Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol No. 24(2) : 172-178 (June 2022)

https://journal.agrimetassociation.org/index.php/jam

Research Paper

Agrometeorological indices influenced by different sowing dates, irrigation and fertilizer levels under late sown Indian mustard in western Haryana, India

PRAMOD KUMAR[1]*, SURESH KUMAR[1], V.S. HOODA[1], NEELAM[1], ANIL KUMAR[2], S.K. THAKRAL[1], SHEILENDRA KUMAR[3] and PARDEEP KUMAR[1]

[1]Department of Agronomy, CCS Haryana Agricultural University, Hisar-125004, India
[2]Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar-125004, India
[3]Department of Agronomy, SK Rajasthan Agriculture University, Bikaner-334006, India
**Corresponding author's email: pramodthory70@gmail.com*

ABSTRACT

A field experiment was carried out during 2018-19 and 2019-20 at Agronomy Research Farm, CCS HAU, Hisar to compute the temperature based agrometeorological indices for Indian mustard sown under different growing environments in split plot design. Two sowing environments were imposed through different sowing dates (2nd week of November and 4th week of November) and two irrigation levels (at flowering stage and no post-sown irrigation) in main plots and four fertilizer levels (87.5%, 100%, 112.5% and 125% RDF) in subplots and replicated thrice. Crop sown during 2nd week of November had significantly higher agrometeorological indices (GDD, HTU, T_{photo}, T_{nycto} and T_{IDR}) values over 4th week of November sowing. Among irrigation levels, one irrigation performed better with respect to agrometeorological indices. Among fertilizer levels, application of 125% RDF exhibited significantly higher agrometeorological indices followed by 112.5%, 100% and 87.5% RDF. The seed yield and biological yield were highly significantly co-related with the accumulated GDD (0.95**), HTU (0.83**) T_{photo} (0.96**), T_{nycto} (0.951**) and T_{IDR} (0.970**) clearly showing significant effect of these indices on the mustard crop. These indices can therefore be very well used as indicators of crop performance, once these relationships are quantified and tested.

Key words: Mustard, heat units, photo temperature, nycto temperature, irrigation, fertilizer

Rapeseed-mustard is the third most important source of edible oil next to soybean and groundnut in India, and is grown in certain tropical and subtropical regions as a cold season crop (Shekhawat *et al*., 2012). In India it is cultivated on 6.23 million hectares with production of 9.26 million tonnes and productivity of 1511 kg ha^{-1} in 2018-19. Haryana is one of the major rapeseed-mustard growing states and crop occupied 0.61 million ha of area producing 1.25 million tonnes giving an average yield of 2058 kg ha^{-1} (Anon., 2019). Indian mustard is very sensitive to climatic variables due to the determinate characteristics, the variations of weather parameters has a significant influence on the phenology and yield attribute and hence, climate change could have significant effects on its physiological activity and production. The main aim of present study was to determine thermal regime of mustard crop and its impact on phenology and yield under different growing environments along with different irrigation and fertilizer levels. As sowing time is one of the most important non-monetary input affecting crop yield and other agronomic traits among them, optimization of sowing time for mustard is essential. Sowing either too early or too late has been reported unfavourable (Uzun *et al.,* 2009). Late sown Indian mustard is exposed to high temperature coupled with high evaporative demand of the atmosphere during reproductive phase (ripening and grain filling) which consequently results in forced maturity and low productivity. One month delay in sowing from mid October resulted in loss of 40.6% in seed yield (Lallu *et al*., 2010). It suffers from exposure to low temperature during vegetative and early pod filling stage and relatively higher temperature during germination and maturity (Nayak *et al.,* 2018). On the other hand, irrigation is also a prime requirement for crop production in Haryana. Generally, Indian mustard is grown in sub-marginal land under rainfed conditions. Among the commonly applied major nutrients, nitrogen is the key element which is structural component of protein molecules, amino acids, chlorophyll and other constituents. Phosphorus plays an important role in improving water use efficiency due to its favourable effect on crop growth root development and high seed yield production per unit of water use. Consequently, a study was planned to explore the impact of sowing environment, irrigation and nutrient on importance of various indices in mustard.

MATERIALS AND METHODS

A field experiment was conducted at the research farm

Article info - DOI: *https://doi.org/10.54386/jam.v24i2.1556*
Received :24 February 2021; Accepted: 06 April 2022; Published online: 28 May 2022

of Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar during *Rabi* seasons of 2018-19 and 2019-20. This location is situated in the sub-tropical region at 29°10' N latitude and 75°46' E longitude with an elevation of 215.2 m above mean sea level. The experiment was laid out in a split plot design with sixteen treatment combinations which were replicated thrice with a plot sized of 5.4 m × 3.8 m. The treatment combinations were comprised of two sowing dates viz. 2nd week of November and 4th week of November; two irrigation levels viz. no post-sown irrigation and one irrigation at flowering stage in main plots and four fertilizer levels viz. 87.5% RDF, 100% RDF (80 kg N, 30 kg P_2O_5, 20 kg K_2O), 112.5% RDF and 125% RDF in sub-plots. The Indian mustard variety PM-26 was sown using seed rate of 5 kg/ha at 30 cm row interval by "pora" method on 14th and 27th November 2018 and 12th and 22nd November 2019. Fertilizer (kg/ha) applied as per treatments through urea, single super phosphate (SSP) and muriate of potash (MOP). Fertilizers were applied as per treatments. Intercultural operations, weeding, insect and pest management was done as and when required. The weather data recorded at Agrometeorology Observatory of CCS HAU was collected to quantify the indices and observations on crop phenology, seed and biological yield were used to compute agrometeorological indices.

Temperature based agrometeorological indices

Cumulative growing degree days were determined by summing the daily mean temperature above base temperature, expressed in day °C. This was calculated by using the Nuttonson, 1995 formula. Heat use efficiency (HUE) was determined by dividing the biological yield by accumulated heat units (degree day), expressed in kg ha^{-1} degree day^{-1}.

Cumulative helio-thermal units were (HTU) determined by multiplying the HU to the actual bright sunshine hours, expressed in °C day hours.

$$\text{HTU} = \text{GDD} \times \text{actual bright sunshine hours}$$

The effective day temperature was calculated by using the following formula (Went, 1957):

$$T_{photo} = T_{max} - \frac{1}{4} \times (T_{max} - T_{min})$$

Where, T_{max} and T_{min} are the daily maximum and minimum temperatures in °C, respectively. The index is computed cumulatively for the phenological stages and reflects the significance of the mean temperature during daytime (Dalezios *et al.,* 2002).

Like phototemperature, nyctotemperature corresponds to a mean temperature during night, when light levels are limited or non-existent. This index is expressed as:

$$T_{nycto} = T_{min} + \frac{1}{4} \times (T_{max} - T_{min})$$

The inter diurnal range of temperature was calculated by using the formula proposed by Wang (1960):

$$T_{IDR} = (T_{max})_i - (T_{min})_{i+1}$$

Where, $(T_{max})_i$= Maximum temperature of the i^{th} day, $(T_{min})_{i+1}$= Minimum temperature of the $(i+1)^{th}$ day. Water productivity (kg/ha-mm) of different treatments was computed based on total water used by the following formula:

$$WP = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Total water applied (mm)}}$$

The coefficient of determination was computed between the observed and simulated values using the following formula: R^2 = 1 - (SSregression/SStotal) Where, SSregression = regression sum of square, SStotal = total sum of square.

RESULTS AND DISCUSSION

Crop phenology

Sowing time, irrigation and fertilizer levels had significant effect on phenology of Indian mustard (Table 1). The crop sown in 2nd week of November took 135.8 days to attain physiological maturity as compared to 4th week of November sowing (125.9 days). The crop duration decreased with delay in sowing. Higher temperature coupled with low relative humidity at reproductive phase, resulted into forced maturity in late sown crop and reduced crop duration. In general, increase in temperature, sunshine hours and day length lead to shortening in the maturity phase. Among the irrigation levels, the crop grown with one irrigation consumed higher number of days than no irrigation at all the crop growth stages. Application of irrigation, improved the moisture supply to the crop plants at its critical stage favouring its growth and development, which might have resulted in a longer vegetative phase of the crop letting it require more number of days to attain physiological maturity over no post-sown irrigation. Similarly, crop received 125% RDF took higher number of days to attain different phenological stages with significant differences. Higher level of fertilizers enhances the cell division and enlargement; the new tissue developed the younger leaves, which slowed down the development of different phenophases resulting in slow process of senescence, hence, delayed the physiological maturity.

Growing degree days and Helio-thermal units

The growing degree days and Helio-thermal units accumulated for occurrence of different phenophases among the treatments on pooled basis has been presented in Table 2. A peep into data revealed that 2nd week of November sown crop consumed significantly higher heat units and helio-thermal units (1322 day °C and 6904 °C day hours) as compared to 4th week of November sowing (1188 day °C and 6417 °C day hours) to attain physiological maturity. On an average of two years, the accumulated HU and helio-thermal units declined with delay in sowing. The late sown crop accumulated fewer HU during early phenophases than early sown crop due to prevalence of comparatively lower temperature. Under irrigation treatment of one irrigation, the crop took significantly higher heat units and helio-thermal units to attain different stages. The crop consumed 1290 °C days and 6896 °C day hours to attain physiological maturity under irrigation treatment of one irrigation as compared to no post-sown irrigation (1219 day °C and 6425 °C day hours) on pooled basis. This might have been due to more growth period available to Indian mustard crop under irrigation level of one irrigation at flowering stage. Among fertilizer levels, crop sown with the application of 125% RDF had significantly higher consumption of heat units and helio-thermal units to attain various crop growth stages. The crop consumed 1291 °C days heat units and 6905 °C day hours helio-thermal units to attain physiological maturity with the application of 125% RDF, followed by 112.5% RDF (1270 day °C and 6754 °C day hours), followed by 100% RDF (1243 day °C and 6580 °C day hours), while the lowest heat units and helio-thermal units were consumed by the application of 87.5% RDF (1215 day °C

Table 1: Effect of date of sowing, irrigation and fertility levels on days to attain different phenophases by Indian mustard (pooled data over two years 2018-19 and 2019-20)

Treatments	Days to 50% flowering	Days to completion of siliquae formation	Days to physiological maturity
Date of sowing			
2nd week of Nov	54.3	101.1	135.8
4th week of Nov	57.4	103.1	125.9
S.Em±	0.2	0.4	0.7
CD (P=0.05)	0.6	1.2	2.2
Irrigation levels			
No post-sown irrigation	54.6	101.1	128.8
One irrigation at flowering stage	57.2	103.2	132.9
S.Em±	0.2	0.4	0.7
CD (P=0.05)	0.6	1.2	2.2
Fertilizer levels			
87.5% RDF	53.9	100.2	128.7
100% RDF	55.2	101.5	130.1
112.5% RDF	56.6	102.9	131.6
125% RDF	57.8	104.0	133.0
S.Em±	0.3	0.5	0.8
CD (P=0.05)	0.8	1.5	2.1

Table 2: Effect of date of sowing, irrigation and fertility levels on growing degree days requirements, helio-thermal units and heat use efficiency of Indian mustard (pooled data over two years 2018-19 and 2019-20)

Treatments	GDD (day °C)			HTU (°C day hours)			HUE (kg ha^{-1} degree day^{-1})
	50% flowering	Completion of siliquae formation	Physiological maturity	50% flowering	Completion of siliquae formation	Physiological maturity	
Date of sowing							
2nd week of Nov	518	873	1322	2130	3974	6904	5.43
4th week of Nov	454	864	1188	1808	4257	6417	3.47
S.Em±	2.11	4.03	12.51	6.71	29.54	73.00	0.05
CD (P=0.05)	6.51	12.41	38.54	20.68	91.03	224.93	0.16
Irrigation levels							
No post-sown irrigation	477	857	1219	1940	4039	6425	4.28
One irrigation at flowering stage	495	881	1290	1997	4192	6896	4.62
S.Em±	2.11	4.03	12.51	6.71	29.54	73.00	0.05
CD (P=0.05)	6.51	12.41	38.54	20.68	91.03	224.93	0.16
Fertilizer levels							
87.5% RDF	472	846	1215	1920	3962	6404	4.23
100% RDF	481	861	1243	1957	4069	6580	4.45
112.5% RDF	491	878	1270	1987	4174	6754	4.53
125% RDF	500	891	1291	2011	4257	6905	4.59
S.Em±	2.35	6.82	13.49	6.38	25.00	52.07	0.05
CD (P=0.05)	6.67	19.40	38.37	18.14	71.10	148.07	0.13

Table 3: Effect of date of sowing, irrigation and fertility levels on photo temperature, nycto temperature and inter diurnal temperature range of Indian mustard (pooled data over two years 2018-19 and 2019-20)

Treatments	Tphoto (°C day)			Tnycto (°C day)			TIDR (°C day)		
	50% flowering	completion of siliquae formation	physiological maturity	50% flowering	completion of siliquae formation	physiological maturity	50% flowering	completion of siliquae formation	physiological maturity
Date of sowing									
2nd week of Nov	984	1732	2478	596	1026	1523	779	1415	1908
4th week of Nov	936	1734	2258	546	1025	1376	785	1418	1759
S.Em±	3.08	7.52	18.02	2.41	4.64	12.46	2.14	5.00	10.93
CD (P=0.05)	9.48	23.17	55.53	7.43	14.30	38.38	6.60	15.41	33.66
Irrigation levels									
No post-sown irrigation	941	1713	2314	559	1012	1412	768	1403	1801
One irrigation at flowering stage	979	1754	2422	583	1039	1487	797	1430	1866
S.Em±	3.08	7.52	18.02	2.41	4.64	12.46	2.14	5.00	10.93
CD (P=0.05)	9.48	23.17	55.53	7.43	14.30	38.38	6.60	15.41	33.66
Fertilizer levels									
87.5% RDF	931	1694	2309	553	999	1408	760	1391	1798
100% RDF	950	1720	2350	565	1017	1437	775	1408	1822
112.5% RDF	969	1749	2391	577	1036	1466	790	1426	1847
125% RDF	988	1771	2423	589	1050	1487	804	1442	1868
S.Em±	4.20	10.17	17.21	2.52	5.96	10.93	2.80	6.97	10.87
CD (P=0.05)	11.95	28.93	48.95	7.17	16.96	31.08	7.95	19.81	30.92

Table 4: Effect of date of sowing, irrigation and fertility levels on total water use and water productivity of Indian mustard (pooled data over two years 2018-19 and 2019-20)

Treatments	Total water use (mm)	water productivity (kg/ha-mm)
Date of sowing		
2nd week of Nov	292	7.45
4th week of Nov	272	4.75
Irrigation levels		
No post-sown irrigation	269	6.10
One irrigation at flowering stage	295	6.19
Fertilizer levels		
87.5% RDF	277	5.62
100% RDF	281	6.14
112.5% RDF	279	6.53
125% RDF	291	6.29

and 6404 °C day hours) on an average of two years. Higher doses of nitrogen enhanced the cell division and enlargement, the new tissue developed the younger leaves, which slowed down the development of phenophases and finally slowed down the process of senescence, hence delayed the maturity.

Photo temperature (T_{photo}) and Nycto temperature (T_{nycto})

The photo temperature (T_{photo}) and nycto temperature (T_{nycto}) were significantly influenced by different sowing dates

Table 5: Correlation coefficient between seed and biological yield of Indian mustard with temperature based agrometeorological indices

Agrometeorological Indices	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})
GDD (day °C)	0.95	0.95
HTU (°C day hours)	0.83	0.83
T_{photo} (°C day)	0.96	0.96
T_{nycto} (°C day)	0.95	0.95
T_{IDR} (°C day)	0.97	0.97

(Table 3). Indian mustard sown in 2nd week of November recorded significantly higher photo and nycto temperature (2478 °C day and 1523 °C day) as compared to 4th week of November (2258 °C day and 1376 °C day) sown crop to attain physiological maturity. Among irrigation levels, one irrigation at flowering obtained higher photo and nycto temperature (2422 °C day and 1487 °C day) as compared to no post-sown irrigation (2314 °C day and 1801 °C day) to attain physiological maturity. Among fertilizer levels, the highest photo and nycto temperature (2423 °C day and 1487 °C day) was recorded by the application of 125% RDF, which was followed by 112.5% RDF (2391 °C day and 1466 °C day) and 100% RDF (2350 °C day and 1437 °C day), while the lowest photo and nycto temperature (2309 °C day and 1408 °C day) was recorded by the application of 87.5% RDF to attain physiological maturity.

Interdiurnal temperature range (T_{IDR})

The interdiurnal temperature range (T_{IDR}) was significantly influenced by different sowing dates (Table 3). Indian mustard

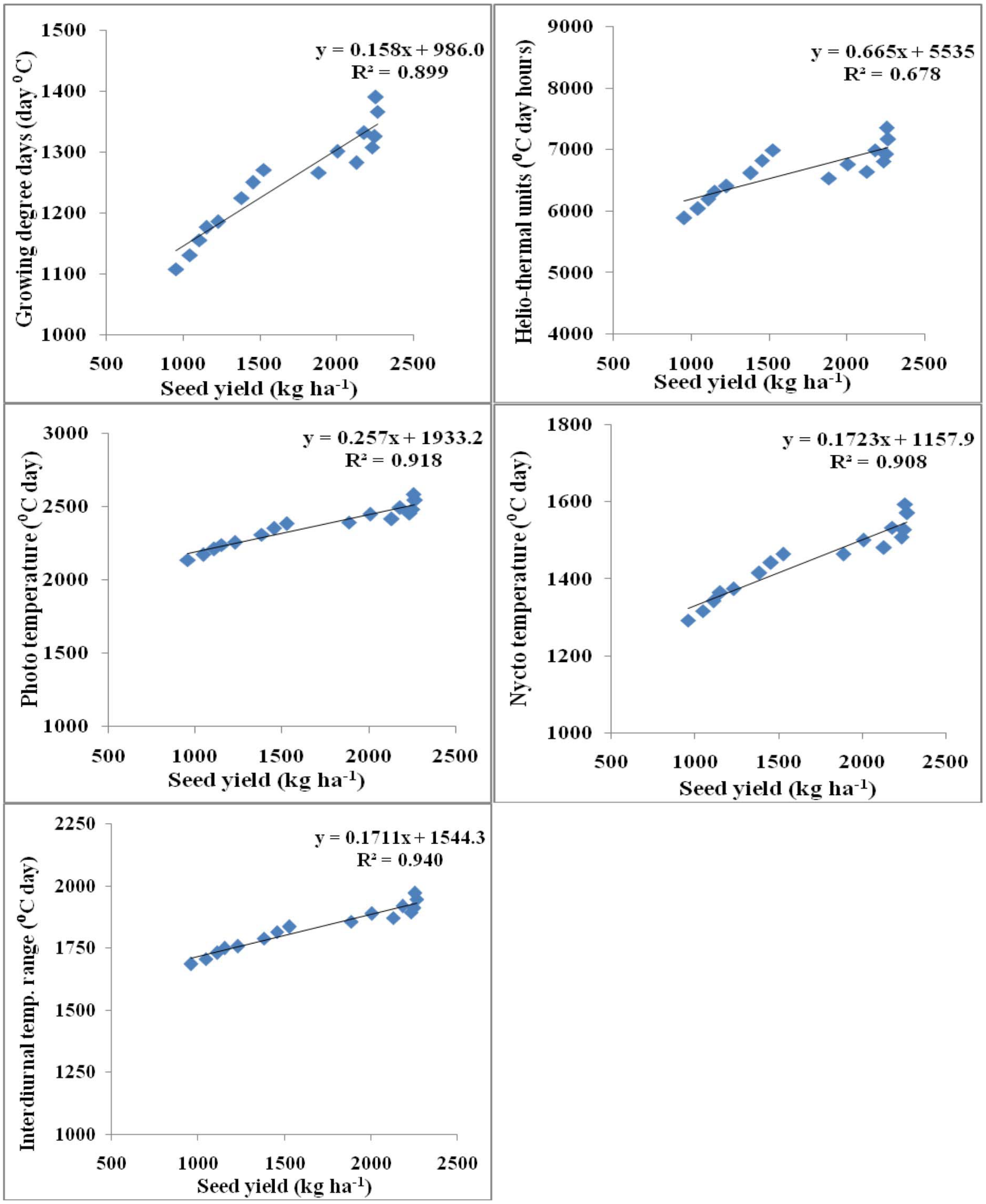

Fig.1: Regression between seed yield and (a) growing degree days; (b) helio-thermal units; (c) photo temperature; (d) nycto temperature; (e) interdiurnal temperature range

sown in 2nd week of November recorded significantly higher T_{IDR} (1908 °C day) as compared to 4th week of November (1759 °C day) sown crop to attain physiological maturity. Among irrigation levels, one irrigation at flowering obtained higher T_{IDR} (1866 °C day) as compared to no post-sown irrigation (1801 °C day) to attain physiological maturity. Among fertilizer levels, the highest T_{IDR} (1868 °C day) was recorded by the application of 125% RDF, which was followed by 112.5% RDF (1847 °C day) and 100% RDF (1822 °C day), while the lowest T_{IDR} (1798 °C day) was recorded by the application of 87.5% RDF to attain physiological maturity.

Heat use efficiency

The heat use efficiency (HUE) was significantly influenced by different sowing dates (Table 2). The Indian mustard crop sown during 2nd week of November recorded significantly higher heat use efficiency (5.43 kg ha^{-1} degree day^{-1}) as compared to 4th week of November (3.47 kg ha^{-1} degree day^{-1}) sown crop. Among irrigation levels, one irrigation at flowering obtained higher heat use efficiency (4.62 kg ha^{-1} degree day^{-1}) as compared to no post-sown irrigation (4.28 kg ha^{-1} degree day^{-1}). Among fertilizer levels, the highest heat use efficiency (4.59 kg ha^{-1} degree day^{-1}) was recorded by the application of 125% RDF, which was followed by 112.5% RDF (4.53 kg ha^{-1} degree day^{-1}) and 100% RDF (4.45 kg ha^{-1} degree day^{-1}), while the lowest heat use efficiency (4.23 kg

ha^{-1} degree day^{-1}) was recorded by the application of 87.5% RDF to attain physiological maturity.

Regression analysis between Agrometeorological indices and mustard seed yield

The crop sown in 2nd week of November accumulated higher values for all temperature based agrometeorological indices to produce higher seed yield in comparison with 4th week of November sowing. Sowing time influences phonological development of crop plants through temperature related agrometeorological indices. Very high values of coefficients of determination (R^2) between the agrometeorological indices and the mustard yield indicated that the occurrence of various phenophases can very accurately be predicted using these agrometeorological indices (Fig. 1). These results are in conformity with the findings of Khushu *el al*. (2008) and Singh *et al.* (2013).

Correlation analysis between Agrometeorological indices and mustard yield

The correlation coefficients between accumulated agrometeorological indices and yield are presented in Table 5. A highly significant and positive correlation was noted between mustard yield and all the agrometeorological indices (GDD, HTU, T_{photo}, T_{nycto} and T_{IDR}). The crop sown in 2nd week of November maintained better agrometeorological indices in terms of GDD, HTU, T_{photo}, T_{nycto} and T_{IDR} which helped in maintaining optimal thermal requirements for various pant process hence increased the biological and seed yield.

Water productivity

The Indian mustard sown in 2nd week of November achieved higher water productivity of 7.45 kg/ha-mm as compared to the crop sown in 4th week of November (4.75 kg/ha-mm) on an average of two years (Table 4). Lower water productivity under delayed sowing may be ascribed to proportionately lower yield in relation to water used. Similar results have also been reported by Singh and Singh (2014). Higher water productivity of 6.19 kg/ha-mm was recorded with application of one irrigation at flowering stage as compared to no post-sown irrigation (6.10 kg/ha-mm) on an average of two years (Table 4). This might be because of more biomass production, better sink development and translocation of assimilates to sink in Indian mustard grown with increased availability of moisture. Similar results were reported by Kumar *et al.* (2016) and Jagtap *et al.* (2020). Among the fertilizer levels, the maximum water productivity of 6.53 kg/ha-mm was recorded with the fertilizer level of 112.5% RDF followed by 125% and 100% RDF. Whereas, minimum water productivity of 5.62 kg/ha-mm was recorded with the fertilizer level of 87.5% RDF (Table 4). This increase in water productivity with increasing doses of fertilizers might be because of the fact that higher fertilizer doses increased the seed yield of Indian mustard than the total consumptive use of water. The present results are in agreement with Verma *et al.* (2018) and Rathi *et al.* (2019).

CONCLUSIONS

The present study concluded that sowing of Indian mustard during 2nd week of November exhibited significantly higher yield due to optimal thermal requirements for various plant processes. The thermal unit requirement of Indian mustard decreased with delayed sowing beyond 2nd week of November in Haryana. Among irrigation levels, one irrigation at flowering stage had higher yield because of higher thermal unit requirement due to comparatively increase in crop duration and higher assimilation to the crops. Application of 125% RDF proved to be most efficient for improving heat utilisation efficiency of Indian mustard. Such management options can be used effectively to manage climate change impacts on Indian mustard to sustain crop productivity and food security under changing climatic scenarios in future.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

Disclaimer: The contents, opinions and views expressed in the research article published in Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Anonymous, (2019). Directorate of Economics and Statistics, Government of India.

Dalezios, N.R., Loukas, A. and Bampzelis, D. (2002). Assessment of NDVI and agrometeorological indices for major crops in central Greece. *Phy. Chem. Earth*., 27: 1025-1029. (https://doi.org/10.1016/S1474-7065(02)00138-9)

Jagtap, D.N., Dademal, A.A., Mane, M.J., More, V.G., Bodake, P.S. and Sanap, P.B. (2020). Scheduling of irrigation at different growth stages of chickpea under overhead sprinkler. *Int. J. Sci. Environ. Technol.,* 9(3): 395-401.

Khushu, M.K., Rahman, N., Singh, M., Tiku, A.K. and Bali, A.S. (2008). Thermal time indices for some mustard genotypes in the Jammu region. *J. Agrometeorol*., 10(2): 224-227. (https://doi.org/10.54386/jam.v10i2.1210)

Kumar, A., Nand, V. and Kumar, R. (2016). Effect of different levels of irrigation under integrated nutrient management (INM) on wheat (*Triticum aestivum* L.) for central plain agro climatic zone of utar Pradesh, India. *Plant Arch.,* 16: 395-398.

Lallu, R.S., Baghel, V.S. and Srivastava, S.B.L. (2010). Assessment of mustard genotypes for thermo tolerance at seed development stage. *Indian J. Plant Physiol.*, 15: 36-43.

Nayak, M.K., Singh, R., Kumar, A., Ahatsham, M., Singh, S. and Dagar, C.S. (2018). Influence of agrometeorological indices in wheat under different growing environment and irrigation regimes. *J. Agrometeorol.*, 20 (Special Issue): 199-206.

Nuttonson, M.Y. (1995). Wheat climate relationship and use phenology in ascertaining the thermal and photothermal requirement of wheat. *American Institute of Crop Ecology, Washington DC*, 338.

Rathi, N., Singh, B., Hooda, V.S., Harender and Mohsin, M. (2019). Impact of different doses of fertiliser and crop geometry on growth, seed and oil quality, consumptive water use, water use efficiency and soil moisture extraction in late sown Indian mustard (*Brassica juncea* L.) crop. *Int. J. Plant Soil Sci.,* 27(6): 1-7.

Shekhawat, K., Rathore, S.S., Premi, O.P., Kandpal and Chauhan, J.S. (2012). Advances in agronomic management of Indian mustard (*Brassica juncea* (L.) Czernj. Cosson): An overview. *Int. J. Agron.*, 2012: 1-14. (https://doi.org/10.1155/2012/408284)

Singh, A., Avtar, R., Singh, D., Sangwan, O. and Balyan, P. (2013). Genetic variability, character association and path analysis for seed yield and component traits under two environments in Indian mustard. *J. Oilseed Brassica*, 4(1): 43-48.

Singh, P.K. and Singh, A.K. (2014). Effect of sowing dates and irrigation schedules on yield and quality of Indian mustard. *J. Soil Water Conserv.,* 13(3): 270-273.

Uzun, B., Zengin, U., Furat, S. and Akdesir, O. (2009). Sowing date effects on growth, flowering, seed yield and oil content of canola cultivars. *Asian J. Chem.,* 21: 1957-1965.

Verma, O.P., Singh, S., Pradhan, S., Kar, G. and Rautaray, S.K. (2018). Irrigation, nitrogen and sulphur fertilization response on productivity, water use efficiency and quality of Ethiopian mustard (*Brassica carinata*) in a semi-arid environment. *J. Appl. Nat. Sci.,* 10(2): 593-600. (https://doi.org/10.31018/jans.v10i2.1741)

Wang, J.Y. (1960). A critique of the heat unit approaches to plant response studies. *Ecol.,* 41: 785-790. (https://doi.org/10.2307/1931815)

Went, F.W. (1957). The experimental control of plant growth. *Chron. Bot.,* 17: 343.