Annales Universitatis Paedagogicae Cracoviensis
Studia Naturae, 5: 83–95, 2020, ISSN 2543-8832
DOI: 10.24917/25438832.5.6

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Agronomic performance of autumn- and winter-cropped Indian mustard (*Brassica juncea* L.) in response to varying levels of nitrogen fertiliser

Introduction

Currently, a huge gap in supply and demand for oilseed calls for a considerable increase in oilseed crop production around the globe (Radha Kumari et al., 2004). Based on reports by the Food and Agriculture Organization of the United Nations (2019), the world average yield of oilseed crops is 350 Mt, which is 875 times more than Iran's oilseed production (400,000 t). Generally, oilseed crops are grown in many countries, and in Iran they are especially cultivated for oil production (Shirani Rad, Zandi, 2012). Indian mustard (*Brassica juncea* L. Czern) is an opportune crop for regions with short seasons and low rainfall (Burton et al., 1999), and its use and cultivation are increasing in the world as a medicinal plant with oily seeds and high nutritional value. The noted mustard-growing countries are India, Canada, China, Pakistan, Poland, Bangladesh and Sweden (Iraddi, 2008). Currently, Iran has insufficient agronomic knowledge for mustard (locally known as Khardal) production, and this problem has restricted its conventional production; yet, it can be found as a wild plant throughout a wide range of the country. Proper sowing time is a climate-dependent factor that provides sufficient growth and development and plays a central role in the satisfactory production and productivity of any crop (Pandey et al., 1981; Verma et al., 2012), as it provides optimum growth conditions such as temperature, light, humidity and rainfall (Gul, Ahmad, 2007; Iraddi, 2008). The role of sowing time in mustard growth has been investigated by many researchers, as shown in table 1. Most of them concur that sowing time is crucial for mustard production (Rahman et al., 1988; Rafiei et al., 2011). Early sowing of crops in semi-dryland conditions, like the Takestan region, may be confronted by drought stress; however, the risk of frost loss increases if sowing is delayed in autumn cultivation. A later sowing date for mustard can reduce the adequate growth period due to high temperatures during the reproductive phase, which can subsequently decrease yield (Radha Kumari et al., 2004), especially in winter-sown crops. Various sowing dates and varieties provide variable environmental conditions within the same region in terms of crop growth and development and yield stability (Daneshian et al., 2008). Bhuiyan et al. (2008) pointed out that environmental conditions affected the seed yield and maturity of mustard to a large extent.

Tab. 1. The recommended proper sowing dates for mustard production

Growth qualitative and quantitative parameters	Sowing dates for optimum crop performance
Plant height	August 30 (Rafiei et al., 2011), 10th and 30th October (Angrej et al., 2002), October 14 (Singh, Singh, 2002), October 16 (Panda et al., 2004), 2nd and 3rd week of October (Singh et al., 2001), November 15 (Aziz et al., 2011), and November 17 (Kurmi, 2002)
Number of siliques per plant	August 30 (Rafiei et al., 2011), September 25 and October 5 (Shivani, Sanjeev, 2002),10th and 30th October (Angrej et al., 2002), October 14 (Singh, Singh, 2002), October 16 (Panda et al., 2004), 2nd and 3rd week of October (Singh et al., 2001), November 15 (Aziz et al., 2011), and November 17 (Kurmi, 2002)
Seed yield	August 30 (Rafiei et al., 2011), During II fortnight of September (Iraddi, 2008), October 1 (Radha Kumari et al., 2004), October 14 (Singh, Singh, 2002), October 15 (Awasthi et al., 2008), October 16 (Panda et al., 2004), 2nd and 3rd week of October (Singh et al., 2001), 3nd week of October (Gajendra, 2001; Raj Singh et al., 2001), October 17 (Yadav et al., 1999), October 20 (Khichar et al., 2000; Khan, Tak, 2002; Yadav Yogesh et al., 2011), October 24 (Khushu, Singh, 2005), 30th October (Bhuiyan et al., 2008) and November 15 (Aziz et al., 2011)
Biomass yield	October 5 (Singh et al., 2002), October 14 (Singh, Singh, 2002), October 15 (Sihag et al., 2003), October 16 (Panda et al., 2004), October 18 (Jadhav, Singh, 1992) and October 24 (Khushu, Singh, 2005)
Oil content	October 10 (Bishnoi, Singh,1979), 10th and 30th October (Angrej et al., 2002), and October 27 (Das, 1998), November 17 (Kurmi, Kalita ,1992)

The differences between the reported dates may come from the various environmental regions under which these experiments have been undertaken

Nitrogen management is one of the critical focal points in the cropping system (Maresma et al., 2019). It is often a demanding task to strike a balance between levels sufficient for normal plant growth and those that are approved for human consumption (Maereka et al., 2007). Usually, plants take up nitrogen through fertiliser application. Allen and Morgan (1972) stated that rapid growth, increased seed and fruit production and enhanced leaf quality in oilseed crops are, together, highly dependent on nitrogen supply. Long-term field experiments on mustard revealed that sufficient levels of nitrogen progressively led to an increase in crop performance (Yadav et al., 1994; Bhalerao, 2001; Garg et al., 2001; Premi, Manoj, 2004; Mckenzie et al., 2006; Verma et al., 2012). Nitrogen application during the sowing and flowering stages resulted in rapid leaf area development; prolonged life of leaves; improved duration of leaf area after flowering; enhanced number and weight of siliques, seeds and flowers per stand and increased overall crop assimilation, which as a result led to increased seed yield and quality in most stand crops (Wright et al., 1988; Geetha et al., 2011). It was also shown that increasing available nitrogen prolonged the vegetative growth and increased dry matter accumulation (Šidlauskas, Tarakanovas, 2004). However, a considerable decrease in physiological yield potential and slowing of the final growth stage through bending stems (or lodging) was noticed by Wright et al. (1988) in response to crop supplementation with a large amount of nitrogen fertiliser.

This paper aims to evaluate the effects of five levels of nitrogen fertiliser, supplied in the form of urea, during two planting seasons, on the growth parameters, seed yield and agronomic properties of Indian mustard in the agro-climatic conditions of Takestan (Iran).

Materials and methods

Study site

The field experiments were conducted at the research station of Takestan Azad University in south-west Qazvin plain (36°03′N; 49°42′E) from 2009 to 2010. This site is 1,283.4 m above sea level, accentuated by a thermo-Mediterranean (semi-arid) climate, according to De Martonne′s classification, which is summarised as hot and dry summers and cool and wet winters. The average from a 30-year climatic data record shows a mean annual rainfall of 312 mm with uneven distribution during the year, which is mostly concentrated in late autumn and early spring. In the region, the winter temperature can fall below 8.2°C and in the summer it can rise above 38.7°C. Meteorological data records were acquired from the agrometeorological station in the University. The total precipitation that occurred during the study (October 2009–July 2010) was 326.3 mm. Moreover, during the 2009 mustard-growing period, the total rainfall was lower than 2010 (56.2 mm and 270.1 mm, respectively), especially during the vegetative phase for the first sown treatments (Fig. 1).

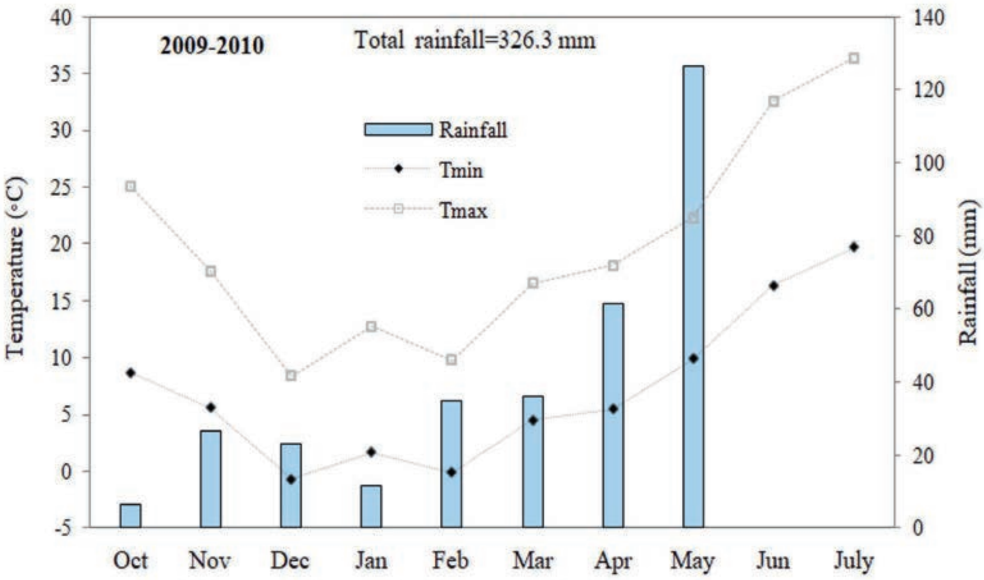

Fig. 1. Monthly minimum temperature (Tmin), maximum temperature (Tmax) and rainfall during the first (October 2, 2009–2010 to June 15, 2010) and the second (March 1, 2009–2011 to July 16, 2010) crop cycle of mustard

Soil properties

Tab. 2. Physical and chemical analysis of soil of the experimental field (2009–2010)

Physical properties Soil texture		0–60 depth [cm] Clay Loam
Clay [%]		29
Silt [%]		45
Fine sand [%]		26
Chemical analysis [mg/1000 g soil]		
Exchangeable	K	330
	Mn^{++}	2.90
	Cu^{++}	0.90
Available	Fe^{++}	7.80
	Zn^{+}	1.20
	P	26.60
Total nitrogen N [%]		0.089
Organic carbon C [%]		1.03
EC [dS/m/25°C]		1.43
pH [H_2O]		8.10

The presented data are the mean values for two soil depths of '0–30' and '30–60' cm; EC – electrical conductivity

Soil samples to a depth of 60 cm were collected from 15 cores in each block prior to cultivation, and the composite samples were prepared for soil fertility analysis. The soil had a low content of both nitrogen (N) (0.08–0.09%) and organic carbon (OC) (1.03%), was slightly alkaline (pH (H_2O) = 8.10) and had a soil textural class of clay loam (Tab. 2).

Experimental design

A split-plot trial arrangement based on a randomised complete block design with four replicates was established, with two planting seasons (PS1 = October 2, 2009 and PS2 = March 1, 2010) as the main plots and nitrogen levels (0, 50, 100, 150, and 200 kg N ha^{-1}), supplied as urea, as subplots. Each subplot consisted of 8 rows, 30 cm apart and 4 m long × 3 m width (plot size: 27.5 m long × 4 m width). The trial field was initially irrigated and, at the stage of soil puddling, it was ploughed once deeply via a mouldboard plough. Next, to fragment clods and to create uniform soil conditions, a perpendicular disk was used. This was followed by use of a harrowing thrice and smoothing with a wooden board to supply a fine seedbed – the furrows and ridges were constructed with a furrower and the distance between the ridges was 30 cm.

For treatment, a standard dose of phosphorus, i.e. 70 kg ha^{-1} single super phosphate along with one-third of the nitrogen treatment, was incorporated and added to the soil at the time of final land preparation prior to drilling by disking. Pre-sowing watering was done to ensure normal germination and isomorph plant stands. Irrigations was provided when required to preserve the soil's moisture at an optimum condition. The mustard cultivar 'Landrace' was used in the trial. The pre-soaked seeds were sown using a single row hand drill with a seeding rate of 5 kg ha^{-1} at 2 cm depth in rows with 30 cm spacing. A thinning operation was performed about two weeks after sowing to leave more vigorous stands and to finally maintain plant-to-plant distance at 5 cm. The weeds were eradicated by hand-hoeing as necessary. A basal half dose of non-applied nitrogen was given at the 4–6 leaves phase and the remaining dose was top-dressed at the start of flowering. All other recommended crop management practices were carried out uniformly and regularly for all of the treatment groups during the probationary period to ensure proper crop growth. The plots were harvested in late spring (10 to 15 June, 2010) and early summer (11 to 16 July, 2010) for the first and second seeding dates, respectively. The shoots of five randomly selected and tagged plants belonging to subplots were hand-harvested at the end of the growing period and the plant height and the number of siliques per plant were recorded. The mean height of five randomly selected plants from the base to the tip of the main stem was measured and expressed in centimetre (cm). When the majority of stands were at full maturity in all plots, an area of 3.6 m^2 (the inner five rows) was evaluated to determine the biomass and seed yield. Simultaneously, the quadrate samples were cut by hand at approximately 5 cm above the ground and left in the field for sun drying until they reached a constant weight. After one week, when the plant water content was less than 12%, the samples were weighed and recorded as biomass yield [t ha^{-1}] per subplot. Next, they were threshed using a Kurt Pelz stationary thresher and hand-cleaned.

The separated seeds were air-dried to 10–12% humidity and weighed with a digital balance (Kaifeng Group Co., Ltd., China). The seed yield was then determined and expressed in kg seed ha^{-1}. A sample of 100 seeds was taken from every seed lot related to subplots, oven-dried at 105°C for 1.30 h and ground into fine particles. The oil content in powdered samples [%] was determined using a soxhlet instrument with carbon tetrachloride as an organic solvent (250 cc; 1:1 ratio; at 70°C).

Statistical analysis

Data were analysed statistically using Proc GLM (*SAS Inc*., 2001) to detect significant differences ($p \leq 0.05$) among treatments and the comparisons of means were carried out applying the method of Duncan's multiple range test (DMRT) at a 5% level of significance. The Ombrothermic diagram was drawn with MS Excel ver. 2007.

Results and discussion

Results revealed that the simple effect of cultivation season and nitrogen rate was significant for plant height, biomass yield, the number of siliques per plant, seed oil content and seed yield ($p \leq 0.01$). The interaction of cultivation season and nitrogen rates also had a significant effect on plant height and the number of siliques per plant (Tab. 3).

The means comparison of planting season and nitrogen rate interaction showed that 150 and 200 kg N ha^{-1} treatments were significantly more effective than other treatments in terms of plant height, for autumn planting on October 2. The lowest plant heights occurred with the zero dose of nitrogen in both the winter (81.7 cm) and autumn (99.5 cm) cultivation season (Tab. 3). Increasing nitrogen consumption increases the amount of protein in the cells, a subsequent increase in cell size and larger leaf area, resulting in greater photosynthetic activity and ultimately leading to an increase in plant height in rapeseed (Wysocki et al., 2007). Greater plant heights are due to having a longer inflorescence axis, or in other words, having the largest number of flowers and pods on the inflorescence of the stem. Additionally, leaf fall during the filling of siliques with seeds requires plant photosynthesis to be maintained by the siliques and the stems. Therefore, having a longer stem means having a higher photosynthetic surface and producing more metabolic material to fill siliques and seeds (Norton et al., 1991).

The means comparison of planting season effect on the amount of biomass showed that the autumn planting season of October 2, with an average of 12.64 t ha^{-1}, resulted in statistically higher levels of biomass than the winter planting season of March 1. The results also showed that treatments of 150 and 200 kg N ha^{-1} resulted in the highest biomass yield, while the lowest amount of biomass was found for the control treatment (Tab. 3).

Tab. 3. Plant parameters of Indian mustard (*Brassica juncea* L. Czern) in response to different cultivation seasons and rates of nitrogen fertiliser application (mean 2009–2010)

Treatments		Plant height [cm]	Biomass yield [t ha^{-1}]	Number of siliques per plant [No.]	Seed oil content [%]	Seed yield [kg ha^{-1}]
Autumn cultivation		144.5a	12.64a	118.60a	42.57a	3394a
Winter cultivation		116.2b	9.58b	89.00b	41.13b	2459b
Nitrogen fertilisation (N)						
N1: 0 kg ha^{-1} (CK)		90.60d	8.26d	61.20e	41.25c	1506e
N2: 50 kg ha^{-1}		121.60c	10.46c	93.10d	42.59b	2549d
N3: 100 kg ha^{-1}		139.10b	11.81b	112.50c	43.51a	3162c
N4: 150 kg ha^{-1}		147.70a	12.40a	123.40b	41.86bc	3624b
N5: 200 kg ha^{-1}		152.70a	12.62a	128.80a	40.03d	3794a
Planting season (PS)						
Autumn cultivation (PS1: October 2, 2009)	N1	99.5e	9.93	72.6g	41.87	1985
	N2	130.6c	12.00	107.2d	43.23	2976
	N3	152.8b	13.23	127.4c	44.16	3562
	N4	165.7a	13.94	139.2b	42.76	4123
	N5	173.8a	14.12	146.6a	40.85	4325
Winter cultivation (PS2: March 1, 2010)	N1	81.7f	6.58	49.8h	40.63	1026
	N2	112.6d	8.93	79.0f	41.95	2122
	N3	125.3c	10.39	97.6e	42.86	2761
	N4	129.7c	10.86	107.6d	40.97	3125
	N5	131.6c	11.13	111d	39.22	3262
Source of variations		Analysis of variance				
PS		**	**	**	**	**
1N		**	**	**	**	**
PS×N		**	ns	*	ns	ns
C.V. [%]		4.72	2.35	2.77	1.46	3.88

Means with the same letters are not significantly different at $p < 0.05$; 1N: Nitrogen fertiliser as urea was applied in three equal portions: 1) at the pre-sowing stage, 2) on 4–6 leaves growing phase and as top-dress fertiliser 3) in the reproductive stage; PS×N: represents interaction terms between treatment factors; C.V. – coefficient of variation; ns, F test not significant, *F test significant at $p \leq 0.05$, **F test significant at $p < 0.01$

Comparison of the mean effects of planting season and nitrogen levels showed that the application of 200 kg N ha^{-1} during autumn cultivation on October 2 resulted in the highest number of siliques (146.6) in the plant. However, a lack of nitrogen fertilisation decreased the average number of siliques (49.8) for winter cultivation (Tab. 3).

It follows from the results that nitrogen application caused a significant increase in the number of branches per plant (data not shown) (Raghuvanshi et al., 2018), and subsequently led to the production of more siliques in mustard (Bilsborrow et al., 1993). It has been reported previously that the main reason for a decrease in the number of siliques per plant is associated with a decrease in the number of sub-branches (Tayo, Morgan, 1979). Clark and Simpson (1978) argue that the numbers of branches in a plant, as well as the number of seeds in a small silique, are influenced by environmental conditions.

The results showed that the autumn planting season of October 2 provided the highest content of seed oil, with an average of 42.57%, which was significantly higher than the winter planting season. The reason for the decrease in the percentage of seed oil in winter cultivation is likely due to temperature changes during the stage of seed filling and a reduction in net photosynthesis (Daneshian et al., 2008). In this case, less overall material is produced, and those carbohydrates are converted to oil. The longer the flowering to ripening period is, the greater the time for oil synthesis and, ultimately, the percentage of oil increases (Gecgel et al., 2007).

The highest seed oil content was 100 kg N ha^{-1}, with an average of 43.51% oil, followed by an increase in nitrogen application, which reduced seed oil content (Tab. 3).

Seed yield results showed that the autumn planting season, with an average of 3,394 kg ha^{-1}, had a significant advantage over the winter planting season, with an average of 2,459 kg ha^{-1}. Increasing the length of the growing season, along with the proper conditions for germination and optimal plant establishment, can increase seed yield. Planting date is an important factor that affects seed yield and seed oil content (Koutroubas, Papasoska, 2005).

Johnson et al. (1995) compared different planting dates in canola and concluded that the delay in planting date significantly reduced seed yield, which was due to a decrease in the number of siliques in the plant and a decrease in harvest index. Increasing nitrogen consumption to 200 kg N ha^{-1} increased seed yield. The treatment of 200 kg N ha^{-1} resulted in an average of 3,794 kg ha^{-1}, the highest seed yield (Tab. 3). Kazemeini et al. (2010) showed that increasing nitrogen levels led to an increase in yield components and, ultimately, seed yield of rapeseed genotypes. Elewa et al. (2014) also examined new rapeseed cultivars at different nitrogen levels and demonstrated that increasing the amounts of nitrogen increased the seed yield for the studied cultivars.

Conclusions

Cultivation season and nitrogen level significantly affected plant height, biomass yield, number of siliques per plant, seed oil content and seed yield of Indian mustard (*Brassi-*

ca juncea L. Czern). The mean comparison of the interaction between planting season and nitrogen level showed that 150 and 200 kg N ha^{-1} treatments resulted in higher and superior values for the parameters of interest, with autumn planting, than the other treatments. The lowest values were observed in control plants. The use of nitrogen had a positive effect on the growth and development of mustard. Appropriate fertilisation, climatic conditions and plant care allow for high quality and high quantity of crops.

Acknowledgements

We are very thankful to those who funded us during the study, especially the research board of Science and Research Branch, Islamic Azad University, Tehran, Iran.

Conflict of interest

The authors declare no conflict of interest related to this article.

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Abstract

Indian mustard (*Brassica juncea* L. Czern) cultivation is suggested for regions with short seasons and low rainfall. Although there have been many studies conducted on agronomic production of mustard in Iran, the information regarding the interactive impact of cropping seasons and nitrogen fertiliser on growth characteristics and yield quality of mustard plant is still insufficient and requires further investigation. This study focused on the possible implications of different cropping seasons and different nitrogen levels on selected agronomic traits in mustard. In this experiment, five different doses of nitrogen and two sowing periods were used to assess for their combined effects on the growth parameters, seed yield and agronomic characteristics of mustard in the semi-arid climatic conditions of Takestan. The results revealed that cultivation seasons and nitrogen rates had a significant effect on plant height, biomass yield, number of siliques per plant, seed oil content and seed yield.

Key words: Indian mustard, nitrogen fertilisation, planting season, seed oil content, seed yield

Received: [2020.06.11]

Accepted: [2020.09.07]

Agronomiczna wydajność jesienno-zimowej uprawy gorczycy sarepskiej (*Brassica juncea* L.), w odpowiedzi na różne dawki nawozu azotowego

Streszczenie

Gorczyca sarepska = kapusta sitowata (*Brassica juncea* L. Czern), jest charakterystyczna dla upraw w regionach o krótkich porach roku oraz mniejszych opadach. Obecnie w Iranie brakuje wystarczającej wiedzy rolniczej do wydajnej produkcji gorczycy. W artykule tym, będącym formą pracy przeglądowej i badawczej jednocześnie, skoncentrowano się na produkcji gorczycy w półsuchym regionie oraz ocenie jakości jej oleistych nasion. Celem było również porównanie nawożenia pięcioma różnymi dawkami azotu (w postaci mocznika), w trakcie dwukrotnego wysiewu oraz zbadanie wpływu tych dawek na wzrost, plon nasion i niektóre właściwości agronomiczne gorczycy, w warunkach agroklimatycznych Takestanu (Iran). Wyniki pokazały, że sezon uprawy oraz dawki azotu, miały znaczący wpływ na wzrost roślin, plon biomasy, liczbę owoców – łuszczyn przypadających na roślinę, zawartość oleju siewnego i ogólny plon ziarna. Data sadzenia, warunki środowiskowe, nawożenie są ważnymi

czynnikami wpływającymi na jakość i wielkość plonów gorczycy.

Słowa kluczowe: gorczyca indyjska, nawożenie azotem, sezon sadzenia, zawartość oleju w nasionach, plon nasion

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