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Growth, yield and water use efficiency of Indian mustard (*Brassica juncea* L.) as influenced by irrigation frequency and row spacing

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Abstract

Effect of irrigation frequency and row spacing on growth, yield and water use efficiency of Indian mustard [*Brassica juncea* (L.) Czern & Coss.] cultivar Pusa Tarak was studied at J.N.K.V.V., College of Agriculture, Tikamgarh (Madhya Pradesh), India during two consecutive *Rabi* seasons of 2012-13 and 2013-14. The experiment was laid out in split-plot design with three replications, consisted three irrigation frequencies *viz*., I_0 (no post sowing irrigation), I_1 (one irrigation at 40 DAS) and I_2 (two irrigation at 40 and 75 DAS) as main plot treatments and three row spacing *viz*., S_1 (20 cm), S_2 (30 cm) and S_3 (40 cm) as sub-plot treatments. Results showed that application of two irrigations at 40 and 75 DAS (I_2) resulted into significantly greater plant height, more number of branches (plant^{-1}), total dry biomass (g plant^{-1}), LAI at 75 DAS, more number of siliquae (plant^{-1}), number of seeds (siliqua^{-1}), seed yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index followed by one irrigation (I_1) and the lowest under no post sowing irrigation (I_0). Irrigation frequency increased the consumptive water use (CU) considerably and an increased in CU by application of two irrigations (I_2) and one irrigation (I_1) was 33.1% and 8.34%, respectively over no-post sowing irrigation (I_0). On the other hand, WUE (kg ha^{-1}-mm) was recorded significantly higher with the application of one irrigations (I_1) followed by 2 irrigations (I_2) and no-post sowing irrigation ((I_0)). WUE between no-post sowing irrigation (I_0) and application of 2 irrigations (I_2) did not differ significantly. The significantly greater plant height at harvest was observed at closer spacing of 20 cm (S_1) followed by 30 cm (S_2) and 40 cm (S_3). The significantly more number of branches (plant^{-1}), LAI, dry biomass (g plant^{-1}), number of siliquae (plant^{-1}), number of seeds (siliqua^{-1}) and higher 1000 seed weight (g) were recorded at wider spacing of 40 cm (S_3) and these parameters were the lowest at closest spacing of 20 cm (S_1). Similarly, wider spacing of 40 cm (S_3), been on par with 30 cm (S_2) also produced significantly higher seed yield (kg ha^{-1}) and biological yield (kg ha^{-1}) over the closer row spacing of 20 cm (S_1). Harvest index among row spacing did not differ significantly. WUE was realized significantly higher with 40 cm (S_3) followed by 30 cm (S_2) and 20 cm (S_1). However, consumptive water use was higher with closer row spacing of 20 cm followed by row spacings of 30 cm and 40 cm. Higher accumulation of dry biomass, more number of branches, more number of siliquae and more number of seeds in mustard ultimately elevated the seed yield as confirmed by relationship study between seed yield and these parameters.

Key words: *Brassica juncea, growth, irrigation frequency, row spacing, water use efficiency*

Introduction

Indian mustard (*Brassica juncea* L.) is a member of the Brassicaceae family and has become one of the most important sources of oil production in the world. India is the third largest oil seed producing country in the world. Rapeseed-mustard is the second most important edible oilseed after groundnut sharing 27.8% in the India's oilseed economy. The area, production and productivity of rapeseed-mustard in India is 6.70 million ha, 7.96 million ton and 1188 kg ha^{-1}, respectively during the 2013-14 (Anonymous, 2014). However, its productivity is quite low in the country against the world average of 1400 kg ha^{-1} in world. Of the several reasons, non-availability of adequate irrigation is the most important one. Owing to hardy and capacity to thrive well under poor soil moisture, mustard is seldom irrigated and is generally raised as a rainfed crop in India. However, the crop responds well to irrigation and it is a vital factor for proper growth and development of this crop in dry season. Plant growth and development are the result of many physiological processes which are influenced by soil moisture (Pirri and Sharma, 2007). Yield of mustard is greatly influenced by irrigation and better results both in terms of biometric components and seed yield can be achieved by the application of optimum irrigation. Non-availability of sufficient irrigation water as per requirements of mustard crop causes moisture stress at critical stages of growth and development. There are several reports, which indicate that irrigation increased the production of mustard. Raut *et al.* (2000) reported about 33% increase in yield with the application of 2 irrigations at pre-flowering and pod filling stages. Pirri and Sharma (2007) also reported that application of two irrigations (45 and 90 DAS) significantly increased the yield attributes and seed yield of mustard over single irrigation (45 DAS) and no irrigation. Hence, irrigation water plays a vital role in enhancing mustard production and its judicious use becomes a necessity.

Among the agronomic factors known to augment the mustard production are spacing and plant geometry, which play a pivotal role in enhancing the production and secure a better translocation of photosynthates, which render better yield of crop (Alam, 2004). Spacing is a non-monetary input, but it plays a vital role by changing the magnitude of competition. Optimum row spacing are necessary for interception of sunlight to each strata of leaves. This will enhance the rate of photosynthesis and consequently, the dry matter production, which can ultimately increase the crop yield. Establishment of optimum plant population by maintaining proper row spacing is one of the important factors to The plant density per unit area and the yield per plant are two most important and inter-dependent factors responsible for crop yield (Singh and Dhillon 1991). Therefore, the present investigation was undertaken to study the effect of irrigation frequency and row spacing on growth, yield and water use efficiency of Indian mustard (*Brassica juncea* L.) var. Pusa Tarak.

Materials and Methods

Field experiment was conducted at Research Farm, J.N.K.V.V., College of Agriculture, Tikamgarh (24° 43' N latitude, 78° 49' E longitude at an altitude of 358 m above mean sea level), Madhya Pradesh, India during two consecutive *Rabi* seasons of 2012-13 and 2013-14. The experimental site is of sub-tropical climate characterized by hot dry summers and cool dry winter lies in the Bundelkhand Zone (Agro-climatic Zone-VIII). The soil of experimental plot was medium to deep black and clayey loam in texture having pH 7.0, EC 0.12 dS m^{-1}, organic carbon 5.0 g kg^{-1}, available N 266 kg ha^{-1}, available P 11.3 kg ha^{-1} and available K 255 kg ha^{-1}, respectively. The average annual rainfall of this region is about 1000 mm, which is mostly received between June to September, and a little rainfall (90 mm) is also obtained during October to May. The average temperature ranges between 4.5 °C to 45 °C. The weather parameters during experiment were recorded at the Meteorological Observatory located at Research Farm, College of Agriculture, Tikamgarh, MP, India.

The experiment was laid out in split-plot design with 3 replications and comprised of three irrigation frequencies *viz*., no-post sowing irrigation (I_0), one irrigation at 40 DAS (I_1) and 2 irrigations at 40 and 75 DAS (I_2) as main plot treatments and three row spacing *viz*., 20 cm (S_1), 30 cm (S_2) and 40 cm (S_3) as sub-plot treatments.. The sowing of Indian mustard variety 'Pusa Tarak' was done on 01 November of 2012 and 2013 in lines, 20, 30 and 40 cm apart (as per treatments) drawn by *kudali* using a seed rate of 5 kg ha^{-1}. The full recommended doses of nitrogen (20 kg N ha^{-1}), phosphorus (40 kg P_2O_5 ha^{-1}), and potassium (20 kg K_2O ha^{-1}) were applied as basal through urea, SSP and murate of potash, respectively just below the soil. All other agronomic and plant protection measures were applied as per recommendations.

Ten plants were taken out randomly from each plot leaving the border plants to collect data on growth characters and yield attributes at harvest. Leaf area index was recorded at 75 DAS. Seed yield was determined from net plot area of 9.6 m^2 of each plot. The consumptive use of water (CU) was computed from the water balance as described by Dastane (1972). A factor of 0.6 of evaporation from USBW class A Pan evaporimeter for the period between irrigation and soil sampling for moisture content, effective rainfall and soil moisture used between two irrigations from the soil profile were added according to following formula :

Where, Cu = consumptive use of water (mm); Ep=Pan evaporation values (mm) from the USWB Class 'A' pan for the interval from the date of irrigation to the date of sampling after irrigation; 0.6=A constant factor used to get Et value by multiplying Ep value for a given period; M_1i=moisture percentage of i^{th} layer on the date of sampling after irrigation; M_2i=moisture percentage of i^{th} layer on the date of sampling before irrigation; dbi=bulk density of the i^{th} layer (g cc^{-1}); Di=depth of the i^{th} layer of the soil (mm); ER=effective rainfall (mm), if any during the period under consideration; n= number of soil layers; N=number of days from irrigation to sampling after irrigation.

The water use efficiency (kg ha^{-1}-mm) for a given treatments was calculated by dividing the seed yield with the respective total consumptive water use for the crop period.

$$\text{WUE} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Consumptive water use (mm)}}$$

The results of both the years were more or less similar and hence two years data were pooled and analyzed statistically to draw suitable inference as per standard ANOVA technique described by Gomez and Gomez (1984). Regression analysis was made following Microsoft Excel 2003 Software.

Results and Discussion

Growth characters

The data pertaining to growth characters as influenced by irrigation frequency and row spacings are given in Table 1. The irrigation schedule of two irrigations at 40 and 75 DAS (I_2) was found significantly superior in terms of plant height (98.8 cm), number of primary branches (5.20 $plant^{-1}$), total dry biomass (9.11 g $plant^{-1}$) at harvest and leaf area index at 75 DAS (2.36) over one irrigation at 40 DAS (I_1) and the lowest in no-post sowing irrigation (I_0). Similar result was also reported by Singh *et al*. (2002) and Hasanuzzaman and Karim (2007) in mustard. Adequate and timely supply of irrigation water in I_2 (at 40 and 75 DAS) treatment ensures cell turgidity and consequently higher meristematic activity leading to improved morphological parameters like greater plant height, more branches, more foliage development, greater photosynthetic rate, higher nutrient uptake, higher dry biomass production and better growth of plant (Agarwal and Gupta, 1991; Karoria, 2009). Jadhav (1988) also reported significantly higher dry biomass production because of increased plant height and number of branch $plant^{-1}$ with higher moisture under two irrigations as compared with less moisture availability to plants under one irrigation and without irrigation. On the other hand, moisture deficit in I_0 (no-post sowing irrigation) and I_1 (one irrigation at 40 DAS) treatments results in dehydration of protoplasm which decreased the turgor potential and turgor driven physiological processes *viz*., cell division and cell elongation which affect the plant growth (height, number of leaves, branches etc.) and ultimately the total dry matter accumulation (Tyagi and Upadhyay, 2016).

Among row spacings, the greater plant height (104.3 cm) at harvest was observed at closer spacing of 20 cm (S_1) followed by 30 cm (S_2) and the widest row spacing of 40 cm (S_3) resulted in the lowest plant height. The plant probably tended to be taller for getting the light in closed spacing. Sharma and Thakur (1993) and Hasanuzzaman and Karim (2007) also reported the highest plant height from the closest row spacing (20 cm). On the other hand, significantly more number of branches (6.41 $plant^{-1}$), LAI (2.41) and total dry biomass (10.4 g $plant^{-1}$) was found in

Table 1: Effect of irrigation frequency and row spacings on growth of Indian mustard var. Pusa Tarak

Treatments	Plant height at harvest (cm)	No. of primary branches plant^{-1}	Leaf area index at 75 DAS	Total dry matter (g plant^{-1}) at harvest
Irrigation frequency				
I_0	89.1	4.16	1.80	6.28
I_1	94.8	4.87	2.36	8.25
I_2	98.8	5.20	2.36	9.11
S.Em±	1.70	0.26	0.10	0.36
CD at 5%	5.49	0.74	0.36	1.15
Row spacings				
S_1	104.3	2.61	1.93	6.20
S_2	92.5	5.21	2.18	7.01
S_3	85.9	6.41	2.41	10.4
S.Em±	2.0	0.14	0.09	0.24
CD at 5%	6.25	0.46	0.30	0.76
Irrigation frequency x row spacing				
I_0 S_1	99.0	2.07	1.52	4.43
I_0 S_2	89.7	4.68	1.85	5.39
I_0 S_3	78.6	5.73	2.01	9.02
I_1 S_1	104.7	2.81	2.17	6.85
I_1 S_2	93.2	5.45	2.31	7.2
I_1 S_3	86.6	6.36	2.59	10.7
I_2 S_1	109.2	2.94	2.09	7.33
I_2 S_2	94.7	5.50	2.38	8.48
I_2 S_3	92.4	7.15	2.61	11.5
S.Em±	3.36	0.46	0.15	0.49
CD at 5%	NS	1.50	0.56	1.64

I_0: No post sowing irrigation I_1: One irrigation at 40 DAS I_2: Two irrigations at 40 & 75 DAS
S_1: 20cm S_2: 30cm S_3: 40cm

the wider spacing of 40 cm (S_3) and these parameters were the lowest in closer row spacing of 20 cm (S_1). Wider spacing increased the number of branches plant^{-1} by 22.7% ovetar closer row spacing of 20 cm (S_1). In rapeseed reduced number of branches (plant^{-1}) due to increasing population density has been reported by Singh and Dhillon (1991), Singh and Verma (1993) and Hasanuzzaman and Karim (2007). In case of wider row spacing (S_3), the plant could get adequate nutrient and space to produce highest LAI and dry matter. On the other hand, closer spacing (S_1), the shortage of space and higher competition for space, nutrient and moisture reduced the LAI and dry matter production. Earlier, Oad *et al.* (2001) also observed more competition for different inputs among rapeseed with closer row spacing.

Interaction effect indicated that treatment I_2S_3 (two irrigations and 40 cm row spacing) produced significantly more number of primary branches (7.15 plant^{-1}), LAI (2.61) and total dry biomass (11.5 g plant^{-1}) and being at par with treatment I_1S_3 (one irrigation and 40 cm row spacing). These results corroborate the findings of Tomar *et al*. (1992) and Hasanuzzaman and Karim (2007).

Yield attributes and seed yield

Frequency of irrigation showed significant variation in yield attributes and yields (Table 2). Application of two irrigations at 40 and 75 DAS (I_2) produced significantly the highest number of siliquae (101.9 plant^{-1}) and number of seeds siliqua-1 (12.0 siliqua^{-1}) followed by one irrigation at 40 DAS (I_1) and the

Table 2: Effect of irrigation frequency and row spacings on yield attributes, yield water use efficiency of Indian mustard var. Pusa Tarak

Treatments	No. of siliquae $plant^{-1}$	No. of seeds $siliqua^{-1}$	1000 seed weight (g)	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Consumptive use of water (mm)	Water use efficiency (kg ha^{-1}-mm)
Irrigation frequency								
I_0	66.7	11.3	5.09	598	2646	23.3	161.6	4.30
I_1	86.5	11.6	5.18	1047	3783	27.3	176.3	6.30
I_2	101.9	12.0	5.47	1217	4162	29.6	241.4	5.02
S.Em±	0.9	0.1	0.14	31	29	1.31	3.52	0.19
CD at 5%	3.4	0.3	NS	108	105	4.22	12.2	0.69
Row spacings								
S_1	67.7	10.8	4.85	566	2192	25.6	207.6	2.83
S_2	82.9	11.4	5.04	1138	4304	26.7	196.9	5.78
S_3	103.9	12.8	5.82	1160	4095	27.9	174.7	7.01
S.Em±	0.8	0.3	0.17	30	126	1.08	9.32	0.25
CD at 5%	2.8	0.9	0.53	93	394	NS	31.2	0.77
Irrigation frequency x row spacing								
I_0 S_1	54.3	10.5	4.82	378	1595	23.9	231.9	1.65
I_0 S_2	65.9	11.1	4.85	737	3316	23.6	136.5	5.39
I_0 S_3	93	12	4.88	680	3028	22.5	116.3	5.85
I_1 S_1	62.7	10.9	4.87	575	2415	24	196.0	2.94
I_1 S_2	88.8	11.1	5.02	1260	4439	28.4	196.0	6.43
I_1 S_3	97.1	12.3	5.23	1306	4496	29.6	136.8	9.53
I_2 S_1	83.2	10.9	5.5	744	2565	29	194.7	3.89
I_2 S_2	104.8	11.9	5.66	1416	5158	28.3	258.4	5.50
I_2 S_3	123.7	13.7	6.3	1493	4762	31.5	271.0	5.66
S.Em±	0.5	0.1	0.15	46	45	1.82	5.23	0.30
CD at 5%	2.1	0.3	0.54	175	165	NS	51.0	1.41

I_0: No post sowing irrigationI_1: One irrigation at 40 DASI_2: Two irrigations at 40 & 75 DAS
S_1: 20cm S_2: 30cm S_3: 40cm

lowest under no post sowing irrigation (I_0). In case of I_2 treatment, the second irrigation during siliqua formation stage helped in producing more number of siliquae without dropping of them. This was confirmed when reduced number of siliquae plant^{-1} was observed in I_1 (one irrigation at 40 DAS, *e.g.* flowering stage) and no post sowing irrigation (I_0). Tomer *et al*. (1992) also found that number of siliquae plant^{-1} was significantly increased up to two irrigations at pre-flowering and fruiting stages. The favourable effect of two irrigations at 40 and 75 DAS (I_2) on sink component (number of siliquae and number of seeds) could also be attributed to better development of the plants in terms of plant height, number of branches and dry biomass production leading to increased bearing capacity due to optimum growth on account of favourable moisture during entire crop growing period (Chauhan *et al*., 2002 and Pirri and Sharma, 2007).

Application of two irrigations (I_2) recorded significantly higher seed yield (1217 kg ha^{-1}) and biological yield (4162 kg ha^{-1}) followed by one irrigation (1047 kg ha^{-1} and 3783 kg ha^{-1}, respectively) and the lowest with no post sowing irrigation (598 kg ha^{-1} and 2646 kg ha^{-1}, respectively). The increase in seed yield due to two irrigations was 50.9% and 14.0% over one and no irrigation, respectively. Similarly, one irrigation increased seed yield over no irrigation by 42.9% (Table 2). The significant improvement in the mustard seed yield under two and one irrigation might be the cumulative effect of significant improvement in the value of yield attributes like number of siliquae plant^{-1} and number of seeds siliqua^{-1}. Chauhan *et al*. (2002), Bharati *et al*. (2003), Panda *et al*. (2004) and Karoria (2009) also reported an increase in seed yield and biological yield with increasing irrigation frequency. The data in Table 2 also reveal that application of two irrigations (I_2), been on par with one irrigation (I_1), significantly increased harvest index over the no-post sowing irrigation (I_0). Availability of more moisture to plants might have resulted in the production of more photosynthates which might have helped in the translocation of more photosynthates to seeds and increased harvest index. These results were in conformity with those of Jadhav (1988) and Hasanuzzaman and Karim (2007).

Yield attributes *viz*., number of siliquae (plant^{-1}), number of seeds (siliqua^{-1}) and 1000-seed weight (g) were gradually declined with the increase in number of plants per unit area due to closer row spacing (Table 2). The significantly more number of siliquae (103.9 plant^{-1}), number of seeds (12.8 siliqua^{-1}) and higher 1000 seed weight (5.82 g) were recorded at wider spacing of 40 cm (S_3) and the lowest at closest row spacing of 20 cm (S_1). These results confirmed the findings of Singh and Dhillon (1991), Misra and Rana (1992), Chauhan *et al*. (1993) and Hasanuzzaman and Karim (2007). Because of less plants population per unit area in case of wider row spacing of 40 cm (S_3), the plants could get adequate nutrients, moisture and space to produce more number of branches and number of siliquae with highest dry biomass production. Whereas, due to more plant population in case of closer row spacing of 30 cm (S_2) and 20 cm (S_1), the shortage of space and higher competition for space, nutrients and moisture reduced the number of branches and siliquae number with dry biomass production in mustard (Hasanuzzaman 2008). Similarly, closer spacing increases population density which decreases the number of seeds siliqua^{-1} due to the competition between plants that had a detrimental effect on siliqua formation in rapeseed (Siddiqui, 1999).

It was also observed from Table 2 that wider row spacing of 40cm (S_3), been on par with 30 cm (S_2), significantly producing the highest seed yield (1160 kg ha^{-1} and 1138 kg ha^{-1}, respectively) over the closer row spacing of 20cm (566 kg ha^{-1}). However, biological yield (kg ha^{-1}) was recorded significantly higher with row spacing of 30 cm and 40 cm over the 20 cm row spacing. Off the treatment, 40 cm (S_3) and 30 cm (S_2) exhibited 51.2% and 50.0% higher seed yield (kg ha^{-1}) over closer row spacing of 20 cm (S_1). The decreased in seed yield at closer spacing (S_1), the shortage of space and higher competition for space, nutrient and moisture reduced the number of siliquae with dry matter accumulation in siliquae which ultimately reflected in lower seed yield (Hasanuzzaman 2008). On the other hand, at wider row spacing (S_3) and (S_2), the plant could get adequate nutrient, moisture and space to produce highest LAI which contributed to maximum photosynthesis and photosynthate had been partitioned to economic parts (siliquae) of mustard. These results were supported by Alam (2004), Hasanuzzaman and Karim (2007) and Hasanuzzaman (2008). The higher biological yield (kg ha^{-1}) with wider row spacing (S_3) and (S_2) might also be due to adequate nutrient, moisture and space to produce highest plant height, number of branches, LAI which attributed to maximum biomass accumulation in plants. On the other hand, more competition among plants for nutrient, moisture and space reflected in reduced plant height, number of branches, LAI which ultimately attributed to minimum biomass accumulation in plants. Harvest index was found to be non-significant among different row spacings. These results were supported by Tyagi (1994) and Thakur (2013).

The interaction between irrigation frequency and row spacing showed that two irrigations with 40 cm row spacing (I_2S_3) produced significantly more number of siliquae (123.7 $plant^{-1}$), more number of seeds (13.7 $siliqua^{-1}$) and 1000-seed weight (6.30 g) over rest of the treatments. Similarly, interactional effect indicated that treatment I_2S_3 (two irrigations and 40 cm row spacing) gave higher seed yield (1493 kg ha^{-1}) and being at par with treatment I_1S_3 (one irrigation and 40 cm row spacing). Any row spacing with no post sowing irrigation failed to produce any comparable yields. The wider spaced plants with two irrigations were grown favorably without intra plant competition thus producing maximum yield components which ultimately elevated the seed yield. On the other hand, the closer plant space had higher intra plant competition due to limited land area and mutual shading effect resulted into poor growth of plant. Tomar *et al*. (1992), Giri (2001) and Hasanuzzaman and Karim (2007) also found maximum yield attributes and seed yield with two irrigations at flowering and siliqua development stage of wider row spaced mustard plants.

Consumptive water use (CU)

It is clear from the data in Table 2 that irrigation frequency increased the consumptive water use (CU) considerably and an increased in CU by application of two irrigations (I_2) and one irrigation (I_1) was 33.1% and 8.34%, respectively over no-post sowing irrigation (I_0). Among different irrigation frequency, CU of 241.4 mm was recorded significantly higher with the application of 2 irrigations, each at 40 and 75 DAS followed by application of one irrigation at 40 DAS (176.3 mm) and no-post sowing irrigation (161.6 mm). The effect was, however, more conspicuous at two irrigations (I_2) than no-post sowing irrigation because of more evapo-transpiration. The higher CU with two irrigations (I_2) was expected because two irrigations increased the available water in the soil profile and this facilitated more loss of water through evapo-transpiration as compared to no irrigation and single irrigation. These results are similar to those obtained earlier by Raut *et al*. (2000), Panda *et al*. (2004), Piri *et al*. (2011) and Kingra and Kaur (2012).

Among row spacing, closer spacing of 20 cm (207.6 mm), been on par with 30 cm ((196.9 mm) exhibited significantly higher CU over the wider row spacing of 40 cm (174.7 mm). The higher consumptive use values with closer row spacings might be due to greater extraction of soil moisture by the plant as a result of higher population density per unit area (Thakur, 2013).

Water use efficiency (WUE)

It is evident from the data in Table 2 that the increased irrigation frequency resulted into decreased water use efficiency (WUE). Among different irrigation levels, WUE of 6.30 kg ha^{-1}-mm was recorded significantly higher with the application of one irrigations at 40 DAS followed by 2 irrigations at 40 and 75 DAS (5.02 kg ha^{-1}-mm) and no-post sowing irrigation (4.30 kg ha^{-1}-mm). However, WUE between no-post sowing irrigation (I_0) and application of 2 irrigations (I_2) did not differ significantly. Increased water use efficiency with the application of one irrigation over no-post irrigation and two irrigations might be because of more rational use of moisture by crops grown with this treatment. Similar results were also found by Tomar *et al*. (1992), Yadav *et al*. (1999) and Piri *et al*. (2011). The lower WUE with no-post sowing irrigation (I_0) was due to more water use (more water loss in evapo-transpiration) by plants without much increased in seed yield.

Among row spacing, WUE was realized significantly higher with 40 cm (7.01 kg ha^{-1}-mm) followed by 30 cm (5.78 kg ha^{-1}-mm) and 20 cm (2.87 kg ha^{-1}-mm). The less plant population under wider row spacing resulted in less transpiration loss of water which in turn reflected in higher water use efficiency (Thakur, 2013).

The interaction between irrigation frequency and row spacings for WUE was found significant (Table 2). Among the treatment, I_1S_3 (one irrigation and 40 cm row spacing) resulted into significantly higher WUE (9.53 kg ha^{-1}-mm) and the lowest with I_0S_1 (1.65 kg ha^{-1}-mm). The more rational use of moisture by crops grown under the treatment I_1S_3 (one irrigation and 40 cm row spacing) resulted in increased WUE (Thakur, 2013).

Relationship between seed yield and growth characters and yield attributes

There was a significant positive linear relationships between number of branches, total dry biomass, number of siliquae, number of seeds and seed yield (Figs. 1, 2, 3, 4), which strongly supported the arguments for seed yield increment of mustard due to different imposed treatments. Chowdhury *et al.* (1999), Hasanuzzaman and Karim (2007), Hasanuzzaman *et al.* (2008) and Tyagi and Upadhyay (2016) also found a correlation between these characters in rapeseed and mustard.

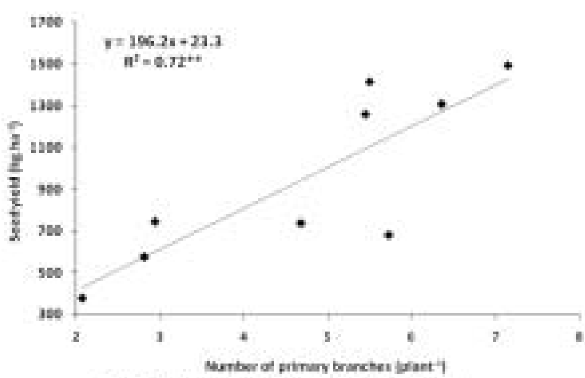

Fig. 1: Relationship between number of primary branches (plant^{-1}) and seed yield (kg ha^{-1})

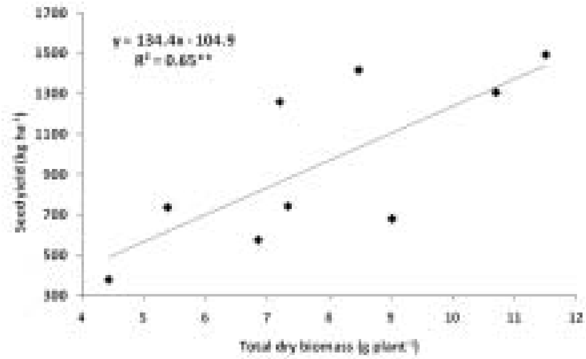

Fig. 2: Relationship between total dry biomass (g plant^{-1}) andseed yield (kg ha^{-1})

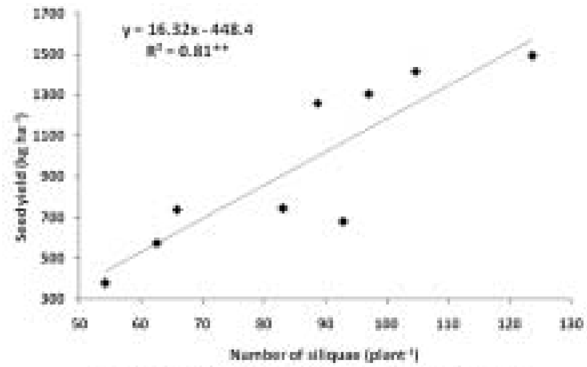

Fig. 3: Relationship between number of siliquae (plant^{-1}) andseed yield (kg ha^{-1})

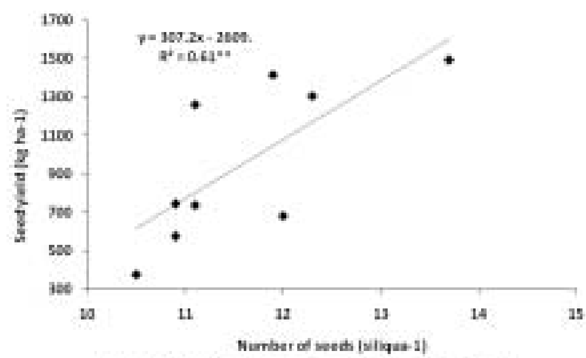

Fig. 4: Relationship between number of seed (siliqua-1) andseed yield (kg ha-1)

Conclusion

Results showed that two irrigations, first at 40 DAS and second at 75 DAS increased the seed yield and increase in seed yield (kg ha^{-1}) with two irrigations was 50.9 % and 14.0% higher than no irrigation and one irrigation, respectively. In most of the cases the wider row spacing coupled with two irrigations were found to be influenced for better growth and yield of plant. Thus, it is concluded that Indian mustard var. Pusa Tarak may be cultivated at 40 cm row spacing along with two irrigations, first at 40 DAS and second at 75 DAS for optimum growth and yield production.

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