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Crop weather relationship in oilseed rape (*Brassica napus*) for north-west foothills of Himalayas, India

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ABSTRACT

Agrometeorological indices have a strong correlation with growth, yield attributes and yield of crop and can be effectively used to select suitable cultivar for specific environmental conditions. Therefore, to study the cumulative effect of weather variables in terms of agrometeorological indices on cultivars of oilseed rape (*Brassica napus* L.) sown under different sowing environments, field experiments were conducted at the research farm of Agrometeorology section, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Jammu and Kashmir during winter (*rabi)* season of 2018–19 and 2019–20. The treatments were comprised of 3 sowing environments, viz. 42nd SMW (standard meteorological week), 44th SMW and 46th SMW along with 3 cultivars (GSL-1, ONK-1 and DGS-1) of oilseed rape in factorial randomized block design with 3 replications. The pooled data of 2 years revealed that all the cultivars of oilseed rape sown in 42nd SMW accumulated higher growing degree days (GDD), photothermal units (PTU) and heliothermal units (HTU) with higher rate of dry matter accumulation in comparison to 44th SMW and 46th SMW sown crop. The agrometeorological indices, viz. GDD, PTU and HTU were significantly positively correlated with growth parameters, yield attributes and yield at vegetative stage, while, PTU and HTU were negatively correlated at reproductive stage of the crop. Due to the significant impact of weather variables, the seed yield of all the oilseed rape cultivars decreased when the sowing was delayed from 42nd SMW to 46th SMW during both the years. Among cultivars, GSL-1 recorded significantly higher seed yield followed by ONK-1 and DGS-1.

Keywords: Agrometeorological indices, Crop weather relationship, Cultivars, Oilseed rape, Sowing environments

Oilseeds are the second largest contributor in Indian agricultural economy after the cereals. Being second largest grower (21.1%) after Canada, and third largest producer (12.6%) after Canada and China, India plays an important role in global rapeseed-mustard industry (Anonymous 2022a). However, the net domestic availability of edible oil is not sufficient to fulfil the demand of burgeoning population of India. Therefore, India imports about 13.45 million tonnes of edible oil worth ₹81682 crores (Anonymous 2022b). During 2019–20, the rapeseed-mustard was grown on an area of 6.86 million ha in India, with a production of 9.12 million tonnes (Anonymous 2021). Farmers in the north-west part of India are bound to do the sowing of rapeseed-mustard at different dates depending upon the harvesting of preceding *kharif* crop, thereby altering the crop's environment and exposing it to diverse weather conditions which largely governs its productivity due to thermo and photosensitive nature of the crop (Pradhan *et al.* 2014). Each crop has its own specific thermal requirements for achieving its potential yield and any significant deviation from the optimum value becomes detrimental for the crop productivity (Gupta *et al.* 2017). To understand the relationship between crop and weather, the quantification of the thermal requirement in terms of agrometeorological indices at developmental stages and their association with growth parameters, yield attributing characters and yield is essential (Pradhan *et al*. 2014, Gupta *et al.* 2017, Islam *et al.* 2019). Moreover, studies on crop weather relationship explain direct and linear relation between crop's responses against its thermal requirements (Kumar *et al.* 2014). Many researchers have studied crop weather relations to describe the yield potential of mustard (Pradhan *et al.* 2014, Islam *et al.* 2019) but limited literature is available regarding oilseed rape (*Brassica napus* L.). Keeping in view the futuristic changes in climate scenario, the experiment was conducted to derive the crop weather relationship with quantification of agrometeorological indices for describing the yield potential of the oilseed rape and to identify the optimal SMW for avoiding terminal heat stress in oilseed rape.

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MATERIALS AND METHODS

Field experiments were conducted at the research farm of Agrometeorology section, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Jammu and Kashmir in the sub-tropical foothills of North-West Himalayas, during winter (*rabi)* seasons of 2018–19 and 2019–20. The soil of the experimental site was sandy clay loam in texture having *p*H of 7.60 with low organic carbon content (0.41%) and available nitrogen (219.5 kg/ha), while, medium in available phosphorus (14 kg/ha) and potassium (132.46 kg/ha). The meteorological data of both years (2018–19 and 2019–20) along with the normal (mean of 30 years) of different weather variables for crop growing period of the oilseed rape were taken from the Agrometeorological observatory, situated at 20 m distance from the experimental field (Fig 1). The crop growing period of various cultivars of oilseed rape sown under different sowing environments varied between 42nd to 15th SMW and 42nd to 13th SMW during 2018–19 and 2019–20, respectively. The total rainfall recorded during both crop growing season was about 291.6 mm and 416.8 mm in 2018–19 and 2019–20, respectively, the rainfall with respect to normal data was about 242.1 mm. The highest mean temperature of 25.8ºC was recorded in the 15th SMW during *rabi* 2018–19, while the lowest mean temperature of 10.2ºC recorded in the 52nd SMW, during 2019–20. The mean temperature rises high to 23.2ºC in 42nd SMW while the lowest mean temperature was recorded in 52nd SMW of about 8.5ºC. The weekly mean temperature of the normal data during the *rabi* season rises to 24.3ºC in the 15th SMW and dips down to 11.5ºC in the 1st SMW. The mean relative humidity recorded during the entire crop growing period was about 69% in 2018–19, 76% in 2019–20 and 66% in the normal data, respectively.

The experiments were laid out in factorial randomized block design with 9 treatment combinations consisted of 3 sowing environments, viz. 42nd SMW [(D_1) (20th October in 2018–19 and 16th October in 2019–20)], 44th SMW [(D_2) (30th October in 2018–19 and 2019–20)] and 46th SMW [(D_3) (9th November in 2018–19 and 14th November in 2019–20)] with 3 cultivars, viz. GSL-1 (V_1), ONK-1 (V_2) and DGS-1 (V_3) during both years. The spacing kept was 45 cm ×10 cm for all 3 cultivars. The crop was supplemented with 60 kg/ha nitrogen, 40 kg/ha phosphorus and 20 kg/ha potassium. The plant height of 5 tagged plants was measured with meter scale and mean values thus worked in centimetres, leaf area worked out, per plant was divided by the ground area occupied by plant to calculate leaf area index, dry matter recorded as the half meter row length was multiplied with total number of plants/m^2. The total number of primary branches, secondary branches and siliquae obtained from 5 tagged plants were counted and averaged, seeds of 20 siliquae from 5 tagged plants were counted and averaged. The produce was harvested from net plot within each treatment and the seeds thus obtained were weighed and expressed in kg/ha. The life cycle of crop was divided into two stages (vegetative and reproductive) and 5 plants from each plot were tagged to record these stages by regular visual inspection. The various agrometeorological indices were calculated at vegetative and reproductive stage as:

$$\text{Accumulated GDD (ºC day)} = \sum_{i=1}^{i-n} \frac{T_{max}+T_{min}}{2} - T_b$$

$$\text{Accumulated PTU (ºC day hours)} = \sum_{i=1}^{i-n} GDD \times N$$

$$\text{Accumulated HTU (ºC day hours)} = \sum_{i=1}^{i-n} GDD \times n$$

where T_{max}, maximum temperature; T_{min}, minimum

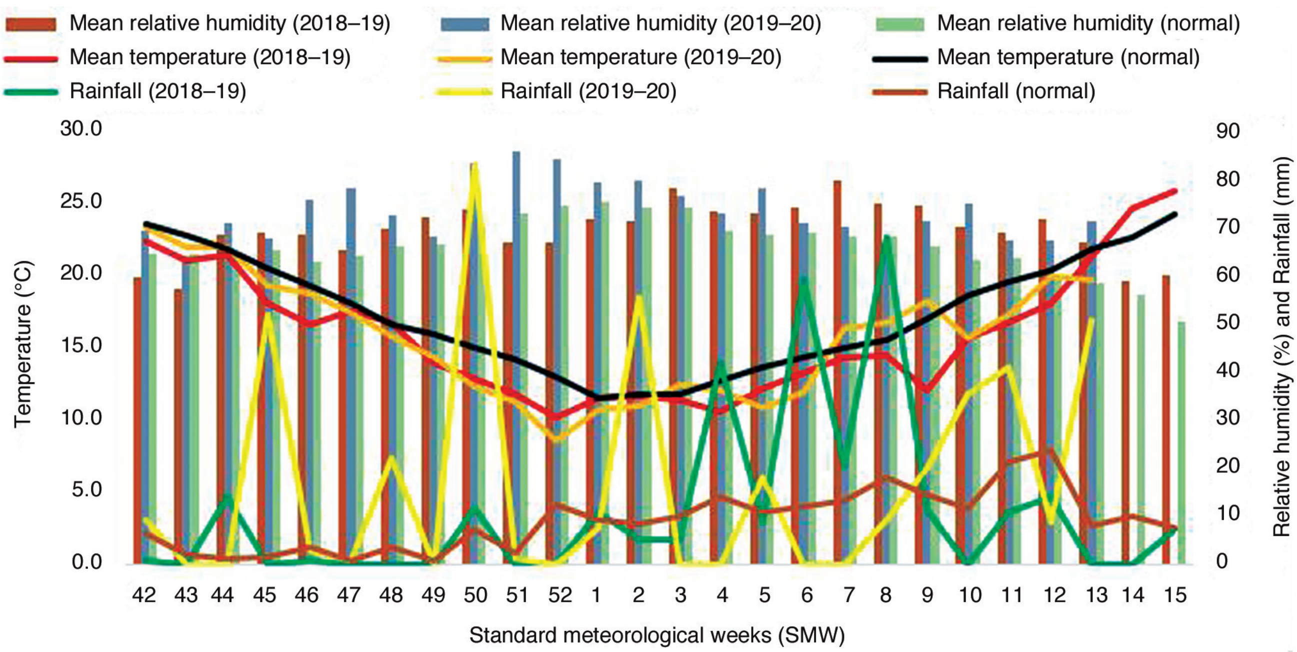

Fig 1 Weekly data of weather variables during the entire growing period of oilseed rape in *rabi*, 2018–19 and 2019–20 along with the normal.

temperature; T_b, base temperature (4.5ºC); N, daylength and n, sunshine hours.

Statistical analysis: The daily data of weather variables during the study period from date of sowing to date of harvest were organised stage wise and agrometeorological indices were calculated treatment wise along with their respective standard deviation and coefficient of variance (Gomez and Gomez 1984). Pearson correlation coefficients (r) and regression analysis were worked out to examine the crop weather relationship by using CPCS-1.

RESULTS AND DISCUSSION

Growing degree days (GDD): The cumulative impact of temperature expressed in terms of GDD for completion of vegetative and reproductive stage by various cultivars of oilseed rape sown under different environments were calculated (Table 1) and its relationship with dry matter production is presented in Table 2. The results revealed that all the cultivars, viz. GSL-1 (851.94ºC days), ONK-1 (863.82ºC days) and DGS-1 (866.27ºC days) sown under first sowing environment (D_1, 42nd SMW) consumed higher GDD to complete its vegetative stage as compared to delayed sown crop (D_2, 44th SMW and D_3, 46th SMW). As a result, rate of increase in dry matter production at vegetative period with respect to accumulated GDD among sowing environments, viz. first (D_1), second (D_2) and third (D_3) was about 0.769 g/m^2/ºC days (R^2=0.77), 0.709 g/m^2/°C days (R^2=0.84) and 0.686 g/m^2/°C days (R^2=0.84), respectively. On contrary, during reproductive stage, the accumulated GDD by all the cultivars was higher under third sowing environment (46th SMW) followed by second sowing environment (44th SMW) and first sowing environment (42nd SMW). Among cultivars, GSL-1 (1692.74°C days) accumulated higher GDD followed by ONK-1 (1685.24°C days) and DGS-1 (1667.03°C days) to complete its both developmental stages. The variation in accumulated GDD in cultivars is due to differential genetic makeup and similar results were reported by Gupta *et al.* (2017). Moreover, GSL-1 sown under the first sowing environment (D_1: 1775.53°C days) accumulated higher GDD to complete its whole crop growing period than second (D_2: 1664.08°C days) and third sowing environment (D_3: 1618.62°C days), with standard deviation of 128.80°C days and coefficient of variance of 16.74%. The reduction in accumulated GDD by the late sown crop at vegetative stage was due to the prevalence of comparatively low temperature, significantly reducing the rate of dry matter accumulation during early stages of the crop whereas abrupt rise in mean temperature (from 20.8°C days in 10th SMW to 32.6°C days in 13th SMW) prevailed during reproductive stage resulted in accumulation of more

Table 1 Agrometeorological indices accumulated by oilseed rape cultivars under different sowing environments (Pooled data of 2 years)

Treatment	∑ GDD (°C days)			∑ PTU (°C days hours)			∑ HTU (°C days hours)		
	Vegetative	Reproductive	Total	Vegetative	Reproductive	Total	Vegetative	Reproductive	Total
V_1, GSL-1									
D_1	851.94	923.59	1775.53	8813.45	10496.89	19310.34	4995.22	4922.76	9917.98
D_2	727.04	937.04	1664.08	7540.08	10466.47	18006.55	3619.43	5203.21	8822.63
D_3	640.08	978.53	1618.62	6653.55	11201.17	17854.72	3081.00	5822.50	8903.50
Mean	739.69	953.06	1692.74	7669.02	10721.51	18390.53	3898.55	5316.16	9214.70
SD±	106.49	22.31	128.80	1085.71	415.68	1501.39	987.16	460.38	1447.55
CV (%)	14.40	2.34	16.74	14.16	3.88	18.03	25.32	8.66	33.98
V_2, ONK-1									
D_1	863.82	896.35	1760.17	8930.51	9944.25	18874.76	5033.55	4606.93	9640.48
D_2	735.71	937.08	1672.78	7642.92	10472.00	18114.92	3656.54	5242.24	8898.78
D_3	637.88	984.90	1622.78	6644.90	11261.82	17906.72	3092.69	5787.65	8880.33
Mean	745.80	939.44	1685.24	7739.44	10559.36	18298.80	3927.59	5212.27	9139.87
SD±	113.30	44.32	157.63	1145.86	663.11	1808.97	998.42	590.93	1589.34
CV (%)	15.19	4.72	19.91	14.81	6.28	21.09	25.42	11.34	36.76
V_3, DGS-1									
D_1	866.27	870.17	1736.43	8956.21	9625.86	18582.06	5016.41	4484.62	9501.03
D_2	738.98	921.88	1660.87	7556.31	10409.24	17965.55	3625.76	5172.56	8798.32
D_3	628.77	975.02	1603.78	6652.84	11008.70	17661.53	3096.78	5699.64	8796.42
Mean	744.67	922.36	1667.03	7721.78	10347.93	18069.72	3912.98	5118.94	9031.92
SD±	118.85	52.43	171.28	1160.57	693.46	1854.02	991.52	609.28	1600.80
CV (%)	15.96	5.68	21.64	15.03	6.70	21.73	25.34	11.90	37.24

SD, Standard deviation; CV, Coefficient of variances. Treatment details are given under Materials and Methods.

Table 2 Relationship between dry matter production and agrometeorological indices (Pooled data of 2 years)

Treatment		Vegetative stage		Reproductive stage	
		Equation	R^2	Equation	R^2
Sowing environment					
Accumulated GDD	D_1	Y = -386.6 + 0.769 X_1	0.77	Y = 338.8 + 0.309 X_1	0.57
	D_2	Y = -360.5 + 0.709 X_1	0.84	Y = 306.3 + 0.231 X_1	0.50
	D_3	Y = -246.0 + 0.686 X_1	0.84	Y = 237.4 + 0.181 X_1	0.55
Accumulated PTU	D_1	Y = -403.0 + 0.086 X_2	0.76	Y = 364.5 + 0.027 X_2	0.56
	D_2	Y = -374.9 + 0.081 X_2	0.84	Y = 304.6 + 0.022 X_2	0.48
	D_3	Y = -247.9 + 0.068 X_2	0.91	Y = 201.6 + 0.021 X_2	0.65
Accumulated HTU	D_1	Y = -454.1 + 0.145 X_3	0.73	Y = 358.2 + 0.054 X_3	0.52
	D_2	Y = -243.0 + 0.123 X_3	0.59	Y = 348.9 + 0.039 X_3	0.45
	D_3	Y = -142.1 + 0.099 X_3	0.55	Y = -276.8 + 0.028 X_3	0.53
Cultivars					
Accumulated GDD	V_1	Y = -276.2+0.685 X_1	0.74	Y = 236.4 + 0.336 X_1	0.37
	V_2	Y = -256.7+0.637 X_1	0.75	Y = 206.2 + 0.319 X_1	0.35
	V_3	Y = -224.6+0.566 X_1	0.76	Y = 183.1 + 0.292 X_1	0.32
Accumulated PTU	V_1	Y = -259.3+0.641 X_2	0.70	Y = 237.1 + 0.032 X_2	0.41
	V_2	Y = -241.4+0.059 X_2	0.71	Y = 295.4 + 0.023 X_2	0.26
	V_3	Y = -210.8+0.053 X_2	0.72	Y = 180.1 + 0.028 X_2	0.37
Accumulated HTU	V_1	Y = -135.8+0.085 X_3	0.48	Y = 266.7 + 0.060 X_3	0.43
	V_2	Y = -125.8+0.079 X_3	0.49	Y = 233.9 + 0.057 X_3	0.41
	V_3	Y = -104.6+0.069 X_3	0.47	Y = 212.5+ 0.051 X_3	0.36

Y, Dry matter accumulation (g/m^2/°C day); X_1, Accumulated GDD; X_2, Accumulated PTU; X_3, Accumulated HTU; R^2, Coefficient of determination. Treatment details are given under Materials and Methods.

GDD in short time span (76 days) causing forced maturity of late sown crop. Early sowing resulted in accumulation of sufficient GDDs of about 953.06°C days due to prevalence of optimum temperature during the entire crop growing period. The accumulation of higher GDDs under early sown crop has also been reported by Pradhan *et al.* (2014), Gupta *et al.* (2017) and Kumar *et al.* (2022).

Photo thermal units (PTU): To evaluate the effect of photoperiod in oilseed rape crop**,** the photo thermal units were calculated at vegetative and reproductive phases (Table 1) and its relationship with dry matter accumulation has been presented Table 2. The results revealed that all the cultivars accumulated higher PTU under first sowing environment as compared to second sowing environment and third sowing environment. The cultivar GSL-1 sown in first sowing environment accumulated higher PTU of about 19310.34°C days hours followed by second sowing environment (D_2, 18006.55°C days hours) and third sowing environment (D_3, 17854.72°C days hours) with standard deviation and coefficient of variance of about 1501.39°C days hours and 18.03% to complete the whole crop growing period, respectively. Cultivar GSL-1 (18390.53°C days hours) accumulated higher PTU followed by ONK-1 (18298.80°C days hours) and DGS-1 (18069.72°C days hours) to complete its whole crop growing period. The rate of dry matter accumulation at vegetative stage under first environment (D_1), second sowing environment (D_2) and third sowing environment (D_3) sown crop was about 0.086 g/m^2/°C day hours, 0.081 g/m^2/°C day hours and 0.068 g/m^2/°C day hours, respectively, while, dry matter accumulation rate of about 0.27 g/m^2/°C day hours, 0.22 g/m^2/°C day hours and 2.21 g/m^2/°C day hours, respectively was at reproductive stage.The value of PTU was higher for early sown crop than late sown crop due to accumulation of more growing degree days during the whole crop growing period in early sown crop and comparatively lower daylength observed during vegetative stage in late sown crop. Similar results substantiate the findings of Gupta *et al* (2017).

Heliothermal unit (HTU): The heliothermal units were computed for vegetative and reproductive period of oilseed rape cultivars sown under three sowing environments (Table 1) and rate of dry matter accumulation with respect to HTU is presented in Table 2. The result showed that, in the vegetative phase, all the cultivars sown on the first sowing environment accumulated higher HTU followed by second sowing environment and third sowing environment, whereas, during the reproductive phase, the delayed sown crop (D_3, 46th SMW) accumulated more HTU in comparison to the early sown crop (D_1, 42nd SMW). The total HTU for the entire crop growing period accumulated higher under the early sown crop (D_1, 42nd SMW) which were about 9917.98, 9640.48 and 9501.03°C days hours by GSL-1, ONK-1 and DGS-1, respectively. The cultivar GSL-1 (9214.70°C days hours) accumulated higher HTU than ONK-1 (9139.87°C days hours) and DGS-1 (9031.92°C days hours) to complete their whole crop growing period. The rate of increase in dry matter production at vegetative stage with accumulated heliothermal units among sowing environments, viz. D_1, 42^{nd} SMW, D_2, 44^{th} SMW and D_3, 46^{th} SMW was about 0.145, 0.123 and 0.099 g/m^2/°C days hours, respectively with an accuracy of 73, 59 and 55%, respectively. Reduction in HTU under late sown conditions indicate that the crop use more heat units under early sown crop which significantly increased dry matter accumulation rate in early sown crops. The reduction in accumulated HTU with the late sown crop has also been reported by Gupta *et al.* (2017) and Kumar *et al.* (2022).

Correlation study: The correlation between the different agrometeorological indices and various growth parameters, yield attributes and yields of oilseed rape cultivars were developed (Table 3). The data of correlation coefficients revealed that during vegetative phase, all agrometeorological indices were found to be highly positive correlated ($P<0.01$) with dry matter accumulation, primary and secondary branches/plant, seed, stover and biological yield of oilseed rape crop. Similarly, plant height, siliquae/plant, and seeds/siliquae also remained significantly positive correlated ($P<0.05$), whereas, at reproductive stage, PTU and HTU were significantly negatively correlated ($P<0.01$) with all growth parameters, yield attributes and yield of oilseed rape. Similar type of statistical trends were reported by Kumar *et al.* (2017). Higher temperature during the reproductive stage inhibits the export of photosynthates to upper and lower pods of terminal raceme thereby reduces sink strength (Alam *et al.* 2014).

Yield: The seed yield of oilseed rape differs significantly with the sowing environmentsand cultivars (Table 4). The data revealed that crop sown on first sowing environment (D_1) produced significantly higher seed yield of about 1758 kg/ha as compared to second sowing environment (1377 kg/ha) and third sowing environment (1053 kg/ha). Among cultivars, GSL-1 (1493 kg/ha) exhibited significantly higher seed yield followed by ONK-1 (1432 kg/ha) and DGS-1 (1262 kg/ha). Moreover, the cultivar GSL-1 (V_1) sown under the first sowing environment (D_1) recorded significantly higher seed yield of about 1885 kg/ha as compared to other treatment combinations (D×V). The decrease in seed yield with delayed sowing occurred primarily due to the lower biomass build-up which resulted in reduced bearing capacity owing to slower growth on account of lower temperatures during early vegetative stage. Higher temperature and long days accelerated rapid maturity by accumulating more GDD in less number of days (76 days) at reproductive stage significantly reduced the seed yield. Moreover, the crop sown in first sowing environment maintained better agrometeorological indices fulfilling the optimal thermal requirements for various plant processes, hence increased seed yield. Similar findings has also been reported by

Table 3 Correlation coefficients between agrometeorological indices and growth parameters, yield attributes and yield of oilseed rape (Pooled data of 2 years)

Crop parameter	Vegetative stage			Reproductive stage		
	GDD	PTU	HTU	GDD	PTU	HTU
Plant height (cm)	0.884*	0.882*	0.855*	-0.574	-0.711*	-0.716*
Dry matter accumulation (g/m^2)	0.928**	0.926**	0.914**	-0.679	-0.720*	-0.836*
Primary branches/plant	0.897**	0.892**	0.889**	-0.583	-0.754*	-0.783*
Secondary branches/plant	0.914**	0.915**	0.899**	-0.663	-0.728*	-0.841*
Siliquae/plant	0.894*	0.883*	0.834*	-0.700	-0.772*	-0.848*
Seeds/siliqua	0.864*	0.855*	0.826*	-0.584	-0.826*	-0.762*
Seed yield (kg/ha)	0.917**	0.919**	0.910**	-0.662	-0.727*	-0.847*
Stover yield (kg/ha)	0.937**	0.941**	0.920**	-0.701	-0.777*	-0.874*
Biological yield (kg/ha)	0.937**	0.941**	0.923**	-0.700	-0.769*	-0.872*

**Significant at 1%, *Significant at 5%.

Table 4 Seed yield of oilseed rape cultivars under different sowing environments (Pooled data of 2 years)

Treatment	Seed yield (kg/ha)			
	Cultivars (V)			
Sowing environments (D)	GSL-1 (V_1)	ONK-1 (V_2)	DGS-1 (V_3)	Mean
First sowing environment (D_1)	1885	1755	1633	1758
Second sowing environment (D_2)	1552	1375	1203	1377
Third sowing environment (D_3)	1043	1165	950	1053
Mean	1493	1432	1262	
CD (P=0.05)	D= 51.14, V= 51.14, D×V= 88.58			

Treatment details are given under Materials and Methods.

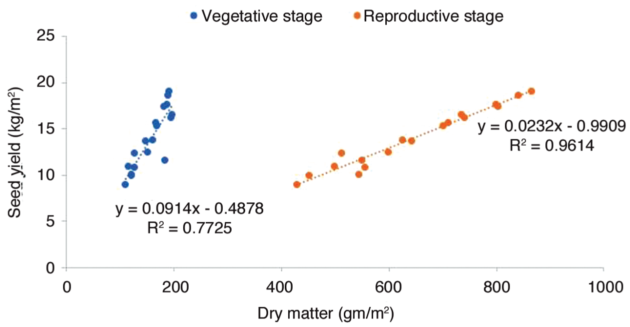

Fig 2 Relationship between dry matter production and seed yield of oilseed rape (Pooled data of 2 years).

Pradhan *et al.* (2014), Gupta *et al.* (2017), Islam *et al.* (2019) and Kumar *et al.* (2022).

Relationship of dry matter production with seed yield: During vegetative stage, linear and positive relationship was observed between dry matter and seed yield with the conversion rate of about 0.091 g/kg/m^2 (R^2=0.77) (Fig 2). Similarly, there was also positive significant relationship between dry matter accumulation and seed yield at reproductive stage with the conversion rate of about 0.023 g/kg/m^2 (R^2=0.96). Oilseed rape having indeterminant growth significantly influences the seed yield by accumulating higher dry matter at vegetative stage which later results to better mobilization and partitioning of photosynthates towards reproductive parts. Islam *et al.* (2019) reported that dry matter production by the plants depends on the temperature and amount of light energy interception by the leaves and its efficiency of conversion into chemical energy. In the present study, oilseed rape cultivars sown on first sowing environment exhibited higher rate of dry matter production (Table 2) and better dry matter production with its proper translocation into reproductive organ are the prime requisites for higher productivity as more biomass production is the foundation of higher seed yield (Kaur *et al.* 2022).

The findings of the study can be safely summarized by stating that all agrometeorological indices accumulated higher under the early sown crop (42^{nd} SMW) due to favourable weather conditions. During vegetative phase, agrometeorological indices (GDD, PTU and HTU) were positively correlated with all growth parameters, yield attributes, and yield; however, in the reproductive phase, all these variables were negatively correlated with PTU and HTU. Thus, from the above study, it can be concluded that sowing of GSL-1 in the first sowing environment (42^{nd} SMW) may be practiced for achieving significantly higher seed yield at north-west foothill of Himalayas, India. Furthermore, developing location specific crop weather relation may be effectively used to manage the effect of climate change on oilseed rape to sustain its productivity and food security.

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