# EFFECT OF NITROGEN LEVELS ON GROWTH, YIELD AND OIL QUALITY OF INDIAN MUSTARD GROWN UNDER DIFFERENT PLANT DENSITIES

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**ABSTRACT.** The study investigated agronomical and qualitative features of Indian mustard in a semi-arid region from Iran. Field trials were designed in split plot arrangement based on a Randomized Complete Block Design with three replicates at the Agricultural Faculty of Takestan, Iran. In the study, plant height (cm), the number of seeds  in the siliqua (seed/siliqua), the number of siliquae  in the plant (siliqua/plant), seed yield (kg/ha), biological yield (kg/ha), thousand-seed weight (g), harvest index (%), oil content (%) and oil yield (kg/ha) were determined. The all growth and yield parameters of mustard plant were significantly affected by nitrogen fertilization. All the parameters, except for harvest index (HI), were drastically affected by used densities. The highest seed yield and oil yield (2961 and 1159 kg/ha, respectively) were obtained for the crop utilized with 200 kg N/ha in plots with 80 plants/m$^2$. The maximum oil content (43.97%) was recorded in the lowest plant density  (80 plants/m$^2$)  and nitrogen application level of 50 kg/ha. Results suggest that in semi-arid region of Takestan, researchers  must  direct  their  selection treatments to increase oil quality of Indian mustard.

**Key words:** *Brassica juncea*; Nitrogen; Plant population; Yield; Yield components; Oil quality.

## INTRODUCTION

Indian mustard (*Brassica juncea* L.), locally known as "khardal", belongs to *Cruciferae* family and genus *Brassica* (Rafiei *et al.*, 2011). It is introduced as an oily herb (38 to 40% oil content), which is appropriate for zones with short seasons and less rainfall (Burton *et al.*, 1999). Nitrogen increases yield by influencing different growth parameters and by producing more vigorous growth and development as reflected via increasing plant height, number of flowering branches, total plant weight, leaf area index and number and weight of siliquae and seeds per plant (Alien and Morgan, 1972). Nitrogen is

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a major nutrient element that provides lush green color in crop (due to increase in chlorophyll) and its deficiency in arid and semi-arid regions is considerable because the amount of organic matters, which are the main nitrogen reserves, is very low in these regions and even if they were found, they would be quickly decomposed (Bani-Saeedi, 2001). Almost all investigations showed that nitrogen fertilizers gave substantial seed yield increase, even in diverse and contradicting conditions (Siadat *et al.*, 2010). However, nitrogen fertilizer's requirements can differ very much according to soil type, climate, management practice, timing of nitrogen application, cultivars, etc. (Holmes and Ainsley, 1977). Bani-Saeedi (2001) stated that nitrogen, by reducing flower abscission and consequently affecting thousand-seed weight (TSW), increasing the number of siliquae per unit area and decreasing the number of seeds per siliqua, caused more seed yield per hectare. Singh and Rathi (1985) reported that increase in nitrogen significantly increased the crop yield; they observed the highest yield with 160 kg N/ha. Notwithstanding, Mirzashahi *et al.* (2000) noticed that increasing rates of N up to 180 kg/ha progressively increased the growth and yield components. Reddy and Sinha (1989) showed that seed yield has increased linearly by increasing nitrogen consumption; comparing with no nitrogen consumption, the amounts of 40 and 80 Kg N/ha increased the seed yield to 49.5% and

96.5%, respectively. Mobasser *et al.* (2008) showed that maximum siliqua number per plant were produced with use of 138 kg N/ha. Arthamwar *et al.* (1996) reported that with increase in nitrogen application, siliqua number would be increased. The number of seeds per siliqua and TSW were significantly increased with increasing levels of nitrogen fertilizer application (Chauhan *et al.*, 1995; Cheema *et al.*, 2001). Some studies showed that the most biological yield was produced with increase in use of nitrogen manure (Kjellstrom, 1993). Kumar *et al.* (1997) also reported higher production of total dry matter with increased rate of fertilizer application. Majnoun-Hosseini *et al.* (2006) and Mobasser *et al.* (2008) suggested that with decrease in planting space and use of nitrogen fertilizer the plant height would be increased. In the experiments conducted by Saleem *et al.* (2001) and Kazemeini *et al.* (2010), the harvest index (HI) values were significantly increased by nitrogen rates of 135 and 150 kg/ha, respectively; while it was remained unaffected according to the findings of Danesh-Shahraki *et al.* (2008).

Usually, plant density is one of the most effective agronomic factors for determining the yield which is individually affected by cultivar and climatic conditions (Zandi *et al.*, 2011) as well as production system. For each crop and environmental conditions, the optimum plant population should be determined through local research. Previous studies have shown that plant density

is an important factor affecting mustard yield; however, it can govern the components of yield and the yield of individual plants (Sing and Verma, 1993). A study by Sharif *et al.* (1990) showed that the highest crop yield is gained from the lowest population density of 30 plants/m$^2$, as compared to other treatments (60 and 90 plants/m$^2$). In a research carried out by Singh and Verma (1993) on mustard, the highest crop yield achieved at 30 cm row spacing against the lowest at 45 and 60 cm, respectively. According to the findings of Yousaf and Ahmad (2002), Mobasser *et al.* (2008) and Kazemeini *et al.* (2010), the highest dry matter (above-ground biomass) was produced under higher plant populations. Several researchers (Munir and McNeilly, 1987; Angadi *et al.*, 2003; Danesh-Shahraki *et al.*, 2008) noticed that seeds per siliqua and thousand-seed weight were remained unaffected (stable) across populations. Yet, McGregor (1987) stated that number of seeds per siliqua and seed weight increased with reduced plant density and the makeup was predominantly attributed to the increase in number of siliquae on the remaining plants. Rana and Pachauri (2001) and Angadi *et al.* (2003) reported that plant height declined as the populations dropped. The decrease and increase in HI values in response to higher plant populations by DeLougherty and Crookston (1978) and Danesh-Shahraki *et al.* (2008), respectively, can be due to the different environmental conditions under which these results obtained.

The most important quality factor of Indian mustard is oil content (Bani-Saeedi, 2001). Cheema *et al.* (2001) and Saleem *et al.* (2001) have recorded the most oil content (46.23%) and oil yield (1422.82 kg/ha) of rapeseed at row spacing of 30 cm, against the least at 60 cm. They also concluded that at higher doses of N, oil yield increased meanwhile decreased the oil content.

Considering that the information on yield dynamics of mustard with respect to nitrogen and density is still not available in Iran, the present study aims to generate more information concerning the effect of different plant populations and nitrogen levels on the agronomic traits, yield and oil quality of Indian mustard under the irrigated conditions of Takestan, Iran.

## MATERIALS AND METHODS

### Site description and soil type

This research was conducted during 2009-2010 cropping season at the Agricultural Research Field (latitude 36°18´ N, longitude 49°57´ E, elevation 1314 m above mean sea level) , Faculty of Agriculture of Islamic Azad University, Takestan, Iran. This region has a semi-arid climate (312 mm mean annual rainfall). The soil at the experimental site was clay loam with an initial fertility status of 0.08% N,14.2 ppm $P_2O_5$ , 165 ppm $K_2O$, 0.83% organic matter, pH of 7.8 and EC =1.33 dS/m.

### Experimental design and treatments

The field experiment was split plot based on randomized complete block design (RCBD), in three replicates. Five nitrogen levels consisting of $N_1$– no

nitrogen application as control, $N_2$–fertilizing with 50, $N_3$ – fertilizing with 100, $N_4$ – fertilizing with 150, and $N_5$ – fertilizing with 200 kg N/ha were applied to the main plots. Subplots, which consisted of split plots, were allocated to three planting densities ($D_1$=80, $D_2$=100 and $D_3$=120 plants /$m^2$).

**Agronomic practices**

Individual experimental plot comprised of six rows, 4 m long, 2.5 m widths and a 30 cm row-spacing with a seeding rate of 7 kg/ha. The experimental fields were mould-board ploughed and seedbed preparation comprised of two passes with a tandem disk. Weeds were controlled by Triflouralin (2.5 l/ha) which was applied prior to planting and incorporated in to the soil by disking. After land leveling and furrow preparation, the plots were irrigated using the furrow irrigation method and subsequent irrigation was applied every 15 days before the rosette appeared in autumn and every 8-10 days during spring. The planting depth was 1.5 to 2 cm at a rate of 100 seeds/ $m^2$ on 10 October 2009. The experimental plots were fertilized before sowing at the rate of N ($N_1$ - $N_0$, $N_2$ - $N_{16}$, $N_3$ -$N_{33,}$ $N_4$ - $N_{50}$ and $N_5$ - $N_{66}$) $P_{75}K_{75}$. Phosphorus and potassium were used in the form of triple super phosphate and potassium sulphate, respectively. Nitrogen fertilizer, in the form of urea (46% N), was added into plots in three equal portions, according to experimental treatments. The first application of N (1/3) was incorporated and added to soil as the basal dressing along with P, K fertilizer (in total amount), at the time of pre-sowing and the remaining N (2/3) was split equally at the beginning of stem elongation and flowering stage. The required plant populations (80, 100 and 120 plants /$m^2$) were maintained by hand thinning after

seedling emergence at two times (during 3-4 leaves phase). During the study, three hand hoeings were given to eradicate the weeds from the field. The crop was sprayed with Diazinon (a synthetic organophosphate pesticide) at 1 l/ha for controlling the cabbage aphid (*Brevicoryne brassicae* L.) in early December and April. Proper management practices were adopted throughout the growing seasons to ensure good crop growth. Final harvest was carried out manually (hand sickle, 5 cm above ground level) on 12 June 2010.

**Estimation of traits**

At maturity, ten random samples were hand harvested from each experimental unit and the following parameters were determined: plant height (PH), number of seeds per siliqua (seed/siliqua) and number of siliquae per plant (siliqua/plant). Main stem length was measured as the plant height. Numbers of siliquae per plant and seeds per siliqua were counted from 30 randomly selected siliquae after hand threshing. The seed yield was measured by harvesting 3.6 $m^2$ of the central part of each plot at crop full maturity (physiological maturity). After harvesting, the plants were left in the field for sun drying to their constant weight (12% moisture content). Then, the total above ground plant weight was computed (biological yield) by a precise scale (0.001 g) and expressed as kg/ha. Eight samples of 100 seeds were taken from each seed lot of the experimental units and they were weighed afterwards. Then, the average multiplied by 10 recorded as 1000 seed weight (TSW). Harvest index (HI) was calculated as ratio of seed yield to biological yield. The seed oil contents were determined with the soxhlet apparatus at the laboratory of Takestan Branch, Islamic Azad University, Iran.

Fully matured siliquae were collected and their seeds were separated; next, they were dried in an oven at 105°C for 1 h. The dried seeds of *Brassica juncea* L. (50 g per sub plot) were ground in a silit mortar into fine particles (0.1 mm - mean diameter). The obtained powder (3 g of diced seed) was subjected to hot solvent extraction in a soxhlet apparatus using carbon tetrachloride (Tetrachloromethane) in 1:1 ratio at temperature range of 70-100°C. Oil yield was computed by multiplying seed yield and oil content.

### Statistical analysis

Data were subjected to analysis of variance (ANOVA) by using the MSTATC statistical package (MSTAT-C, Version 1.41, Crop and Sciences Department, Michigan State University, USA). Duncan's multiple range test ($P < 0.05$) was applied for mean separation when $F$ values were significant.

## RESULTS AND DISCUSSION

### Plant height

Both the plant densities and nitrogen levels had significant effect on mustard plant height (PH) at maturity (*Table 1*). Taller plants (115.2 cm) were observed in a density of 120 plants/m$^2$, against the shorter of 102.7 cm at 80 plants/m$^2$ (*Table 2*). The reduction in plant height with decrease in plant population from $D_3$ to $D_1$ was attributed to reduction in magnitude of competition for light at wider spacing as compared to closer spacing (Rana and Pachauri, 2001). Concerning nitrogen rates, application of 200 kg N/ha led to a notably taller plant height (139.5 cm) than other levels (control, 50, 100, and 150 kg

N/ha). This implies that application of nitrogen had increased the plant height. The plant height was greatly influenced by interaction effect of plant population and nitrogen fertilizer (*Table 1*). The significantly higher interaction for plant height was recorded in $N_5D_1$ (146.2 cm), as compared to the rest of interactions. These results are in accordance with the findings of Majnoun-Hosseini *et al.* (2006) on rapeseed and Zandi *et al.* (2011) on fenugreek.

### Number of seeds per siliqua (seed/siliqua)

Data pertaining to *Table 1* revealed that number of seeds per siliqua was significantly affected by the applied treatments (nitrogen levels, plant densities and interaction thereof). Among the N levels, the crop fertilized at 200 kg N/ha produced significantly more number of seeds per siliqua (17.32) than those of control, 50,100 and 150 kg N/ ha, which produced 10.78, 12.84, 14.31 and 15.96 seeds per siliqua, respectively. Qayyum *et al.* (1998) and Cheema *et al.* (2001) also reported an increase in number of seeds per siliqua with the application of N up to 120 and 135 kg N/ha respectively. In different plant densities, the most seed number per siliqua (14.90) was produced in 80 plants/m$^2$ against the least (13.61) at 120 plants/m$^2$. This finding did not support by Munir and McNeilly (1987), Angadi *et al.* (2003) and Danesh-Shahraki *et al.* (2008), who found that there is no link between plant

population and number of seeds per siliqua. Higher number of seeds per siliqua (17.80) was recorded with $N_5D_1$ interaction over the rest of interactions (*Table 3*). However, $N_5D_1$ and $N_5D_2$ interactions were on par. The higher seed number per siliqua in $N_5D_1$ interaction implicated that in lower densities, due to lesser competition within the plants and a sufficient light intensity as a potent source for increasing crop biomass, higher dry matter accumulated in siliqua. Consequently, it increased the seed number per siliqua by producing lower number of shriveled seeds (Rana and Pachauri, 2001; Siadat *et al.*, 2010).

**Number of siliquae per plant (siliqua/plant)**

The number of siliquae per plant of Indian mustard was highly affected ($P<0.01$) by the plant densities, nitrogen rates and their interaction (*Table 1*). Maximum siliqua number per plant (108.60) was obtained in plots which received 200 kg N/ha. The minimum number of siliquae per plant (50.10) produced in control plots (no nitrogen application). In fact, the increase in number of siliquae per plant due to more nitrogen consumption emphasizes the existence of source limitation which results in competition within plants and different parts of each plant for receiving assimilates. This competition brings forth the flowers/siliquae abscission. Therefore, there was a remarkable difference between the highest and lowest level

of nitrogen consumption regarding this trait. These results confirmed the findings of earlier researchers (Arthamwar *et al.*, 1996; Mobasser *et al.*, 2008; Siadat *et al.*, 2010). Plant population of 80 plants/m$^2$ recorded significantly higher siliqua number per plant (86.70), as compared to 120 plants/m$^2$ which caused the lowest siliqua number per plant (73.68) (*Table 2*). Generally, lower population increased and higher population decreased the number of siliquae per plant. These findings are in agreement with those of McGregor (1987), Ali *et al.* (1996) and Cheema *et al.* (2001). The nitrogen and plant density interaction showed that the most siliqua/plant (115.6) was noticed in 200 kg/ha nitrogen application rate and 80 plants/m$^2$ (*Table 3*). Similar results have been observed by Kazemeini *et al.* (2010) on rapeseed in south of Iran.

**Seed yield**

Result indicated that nitrogen application rate ($P<0.01$), plant density ($P<0.01$) and their interaction ($P<0.05$) had significant effect on seed yield (*Table 1*). Means comparison showed that the most (2832 kg/ha) and the least seed yield (1038 kg/ha) were belonged to the plots which received 200 and 0 kg N/ha, respectively (*Table 2*). The application of 200 kg N/ha, by preventing flower and siliqua abscission, increasing the number of siliquae per unit area and affecting 1000 seed weight (TSW) led to more seed yield. Higher seed yield with

increasing rate of nitrogen was also reported by Singh and Rathi (1985), Reddy and Sinha (1989), Mankotish and Sharma (1997), Mirzashahi *et al.* (2000), Bani-Saeedi (2001), and Siadat *et al.* (2010). Among the plant densities, 80 plants/m$^2$ (D$_1$) produced significantly higher seed yield (2218 kg/ha) than other applied densities of 100 and 120 plants/m$^2$ which gave 2105 and 1984 kg/ha of seed yield respectively (*Table 2*). The higher seed yield in D$_1$ treatment reveals that such plant density facilitated maximum utilization of nutrients and increased dry matter production which ultimately enhanced seed yield (Cheema *et al.*, 2001). Moreover, in this level of density by creating more suitable green canopy in the unit area with the least inter competition, solar radiation was used effectively for producing economic yield (Sharif *et al.*, 1990; Saeed-Shariati, 1996). Interaction effect of nitrogen and plant density showed that the most seed yield (2961 kg/ha) was produced in 200 kg N/ha in case of 80 plants/m$^2$. Furthermore, the least seed yield (952 kg/ha) was obtained in no nitrogen application in case of 120 plants/m$^2$. Clearly, as the plant density increased for each N amount, seed yield in the unit of area decreased as well which did not confirm the results of studies done by Yousaf and Ahmad (2002), Danesh-Shahraki *et al.* (2008) and Kazemeini *et al.* (2010). They found higher seed yield of rapeseed at higher levels of both nitrogen and plant density.

**Biological yield**

Results in *Table 1* show that the individual effects of nitrogen and plant density were highly influenced the crop biological yield (*P*<0.01). The application rate of 200 kg N/ha produced the maximum biological yield (12840 kg/ha), followed by 150 kg N/ha which produced 11330 kg/ha biological yield. The minimum biological yield (4823 kg/ha) was recorded in control treatment (N$_1$) (*Table 2*). These results are in line with the findings of Kjellstrom (1993) and Zandi *et al.* (2011), who reported that biological yield maximized with increasing nitrogen levels. Means comparison results indicated that the highest (9154 kg/ha) and the lowest (8136 kg/ha) biological yield was that of 80 and 120 plants/m$^2$, respectively. The nitrogen and plant density interaction had a considerable effect on biological yield of Indian mustard (*Table 1*). Among all treatment combinations, N$_5$D$_1$ (200 kg N/ha coupled with 80 plants/m$^2$) produced the highest biological yield (13490 kg/ha); while the lowest biological yield (4286 kg/ha) was that of the control treatment (no nitrogen application) coupled with a density of 120 plants/m$^2$ (N$_1$D$_3$) (*Table 3*). The data obtained in our experiment are not in accordance with the information that maximum biomass would be obtained in maximum plant density (Yousaf and Ahmad, 2002; Mobasser *et al.*, 2008; Kazemeini *et al.*, 2010). Higher biological yield at nitrogen rates of N$_5$ was related to the effective role of nitrogen on

assimilates distribution and adjusting the effect of inter/intra plant competition (Zangani *et al.*, 2006). It resulted in producing more foliage (through higher siliqua yield and stover yield) to the seed production. These results complies with the findings of Kazemeini *et al.* (2010) and Zandi *et al.* (2011), who reported that the most biological yield was produced in higher dose of nitrogen application.

**1000 seed weight**

According to results in *Table 1*, 1000 seed weight (TSW) was highly significantly ($P<0.01$) influenced by different plant densities and nitrogen levels. Munir and McNeilly (1987), Angadi *et al.* (2003) and Danesh-Shahraki *et al.* (2008), contradictorily, revealed that TSW is the stable part of yield and is not affected by plant density fluctuations. Data in *Table 2* show that the TSW increased with increasing the nitrogen application rates and decreased with increasing the plant densities. Thus, the highest and lowest values of TSW were obtained from 80 and 120 plants /$m^2$, respectively. Maximum TSW (5.3 g) was recorded at 200 kg N/ha against the minimum (2.47 g) at control. In the studies of Sharma and Kumar (1990) on mustard and Bani-Saeedi (2001) on canola, the TSW enhanced as a response to nitrogen fertilizer. The interaction effects of nitrogen and plant density had a significant effect ($P<0.05$) on this trait (*Table 1*). The $N_5D_1$ interaction recorded

considerably higher TSW (5.5 g) as compared to rest of the interactions. Apparently, lower TSW of 2.1 g was recorded with $N_1D_3$ interaction. As compared to the other traits, TSW changes to the levels of evaluated treatments had fewer fluctuations in this experiment. Furthermore, no sharp drop was noticed in this trait while increasing the density at each level of nitrogen application. The optimum density strengthened the optimal use of environmental condition for the crop and it lessened the inter plant competition which resulted in production of appropriate seeds with more weight. Although the competition between the plants intensified by increasing the plant density, these plants by allocating more photosynthesis materials to the seed, which may be provided *via* remobilization of secondary materials (translocation), prevented severe decrease in seed weight. The plants which were cultivated at higher density ($D_3$) had lost their TSW at higher level of nitrogen application ($N_5$). This may be due to lower partitioning of photosynthetic materials to seeds than other vegetative parts (plant height increased along with increasing crop densities). Moreover, under $N_1D_3$ interaction, the excessive numbers of plants under nutrient' stress condition (no nitrogen application) resulted in severe inter plant competition and a higher canopy transpiration which reduced the effective seed filling duration and restricted the seed growth; consequently the TSW

declined. According to the results obtained by Siadat *et al.* (2010) in Ahvaz, TSW increased as plant density and nitrogen rate increased; which do not totally coincided with our finding.

## Harvest index

The recorded data indicated no statistically significant difference in harvest index, in terms of the applied plant densities (80, 100, and 120 plants/m$^2$). Zandi *et al.* (2011) showed that plant population densities did not affect significantly harvest index. They found the harvest index (HI) to be relatively stable. By contrast, DeLougherty and Crookston (1978) reported that with increasing population density a significant decline in HI would be achieved; whoever, the HI values were greatly increased by increasing the plant densities, according to findings of Danesh-Shahraki *et al.* (2008). HI was highly ($P<0.01$), affected by nitrogen rates. Among the N levels, the plots received 50 kg N/ha resulted in notably more HI values than those of control, 100,150 and 200 kg N/ ha. The interaction effect of plant density × nitrogen levels was significant ($P<0.05$) over this trait (*Table 1*). The $N_2D_3$ interaction recorded significantly higher HI values (30.79%) compared to other interactions; whereas, it was on par with $N_2D_1$, $N_2D_2$, and $N_3D_1$ interactions (*Table 3*). For each population density, when N application increased up to 50 kg/ha,

the crop's HI was augmented as well, and each extra fertilization led to a significant decrease in HI values. It assumes that besides improving the assimilate distribution, by making an effective nutrient management, N could ameliorate the inter-plant competition in a way that increased the amount of seed yield to biological yield and caused the harvest index to increase. Higher N rates disrupted the crop's partitioning efficiency and resulted in more partitioning of dry matter into various plant parts than reproductive organs and it consequently dropped the HI values (Danesh-Shahraki *et al.*, 2008).

## Oil content

Seed oil content was highly significantly ($P<0.01$) affected by different densities and nitrogen rates (*Table 1*). The maximum oil content of 41.36% was recorded at lower densities (80 plants /m$^2$), against the minimum of 40.08% at higher densities (120 plants /m$^2$). The result was not coincided with the findings of Singh *et al.* (1986) and Chauhan *et al.* (1993), who reported the highest oil content with increasing crop population. The differences in results might be due to differences in environmental conditions under which these experiments were conducted. As for oil content (%), the data of *Table 2* revealed that under 50 kg nitrogen rate ($N_2$), oil content was the highest, then significantly decreased under the higher nitrogen rates.

Table 1 - The mean squares of ANOVA for plant height, seed/siliqua, siliqua/plant, seed yield, biological yield, 1000 seed weight, harvest index, oil content and oil yield in variance analysis of 2009 - 2010 data

| Source of variation | df | Plant height | Seed/siliqua | Siliqua/plant | Seed yield | Biological yield | 1000 seed weight | Harvest index | Oil content | Oil yield |
|---|---|---|---|---|---|---|---|---|---|---|
| R | 2 | ** | ** | ** | ** | ** | ** | ns | ns | ** |
| N | 4 | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| Ea | 8 | 3.440 | 0.181 | 4.746 | 23255.53 | 135251.517 | 0.039 | 3.395 | 0.339 | 4669.29 |
| D | 2 | ** | ** | ** | ** | ** | ** | ns | ** | ** |
| N D | 8 | * | * | * | * | * | * | * | * | * |
| Error | 20 | 4.403 | 0.112 | 3.070 | 10.72 | 92312.267 | 0.036 | 2.638 | 0.213 | 2004.13 |
| CV (%) | | 1.92 | 2.35 | 2.19 | 4.77 | 3.51 | 4.81 | 6.56 | 1.13 | 5.25 |

Ns - P > 0.05, * - P < 0.05, ** - P < 0.01, df - degrees of freedom, R - replication effect, N - nitrogen fertilizer effect, D - plant density effect, ND represent interaction terms between the treatment factors.

Table 2 - Means for plant height (PH), seed/siliqua (S/S), siliqua/plant(S/P), seed yield (SY), biological yield (BY),1000 seed weight (TSW), harvest index (HI), oil content (OC) and oil yield (OY) as affected by individual effects of nitrogen fertilizer and plant density.

| Treatments | PH (cm) | S/S | S/P | SY (kg/ha) | BY (kg/ha) | TSW (g) | HI (%) | OC (%) | OY (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Nitrogen fertilizer | | | | | | | | | |
| N1: 0 kg/ha | 74.97e | 10.78e | 50.10e | 1038e | 4823e | 2.47e | 21.55c | 40.80b | 424d |
| N2: 50 kg/ha | 97.97d | 12.84d | 66.47d | 1861d | 6123d | 3.27d | 30.44a | 43.08a | 802.6c |
| N3: 100 kg/ha | 111.5c | 14.31c | 80.60c | 2214c | 8149c | 3.9c | 27.14b | 40.86b | 905.8b |
| N4: 150 kg/ha | 123.9b | 15.96b | 94.10b | 2568b | 11330b | 4.77b | 22.56c | 40.21b | 1034a |
| N5: 200 kg/ha | 139.5a | 17.32a | 108.60a | 2832a | 12840a | 5.3a | 22.07c | 38.64c | 1095a |
| Plant density | | | | | | | | | |
| D1: 80 plants/m$^2$ | 102.7c | 14.90a | 86.70a | 2218a | 9154a | 4.24a | 24.67a | 41.36a | 912.5a |
| D2: 100 plants/m$^2$ | 110.8b | 14.22b | 79.50b | 2105b | 8668b | 3.92b | 24.78a | 40.73b | 853.3b |
| D3: 120 plants/m$^2$ | 115.2a | 13.61c | 73.68c | 1984c | 8136c | 3.7c | 24.86a | 40.08c | 790.9c |

Means in each column followed by the different letters are significantly different (P <0.05) according to Duncan test.

Table 3 - Interaction effect of plant density (D) and nitrogen levels (N) on plant height (PH), seed/siliqua (S/S), siliqua/plant (S/P), seed yield (SY), biological yield (BY),1000 seed weight (TSW), harvest index (HI), oil content (OC) and oil yield (OY) of Indian mustard.

| Interactions | PH (cm) | S/S | S/P | SY (kg/ha) | BY (kg/ha) | TSW (g) | HI (%) | OC (%) | OY (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|
| N1D1 | 65.20l | 11.57i | 56.40i | 1126h | 5322jk | 2.8gh | 21.16d | 41.35c | 465.7h |
| N1D2 | 76.30k | 10.70j | 50.40j | 1035h | 4861k | 2.5h | 21.28d | 40.86cd | 423.3hi |
| N1D3 | 83.40j | 10.07k | 43.50k | 952h | 4286l | 2.1i | 22.22d | 40.22d | 383i |
| N2D1 | 91.60i | 13.57g | 74.70g | 1938fg | 6487h | 3.6 ef | 29.84ab | 43.97a | 852.7ef |
| N2D2 | 99.80h | 12.90h | 66.20h | 1879fg | 6122hi | 3.3f | 30.69a | 42.87b | 805.7fg |
| N2D3 | 102.5h | 12.07i | 58.50i | 1766g | 5761li | 2.9g | 30.79a | 42.39b | 749.3g |
| N3D1 | 106.3j | 14.97e | 87.40e | 2376de | 8485f | 4.2d | 27.99abc | 41.38c | 983cd |
| N3D2 | 112.7f | 14.37f | 78.60f | 2237e | 8176fg | 3.8e | 27.39bc | 40.93cd | 916.7de |
| N3D3 | 115.6ef | 13.60g | 75.80fg | 2028f | 7786g | 3.7e | 26.04c | 40.28d | 817.7fg |
| N4D1 | 118.2e | 16.60c | 99.40c | 2689bc | 11990c | 5.1b | 22.42d | 40.93cd | 1102ab |
| N4D2 | 125.3d | 15.90d | 93.90d | 2553cd | 11290d | 4.7c | 22.60d | 40.38d | 1031bc |
| N4D3 | 128.2d | 15.37de | 89e | 2461d | 10720e | 4.5cd | 22.93d | 39.28e | 967.3cd |
| N5D1 | 132.1c | 17.80a | 115.6a | 2961a | 13490a | 5.5a | 21.92d | 39.12e | 1159a |
| N5D2 | 140.1b | 17.23ab | 108.5b | 2822ab | 12900b | 5.3ab | 21.94d | 38.59ef | 1090ab |
| N5D3 | 146.2a | 16.93bc | 101.6c | 2712bc | 12130c | 5.2ab | 22.35d | 38.21f | 1037bc |

Means in each column followed by the different letters are significantly different (P <0.05) according to Duncan test.

Oil contents were 40.80%, 43.08%, 40.86%, 40.21% and 38.64% under the nitrogen rates of 0.0, 50,100,150 and 200 kg N/ha, respectively. The results confirmed the findings of earlier researchers (Patil and Bhargava, 1987; Cheema *et al.*, 2001; Saleem *et al.*, 2001), who pointed out that oil content decreased with the increasing rate of N. The interaction effect between plant density and nitrogen was significant ($P<0.05$) (*Table 1*). The $N_2D_1$ interaction recorded considerably higher oil content (43.97%) over the rest of the interactions (*Table 3*). The higher oil content in this interaction was due to the fact that the amount of applied manures should be considered regarding the oil content. The excessive nitrogen in soil, as a nutrient material, generates harmful materials in seed oil and causes its difficult extraction (Karimian-Kelishadrokhi *et al.*, 2009). Presence of N-compounds in seed oil complicates the procedure of oil extraction and increases the amount of undesirable materials such as glucosinolates (Zangani, 2002). Zhao *et al.* (2006) and Omirou *et al.* (2009) reported that glucosinolate content increased with the increasing rate of N. The highest oil content in $N_2$ treatment comparing to other nitrogen levels might be due to decreasing the amount of N-compounds in the seed oil.

**Oil yield**

Finally, based on obtained results in *Table 1*, oil yield was also significantly affected by plant densities ($P<0.01$), nitrogen levels ($P<0.01$), as well as interaction thereof ($P<0.05$). In this study, oil yield followed similar trend of seed yield (*Tabs. 2 and 3*). Lesser density of 80 plants/m$^2$ recorded significantly higher oil yield (912.5 kg/ha). Increase in oil yield at lower density of $D_1$ (80 plants/m$^2$) was mainly attributed to more seed yield in this treatment comparing to the higher plant densities (100 and 120 plants/m$^2$) (*Table 2*). These finding are in conformity with those of Mishra and Rana (1992), Chauhan *et al.* (1993), and Rana and Pachauri (2001). Regarding N levels, maximum oil yield (1095 kg/ha) was obtained when the crop was fertilized at 200 kg N/ha. This level of nitrogen was statistically at par with 150 kg N/ha (*Table 2*). Cheema *et al.* (2001) and Saleem *et al.* (2001) reported that increasing the levels of nitrogen up to 135 kg/ha increased the oil yield of canola significantly. Among all combination treatments, $N_1D_3$ interaction has taken lower oil yield (383 kg/ha) as compared to rest of interactions. The $N_1D_2$ and $N_1D_3$ interactions were on par with each other (*Table 3*). The $N_5D_1$ interaction recorded significantly higher oil yield (1159 kg/ha) over the rest of the interactions. However, it was on par with $N_4D_1$ and $N_5D_2$. The higher oil yield in $N_5D_1$ interaction was also attributed to higher seed yield (*Table

*3*). Thus, applying 200 kg N/ha caused nutritive improvement and increase in seed yield as affected by said treatment combination.

## CONCLUSIONS

The study concluded that among different applied densities, $D_1$ (80 plants/m$^2$) influenced the main yield components of Indian mustard and recognized as the best density. For treatments fertilized with $N_5$ level (200 kg N/ha), a significant superiority was shown in estimated traits except for oil content and harvest index. The Indian mustard should preferably be grown at density of 80 plants/m$^2$ and fertilized at 200 kg N/ha, under the agroecological conditions of Takestan for obtaining maximum seed and oil yield/ha. However, further confirmation of the trends seen in this experiment needs to be obtained before more specific recommendations can be made.

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