 2013). Under optimum cultivation conditions, there is a linear relationship between accumulation of dry matter and intercepted radiation. The slope of this linear relationship is called radiation use efficiency (RUE) (*Zhang* et al., 2012). RUE is a key index in determining crop yield, which is associated with leaf area index (LAI), and biomass production (*Miranzadeh* et al., 2011). In simulation models of crops, crop growth rate (CGR), in the absence of limiting factors of growth, is expressed by multiplication of the amount of intercepted photosynthetically active radiation, percentage of received radiation (PRR) and finally RUE. Effects of radiation on plant depends on solar angle, LAI and and how to distribute light in the canopy (*Rizzalli* et al., 2002). Oconnell *et al*. (2004) defined extinction coefficient as the efficiency of canopy to intercept radiation. The value of extinction coefficient depends on direction of radiation and the angle of the leaves, canopy structure, plant species, planting pattern (Zare at el., 2005), nutrient deficiency (*Quanqi* et al., 2008), also affect RUE and PRR. Increasing nitrogen at flowering stage increased intercepted radiation by 20 percent (*Salvagiotti* and *Mirrales*, 2008). Reduction in RUE was observed at high levels of nitrogen fertilizer (*Murinen* and *Peltonen-sainio*, 2006). The values of RUE for winter and spring canola were respectively 1.2 and 1.5g MJ^{-1} of photosynthetically active radiation. These values are related to pre-flowering stage *i.e.* without considering siliques photosynthesis (*Morison* and *Stewart*, 2005).

Nitrogen is the most limiting factor for the growth and crops yield in many areas of the world (*Giller*, 2004) and it is required at all growth stages of plants from the vegetative stage until maturity (*Ali*, 2011; *Rafiq* et al., 2010). Lack of nitrogen in the soil causes the nitrogen to be distributed on extended levels, as a result, the nitrogen content of leaves decrease that leads to reduction of RUE. Wang *et al*.

(2007) reported that plants exposed to more nitrogen have higher expansion rate of leaf area in the early season and their earlier canopy closing. With an increase in soil nitrogen, leaf development, LAI and leaf area duration (LAD) increase more light is intercepted by the canopy. CGR also increases due to increase of RUE. Tasneem *et al*. (2008) showed that RUE was improved by increasing the amount of nitrogen up to 300 kg.ha^{-1}. High level of nitrogen results in faster growth of canopy. In addition light absorption is maintained at high levels for a longer period of time. At lower level of nitrogen after flowering resulted from assimilate transfer to seed, plant faces shortage of nutrients specially nitrogen in leaves. As a result, yellowing and shedding of leaves and reduction of light absorption will appear. Apparently, the presence of nitrogen during plant growth causes on increase in leaf area duration and canopy light absorption.

The objective of this study was to investigate the role of limitation of nitrogen fertilizer on dry matter accumulation and use of solar radiation in spring canola cultivars in Gonbad-e-kavoos climate region (IRAN). The hypothesis is that nitrogen fertilizer level which is affected on dry matter accumulation and some physiological characteristics such as leaf area index (LAI), extinction coefficient (EC or K) and radiation use efficiency (RUE) moreover, the ability of canola cultivars (Hyola 401, Zarfam, Hyola 308 and RGS003) are variable in terms of use of radiation.

2. MATERIAL AND METHODS

This experiment was conducted during crop year 2013-2015 at the research field of Gonbad Kavus University, Iran, located at 37 º 16 ' N and 55º 12 ' E and the altitude of 45 meters above sea level . A factorial experiment was conducted based on a randomized complete block design with four replications. The treatments consisted of four canola cultivars (Hyola 401, Hyola 308, Zarfam and RGS003) and three levels of nitrogen fertilizer [0=N0, 50%=N50 (75 kg/ha urea) and 100%=N100 (150 kg/ha urea) of N fertilizer recommendation]. Nitrogen was used at three stages: planting (1/3 of total), stem elongation (1/3 of total) and beginning of flowering (1/3 of total). Each plot contained 5 rows and each plot was 5 m long with a distance between rows of 25 cm and between plats 5 cm. Distance between blocks and plots were two and one meter, respectively. Planting date was 21 November.

Before conducting the experiment, physical and chemical properties of soil were determined by sampling from 0-50cm depth of soil (Table 1). Based on the analysis, phosphorus (as triple super phosphate) was used at a rate of 100 kgha^{-1}, and nitrogen (as urea) at a rate of 150 kg ha^{-1}. Planting was done manually. To ensure the achievement of the desired density (80 plants m^{-2}), at the time of planting, seeds were sown at higher density and after the establishment of plants; plants were thinned at 3-4 leaf stage. Weed control was done by hand weeding.

To measure leaf area and dry weight, 10 plants were randomly selected from each plot from four-leaf stage onward once every 15 days and from mid-March once every 10 days. They were transferred to the laboratory and leaf area was determined with a leaf area meter (DELTA-T). Dry weight was determined at every sampling by drying the samples in an oven at 70°C for 48 hours. In order to describe the trend of variation in leaf area index , the changes compared to the day after planting, the logistic equation (1) which fitted best with the measured points was used:

LAI= [(a*exp (-a))*((dap-b)*c)]/ [1+exp ((-a)]*[(dap-b) 2] (1)

Where LAI is leaf area index, dap is days after planting, and a, b and c are constants (Soltani, 2006).

The logistic equation (2) was used to describe the dry matter accumulation over time (Soltani, 2006). In this equation, a, is coefficient of equation, b is time to reach N50 dry matter, DMmax is the maximum dry matter accumulation, and Y is dry matter.

Y=DMmax/ (1+exp (-a*(dap-b))) **2) (2)

For calculating EC, fitting equation to the measured data, the ratio of intercepted radiation against the LAI was calculated (equation 3). RUE was determined by regression of accumulated biomass (g m^{-2}) against the intercepted cumulative radiation (MJ m^{-2}) as the slope of the line (*Sun* et al., 2013 and

Singer et al., 2007). In order to measure radiation at the top and bottom of the canopy was used using DELTA-T radiometer device. Measurements were performed from stem elongation stage until canopy closure once every 7 days between 12 to 14 o'clock on sunny and clear days.

$$Fi=1- \exp^{(-K\times LAI)} \quad (3)$$

Where Fi is plant coverage ratio (Fraction of intercepted radiation), K is EC based on photosynthetically active radiation (PAR), and LAI is leaf area index (Alimadadi et al., 2005). Sunshine hours for each day of the growing season was obtained from synoptic weather station of Gonbad-e-Kavus city. They were converted to daily achieve solar radiation (Doorenbos and Pruitt, 1977). Amount of daily received solar radiation was calculated by multiplying reached solar radiation and the ratio of received radiation. To obtain the cumulative received radiation, the amount of daily-intercepted solar radiation was added to total intercepted radiation from the previous days. Radiation use efficiency was calculated by fitting a linear relationship between cumulative radiations intercepted and the total accumulated dry matter from planting to maturity (*Sinclair* and *Muchow*, 1999). The analysis of variance was performed by using SAS software and means were compared using LSD at 5% probability level. Excel software was used for plotting graphs.

3. RESULTS AND DISCUSSION

3.1 Leaf area index changes

In this study, the trend of LAI changes was evaluated under the effect of three levels of nitrogen fertilizer during two years. Canola cultivars produced higher LAI at N100 (Tables 2 and 3) and this superiority was evident during the growing season because at this treatment there was enough available nitrogen for plants growth at vegetative stage and entry into reproductive phase. Under this condition the plants can absorb the maximum solar radiation because of having maximum leaf area, and hence increase the radiation interception. Lower levels of nitrogen (0 and 50% of N fertilizer recommendation) leaded to shortened vegetative period and earlier emergence of the inflorescence and also LAI decreased. It is considered as one of the most important features of vegetative growth. In such conditions the plants did not grow well during the vegetative stage and the reproductive phase starts with a poor leaf potential. Nitrogen fertilizer could produce more LAI. This hence leads to increased radiation interception, photosynthetic capacity and finally dry matter.

The increase of LAI in canola cultivars was not the same in both years. In both crop years, Hyola 308 and RGS003 had the lowest and highest LAI, respectively. Notably, while the cultivars Hyola401 and Zarfam in both crop years followed the relatively similar pattern and in general, their LAI was lower than that of RGS003. The maximum LAI (5.8) obtained in the 2014-2015 with RGS003 at N100 (table 3). In addition to reduced LAI, at treatments lower than 100 percent of N fertilizer recommendation, leaf area index declined sharply at the end of the season due to hastened ageing and shedding of leaves compared to N100. Production of lower leaf area index by canola cultivars at N0 and N50 was lower than at N100 (Tables 1 and 2) that can be attributed to lack of nitrogen that accelerated the growth stages and the crop reproductive phase starts. So that total length of growth period decreased and plants matured earlier. Research studies have shown that intercepted radiation was directly related to LAI. An increase in leaf area index, enhance the intercepted radiation, because increase in leaf area index was stopped at the time of flowering. Farm managements should be done in a way that photosynthesis of plants achieve a maximum rate by intercepting all or the main portion of solar radiation (*Dwyer* et al., 2002 and *Shibles* and *Weber*, 2005). It seems that RGS003 did solar radiation interception very well in due to higher leaf area index and good vertical distribution of leaves on the stem. The considering the close relationship of LAI with intercepted solar radiation and accumulated dry matter, the amounts of accumulated dry matter and radiation use efficiency at N100 for RGS003 were higher than those of other cultivars (Tables 4 and 5).

3.2 Dry matter accumulation

Logistic equation (Equation 2) that was used to calculate the time to reach N50 and maximum dry matter production, gave a good description of justified dry matter accumulation, since all the coefficients of determination were equal or greater than 0.97. The comparison of the time to reach 50 % of maximum dry matter accumulation demonstrated that with an increase in the levels of nitrogen fertilizer, the required time to reach to this stage increased and there was a significant difference between them (Tables 4 and 5) . The difference between cultivars for time to reach 50 % of its maximum dry matter was significant across both years and nitrogen fertilizer levels. In both years of the experiment, Hyola 308 reached to 50 % of maximum dry matter 10 to 12 days earlier due to being earlier-matured than other cultivars. There was also a significant difference between the two growing seasons in term of this growth index. The application of 100 % N fertilizer recommendation indicated much better results than other treatments (Tables 4 and 5).

Generally, in the early growing season due to low temperatures and also incomplete canopy cover to fully intercept solar radiation, the initial increase of dry matter is low. In addition, the plant allocates more assimilate to roots for better roots elongation. There was not any significant difference among cultivars for total dry matter at early growth stages in both crop years. This could be related to lack of noticeable difference in leaf area of cultivars at the early stages of growth. The time interval between the onset of seedling growth to linear growth phase of dry matter production, *i.e.*, the period that due to the low leaf area, the absorption of light by canopy is not complete is called the "lost time" (*Goudriaan* and *Monteith*, 1990).

3.3 Extinction coefficient

The equation 3 well justified the changes in radiation interception for LAI. The values of extinction coefficient (EC or K) and the coefficient of determination (R^2) for 2013-2014 and 2014-2015 are shown in Tables 6 and 7. The extinction coefficient depends on leaves distribution in the canopy. The extinction coefficient values during the two growing seasons varied from 0.4 to 0.8 (Tables 6 and 7). According to the results of the present study, it seems that the extinction coefficient depends on the leave distribution on the surface of canopy and the amount of passed light through the canopy. The relationship between extinction coefficient and leaf area index at different treatments of nitrogen showed that any increase in leaf area index will decrease the extinction coefficient. This reduction was resulted from vertical arrangement of the leaves and reduction of transmitted radiation. The lowest extinction coefficient in the second year showed 20 percent decrease compared to that in the first year. This means that less light reached the under of the canopy. This is due to increased LAI and consequently increased vegetation cover, reduced waste of light and increased amount of absorbed radiation by the canopy. As a result dry matter accumulation per area unit in the second year was higher than that of the first year. The minimum extinction coefficient (0.4) in this experiment was obtained for RGS003 in 2014-2015 at the treatment of N100. The maximum EC (0.8) was observed at without nitrogen treatment for the Hyola 308 (biennial average) so that it had the lowest LAI during two years compared to other canola cultivars.

The difference between extinction coefficient of crops and different varieties can be attributed to difference in the structure of the canopy, particularly leaves arrangement and LAI (Goudriaan and Monteith, 1990). Kiniry *et al*. (2001) stated that in C_3 plants the growth rate and production of dry matter had a negative correlation with the values of extinction coefficient. Majdnasiri (2011) reported that in canola varieties with an increase in LAI, extinction coefficient decreased whereas radiation use efficiency increased. In this regard, Bell *et al*. (2003) showed that by increasing EC, RUE decreased in peanut.

3.4 Radiation use efficiency

Fitting a linear relationship between cumulative intercepted radiation and accumulated dry matter RUE was calculated. The slope of this line is the radiation use efficiency. The values of radiation use efficiency and the coefficient of determination (R^2) for canola cultivars and different levels of nitrogen fertilizer are represented in Tables 8 and 9. High values of determination coefficients shows the proper

relationship between total biomass and cumulative intercepted radiation (Tables 8 and 9). There was a significant difference between different levels of nitrogen fertilizer in terms of radiation use efficiency. In other words it can be stated that in all tested cultivars at the highest levels of fertilizer (150 $kgha^{-1}$) compared to other levels of fertilizer significant difference was observed, *i.e.*, increase in leaf area index as a result of increased nitrogen fertilizer leaded to improvement of radiation use efficiency. One of the conditions for an increase in the total dry matter is to increase the number of fertile branches. Dry matter of RGS003, was higher than the other cultivars due to highest number of fertile branches. That was also in parallel with the increase in the number of fertile lateral branches, silique number per plant and consequently grain number per silique improved that leaded to increase in total dry matter.

Considering the general formula of chlorophyll ($C_6H_{72}O_5N_4Mg$) the role of nitrogen in the structure of chlorophyll is vital. Sufficient nitrogen will increase the production of chlorophyll and vegetative growth of the plant. Since more than half of the nitrogen in the leaf is allocated to photosynthetic system. Photosynthesis is strongly affected by nitrogen availability. The availability to sufficient nitrogen would improve the light saturation point; lead to increase radiation use efficiency. In parallel with the increase in fertilizer levels, leaf area index as well as dry matter increased and increase in leaf area index and dry matter up to 150kg urea per hectare (N100) was higher than other nitrogen fertilizer levels (Tables 2 to 5).

Asgharipour (2007) reported that plants quickly spread at higher amounts of nitrogen and they extend their leaf area early in the season and canopy closure occurs earlier and this leads to maximum intercepted radiation. Wang *et al*. (2003) and Ting-Hui *et al*. (2006) stated that increase of nitrogen in the plant improved LAI and dry matter. The prerequisite for high yield and production is optimization of intercepted radiation through LAI and RUE. Nitrogen deficiency causes nitrogen to be distributed on greater leaf surface that leads to reduction of leaf nitrogen concentration and hence RUE reduces *(Andersen* et al., 2006).

The highest RUE was obtained in the second year (2014-2015) at the treatment of N100 with RGS003, it was equivalent to 1.2 ± 0.08 ($MJ\ m^{-2}$) (Table 9) that reflected the ability of this cultivar to make better use of environmental resources. It also had the ability to grow faster early in the growing season and it closed its canopy earlier. It had also a greater ability to intercept solar radiation. This eventually leads to higher production of dry matter and more grains.

4. CONCLUSIONS

Nitrogen fertilizer and canola cultivars affected the EC and RUE, so that the highest rate of RUE was estimated in RGS003 at 150 kg urea ha^{-1} in 2014-15. Any increase in fertilizer rate, LAI and dry matter improved. The ability of all cultivars, in this study, for the absorption of solar radiation was affected by different amounts of nitrogen. Treatment N100 was closer to the potential maximum of light absorption, due to greater LAI, that increased intercepted radiation by the canopy.

REFERENCES

Ali, E. A. (2011). Impact of nitrogen application time on grain and protein yields as well as nitrogen use efficiency of some two-row barley cultivars in sandy soil. *Am Eurasian J Agric Environ Sc***i**, 10, 425-433.

Andersen, M. N., Heidmann, T., Plauborg, F. (1996). The effects of drought and nitrogen on light interception, growth and yield of winter oilseed rape. Acta agr scand B-S P, 46(1), 55-67.

Asgharipour, M., Mashed, M., Rafiei, M. (2006). The effect of plant density and nitrogen fertilizer on light interception and dry matter yield in hemp (*cannabis sativa* l.) 217-230.

Bell, M. J., Wright, G. C., Harch, G. R. (1993). Environmental and agronomic effects on the growth of four peanut cultivars in a sub-tropical environment. I. Dry matter accumulation and radiation use efficiency. *EXP AGR*, 29(04), 473-490.

Doorenbos, J. Kassam, A. H. (1986) Yield response to water. FAO irrigation and drainage paper no. 33. Rome: FAO

Dwyer, L. M., Stewart, D. W., Hamilton, R. I., Houwing, L. (1992). Ear position and vertical distribution of leaf area in corn. *Agron. J.* 84(3), 430-438.

FAOSTAT (2017) Food and Agriculture Organization of the United Nations. Online at http://faostat.fao.org

Giller, K.E. (2004). Emerging technologies to increase the efficiency of use of nitrogen fertilizer. In: A. R. Moseir, J. K. Syers, J.R. Freney, Agriculture and nitrogen cycle. Scope 65. Island Press Washington DC, 35-51.

Goudriaan, J., Monteith, J. L. (1990). A mathematical function for crop growth based on light interception and leaf area expansion. Ann Bot-london, 66(6), 695-701.

Jing-hui, W. D. J. L., Li-zhong, S. R. J. X., Gang, L. (2003). Optimum nitrogen rate for a high productive rice-wheat system and its impact on the groundwater in the taihu lake area. *J. Acta Pedologica Sinica*, *3*, 015.

Khaliq, T., Ahmad, A., Hussain, A., Ranjha, A. M., Ali, M. A. (2008). Impact of nitrogen rates on growth, yield, and radiation use efficiency of maize under varying environments. *Pak. J. Agri. Sci*, 45(3), 1-7.

Kiniry, J. R., Mccauley G. Xie, Y. Arnold, G. (2001). Rice parameters describing crop performance of four U.S. cultivars. Agronomy Journal, 93 1354-1361

Li, Q., Chen, Y., Liu, M., Zhou, X., Yu, S., Dong, B. (2008). Effects of irrigation and planting patterns on radiation use efficiency and yield of winter wheat in North China. *Agricultural water manag.*, 95(4), 469-476.

Li, Q., Liu, M., Zhang, J., Dong, B., Bai, Q. (2009). Biomass accumulation and radiation use efficiency of winter wheat under deficit irrigation regimes. *Plant Soil Environ*, 55(2), 85-91.

Majdnasiri, B. (2011). The effect of seeding rate and planting date on the distribution of light in the canola canopy. The fifth national conference on new ideas in agriculture. *Isfahan Islamic Azad University, Iran*.

Morison, J.M., Stewart, D.W. (2005). Radiation use efficiency in summer rape. *Agron. J.* 87: 1132-1142.

Muurinen, S., Peltonen-Sainio, P. (2006). Radiation-use efficiency of modern and old spring cereal cultivars and its response to nitrogen in northern growing conditions. *Field Crops Res.* 96(2), 363-373.

O'Connell, M. G., O'Leary, G. J., Whitfield, D. M., Connor, D. J. (2004). Interception of photosynthetically active radiation and radiation-use efficiency of wheat, field pea and mustard in a semi-arid environment. *Field Crops Res.* 85(2), 111-124.

Rafiq, M. A., Ali, A., Malik, M. A., Hussain, M. (2010). Effect of fertilizer levels and plant densities on yield and protein contents of autumn planted maize. *Pak. J. Agri. Sci*, 47(3), 201-208.

Rizzalli, R. H., Villalobos, F. J., Orgaz, F. (2002). Radiation interception, radiation-use efficiency and dry matter partitioning in garlic (*Allium sativum* L.). *Euro J. Agron*, 18(1), 33-43.

Salvagiotti, F., Miralles, D. J. (2008). Radiation interception, biomass production and grain yield as affected by the interaction of nitrogen and sulfur fertilization in wheat. *Euro J. Agron*, 28(3), 282-290.

Shibles, R. M. (1965). Leaf area, solar radiation interception and dry matter production by soybeans. *Crop Sci.*, *5*, 575-577.

Sinclair, T. R., Muchow, R. C. (1999). Radiation use efficiency. *Adv. Agron.* 65, 215-265.

Singer, J. W., Sauer, T. J., Blaser, B. C., Meek, D. W. (2007). Radiation use efficiency in dual winter cereal–forage production systems. *Agron. J.* 99(4), 1175-1179.

Soltani, A. (2006). Determination of the parameters of accumulation and distribution of nitrogen in pea. Research projects report. *University of Agricultural Sciences and Natural Resources of Gorgan, Iran.*

Sun, H., Shao, L., Chen, S., Wang, Y., Zhang, X. (2013). Effects of sowing time and rate on crop growth and radiation use efficiency of winter wheat in the North China Plain. *Int. J. Plant Prod. 7*(1), 117-138.

Ting-Hui, D. A. N. G., Gui-Xin, C. A. I., Sheng-Li, G. U. O., Ming-De, H. A. O., Heng, L. K. (2006). Effect of nitrogen management on yield and water use efficiency of rainfed wheat and maize in northwest China. *Pedosphere* 16(4), 495-504.

Wang, K., Wang, R.J., Buresh, R.J. (2007). Residue management for improving soil fertility sustainable crop productivity in China. Proceeding of International Rice Conference, *New Delhi, India*. 689-697.

Zare, M. J., Ghalavand, A., Daneshian, J. (2005). Effect of planting patterns of sunflower on yield and extinction coefficient. *Agron. Sustain. Develop. 25*(4), 513-518.

Zhang, H., Turner, N. C., Poole, M. L. (2012). Increasing the harvest index of wheat in the high rainfall zones of southern Australia. *Field Crops Res.* 129, 111-123.

Table 1. Physical and chemical properties of farm soil (depth 0-50 cm).

properties	Year 2013-2014	Year 2014-2015
Electrical conductivity (ds/m)	1.9	1.21
Total acidity saturation	7.9	7.99
Neutralizing materials (percent)	9.8	11.8
Organic carbon (percent)	0.68	0.76
Total nitrogen (percent)	0.117	0.112
Absorbable phosphorus (ppm)	13.4	16.2
Absorbable potassium (ppm)	356	370
Clay (percent)	15	25
Silt (percent)	64	60
Sand (percent)	21	15

Table 2. Coefficients (a, n & c) of LAI changes prediction equation against time for canola cultivars in growing season 2013-2014. Number of observation (n), maximum leaf area index (LAImax) and the time it happens in days (Tmax), Root Mean Square Error and the coefficient of determination (R^2)

100 percentage of needed-canola nitrogen fertilizer								
Cultivar	n	a±se	b±se	c±se	LAI_{max}	T_{max}	RMSE	R^2
Hyola 401	10	0.05±0.002	107.9±1.1	395.5±12.9	4.9	112	0.35	0.98
Zarfam	10	0.05±0.002	107.7±1.1	369.2±12.8	4.9	117	0.35	0.98
Hyola 308	10	0.06±0.003	110.9±1.1	276±10.5	4.2	108	0.31	0.97
RGS003	10	0.05±0.009	121.2±4.6	443.6±61.8	5.4	111	0.41	0.97
50 percentage of needed-canola nitrogen fertilizer								
Cultivar	n	a±se	b±se	c±se	LAImax	Tmax	RMSE	R^2
Hyola 401	10	0.07±0.004	107.5±1.2	231.8±10.3	3.8	107	0.31	0.98
Zarfam	10	0.06±0.003	108.8±1.2	243.5±10.4	3.9	110	0.31	0.99
Hyola 308	10	0.07±0.004	109.8±1.05	181.5±7.8	3.2	103	0.25	0.97
RGS003	10	0.06±0.003	107.8±1.2	293.9±11.6	4.3	106	0.33	0.98
Without nitrogen fertilizer								
Cultivar	n	a±se	b±se	c±se	LAImax	Tmax	RMSE	R^2
Hyola 401	10	0.07±0.004	106.8±0.9	164.2±6.5	2.9	105	0.21	0.97
Zarfam	10	0.08±0.004	107.2±0.9	148.6±6.7	2.9	105	0.22	0.97
Hyola 308	10	0.08±0.003	106.1±0.7	115.6±3.9	2.3	100	0.27	0.99
RGS003	10	0.07±0.004	107.2±1	191±7.9	3.3	105	0.25	0.98

Table 3. Coefficients (a, n & c) of LAI changes prediction equation against time for canola cultivars in growing season 2014-2015. Number of observation (n), maximum leaf area index (LAImax) and the time it happens in days (Tmax), Root Mean Square Error and the coefficient of determination (R^2)

Cultivars	n	a±se	b±se	c±se	LAI_{max}	T_{max}	RMSE	R^2
100 percentage of needed-canola nitrogen fertilizer								
Hyola 401	10	0.05±0.003	109.1±1.3	395.5±12.9	4.4	112	0.37	0.98
Zarfam	10	0.05±0.003	111.2±1.3	369.2±12.8	4.5	116	0.39	0.97
Hyola 308	10	0.06±0.003	110±1.3	276±10.5	3.8	108	0.33	0.98
RGS003	10	0.05±0.009	121.2±4.6	443.6±61.8	5.8	111	0.36	0.97
50 percentage of needed-canola nitrogen fertilizer								
Hyola 401	10	0.07±0.003	108.3±1.1	231.8±10.3	3.3	108	0.25	0.98
Zarfam	10	0.06±0.003	110.5±1.2	243.5±10.4	3.4	111	0.28	0.98
Hyola 308	10	0.07±0.004	107.9±1.05	181.5±7.8	2.8	105	0.21	0.97
RGS003	10	0.06±0.003	107.5±1.2	293.9±11.6	3.8	107	0.30	0.99
Without nitrogen fertilizer								
Hyola 401	10	0.07±0.003	106.4±0.8	164.2±6.5	2.4	106	0.14	0.97
Zarfam	10	0.07±0.0004	108.2±0.9	148.6±6.7	2.5	108	0.18	0.98
Hyola 308	10	0.07±0.004	107.8±1.06	115.6±3.9	1.8	102	0.14	0.97
RGS003	10	0.07±0.004	107.5±1.06	191±7.9	2.7	105	0.21	0.98

Table 4. Logistic equation to predict dry matter accumulation against time for canola cultivars in growing season 2013-2014. Number of sampling (n), equation coefficient (a), period of time when dry matter accumulation reaches to 50% of its maximum (b) (in days), maximum produced dry matter (DMmax) (gm^{-2}), Root Mean Square Error (RMSE) and coefficient of determination (R^2)

Cultivars	n	a±se	b±se	DM_{max}±se	RMSE	R^2
100 percentage of needed-canola nitrogen fertilizer						
Hyola 401	10	0.055±0.003	91.7±1.1	946.9±14.5	28.7	0.97
Zarfam	10	0.055±0.003	96.1±1.1	969.7±14.6	27.4	0.98
Hyola 308	10	0.052±0.004	91.1±1.5	870.9±17.2	32.3	0.97
RGS003	10	0.048±0.004	92.8±1.7	999.2±22.4	37.5	0.98
50 percentage of needed-canola nitrogen fertilizer						
Hyola 401	10	0.068±0.009	87.4±1.9	587.8±15.9	39.3	0.99
Zarfam	10	0.0053±0.004	94.4±1.5	660.5±13.2	24.3	0.98
Hyola 308	10	0.049±0.003	98.9±1.5	530.2±10.6	16.4	0.97
RGS003	10	0.054±0.006	87.2±1.8	722.6±17.3	35.8	0.99
Without nitrogen fertilizer						
Hyola 401	10	0.039±0.003	110±2.9	441.1±15.9	13.7	0.98
Zarfam	10	0.043±0.003	103.5±2.3	519.5±15	17.3	0.99

Hyola 308	10	0.042±0.004	98.1±2.4	371.9±11.5	14.7	0.97
RGS003	10	0.061±0.005	96.6±1.4	590.6±11.3	19.5	0.98

Table 5. Logistic equation to predict dry matter accumulation against time for canola cultivars in growing season 2014-2015. Number of sampling (n), equation coefficient (a), period of time when dry matter accumulation reaches to 50% of its maximum (b) (in days), maximum produced dry matter (DMmax) (gm^{-2}), Root Mean Square Error (RMSE) and coefficient of determination (R^2)

Cultivars	n	a±se	b±se	DM_{max}±se	RMSE	R^2
100 percentage of needed-canola nitrogen fertilizer						
Hyola 401	10	0.08±0.007	100.8±1.1	95606±16.5	39.9	0.98
Zarfam	10	0.09±0.008	100.2±1.2	1016.6±18.8	46.4	0.97
Hyola 308	10	0.09±0.005	10202±0.7	872.4±9.1	22.6	0.98
RGS003	10	0.11±0.01	95.4±0.9	1032.4±15.4	43.3	0.98
50 percentage of needed-canola nitrogen fertilizer						
Hyola 401	10	0.07±0.004	87.4±1.9	859.9±12.1	22.4	0.99
Zarfam	10	0.07±0.004	94.4±1.5	901.1±12.9	24.3	0.98
Hyola 308	10	0.07±0.003	98.9±1.5	839.5±16.2	26.4	0.97
RGS003	10	0.07±0.006	87.2±1.8	877.8±10.5	21.8	0.99
Without nitrogen fertilizer						
Hyola 401	10	0.07±0.004	110±2.9	496.6±7.8	13.8	0.98
Zarfam	10	0.06±0.003	103.5±2.3	686.8±14.7	20.6	0.99
Hyola 308	10	0.07±0.003	98.1±2.4	409.6±5.1	9.9	0.97
RGS003	10	0.06±0.003	96.6±1.4	753.6±13.3	19.7	0.98

Table 6. Estimation of the values of extinction coefficient (K) from the equation Y=1-exp (-k×LAI) in canola cultivars during growing season 2013-2014. Number of samples (n), extinction coefficient based on photosynthetically active radiation (K_{PAR}) and coefficient of determination (R^2)

Cultivars	n	K±se	R^2
100 percentage of needed-canola nitrogen fertilizer			
Hyola 401	10	0.6±0.2	0.97
Zarfam	10	0.6±0.03	0.97
Hyola 308	10	0.7±0.06	0.99
RGS003	10	0.5±0.01	0.98
50 percentage of needed-canola nitrogen fertilizer			
Hyola 401	10	0.7±0.09	0.97
Zarfam	10	0.7±0.08	0.99
Hyola 308	10	0.7±0.1	0.95
RGS003	10	0.6±0.06	0.98

Without nitrogen fertilizer			
Hyola 401	10	0.8±0.06	0.99
Zarfam	10	0.8±0.08	0.98
Hyola 308	10	0.8±0.2	0.96
RGS003	10	0.7±0.5	0.97

Table 7. Estimation of the values of extinction coefficient (K) from the equation Y=1-exp (-k×LAI) in canola cultivars during growing season 2014-15. Number of samples (n), extinction coefficient based on photosynthetically active radiation (K_{PAR}) and coefficient of determination (R^2)

Cultivars	n	K±se	R^2
100 percentage of needed-canola nitrogen fertilizer			
Hyola 401	10	0.5±0.1	0.99
Zarfam	10	0.5±0.08	0.97
Hyola 308	10	0.6±0.08	0.98
RGS003	10	0.4±0.07	0.98
50 percentage of needed-canola nitrogen fertilizer			
Hyola 401	10	0.6±0.09	0.98
Zarfam	10	0.6±0.08	0.98
Hyola 308	10	0.7±0.1	0.97
RGS003	10	0.6±0.09	0.99
without nitrogen fertilizer			
Hyola 401	10	0.7±0.07	0.98
Zarfam	10	0.7±0.09	0.97
Hyola 308	10	0.8±0.3	0.98
RGS003	10	0.7±0.1	0.97

Table 8. Determination of coefficient for dry matter accumulation (y=a+bx) (gm^{-2}) vs. cumulative intercepted radiation ($MJ\ m^{-2}$) in growing season 2013-2014. Number of samples (n), Root Mean Square Error (RMSE) and coefficient of determination (R^2)

Cultivars	n	a±se	RUE±se	RMSE	R^2
100 percentage of needed-canola nitrogen fertilizer					
Hyola 401	10	68.2±8.8	0.8±0.01	20.9	0.99
Zarfam	10	68.2±8.5	0.8±0.01	19.9	0.97
Hyola 308	10	12.9±9.6	0.7±0.01	22.9	0.98
RGS003	10	3.1±12.2	0.9±0.02	28.6	0.99
50 percentage of needed-canola nitrogen fertilizer					
Hyola 401	10	54.4±17.2	0.6±0.03	42.2	0.96

Zarfam	10	0.6±0.02	0.6±0.02	37.6	0.97
Hyola 308	10	0.6±0.03	0.6±0.03	34.3	0.97
RGS003	10	0.7±0.03	0.7±0.03	42.8	0.98
Without nitrogen fertilizer					
Hyola 401	10	43.6±9.5	0.4±0.05	24.1	0.97
Zarfam	10	68.5±12.6	0.4±0.02	31.7	0.96
Hyola 308	10	37.9±11.4	0.4±0.01	28.2	0.95
RGS003	10	31.2±14.1	0.4±0.02	31.9	0.97

Table 9. Determination of coefficient for dry matter accumulation (y=a+bx) (gm-^{2}) vs. cumulative intercepted radiation (MJ m-^{2}) in growing season 2014-2015. Number of samples (n), Root Mean Square Error (RMSE) and coefficient of determination (R^2)

Cultivars	n	a±se	RUE±se	RMSE	R^2
100 percentage of needed-canola nitrogen fertilizer					
Hyola 401	10	55.5±36.1	1±0.06	90	0.98
Zarfam	10	49.5±38.2	1±0.05	94.6	0.98
Hyola 308	10	75±55.3	0.9±0.09	141.4	0.97
RGS003	10	54.2±50.6	1.2±0.08	117.9	0.98
50 percentage of needed-canola nitrogen fertilizer					
Hyola 401	10	28.9±18.8	0.8±0.01	50.2	0.97
Zarfam	10	0.3±19.7	0.8±0.06	50.3	0.97
Hyola 308	10	5.1±29.3	0.7±0.05	77.3	0.97
RGS003	10	3.2±20.4	0.9±0.03	50.3	0.98
Without nitrogen fertilizer					
Hyola 401	10	72.3±19.2	0.7±0.05	43.3	0.97
Zarfam	10	67.5±18.6	0.7±0.02	43.1	0.98
Hyola 308	10	33.5±8.3	0.5±0.01	17.1	0.99
RGS003	10	15.5±11.3	0.8±0.06	9.5	0.97