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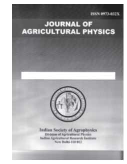

Research Article

Bio-physical Parameters of Rapeseed and Mustard as Influenced by Soil Temperature

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ABSTRACT

Soil thermal regimes were studied in *rabi* season 2019-20. A linear and positive regression relationship was observed between air temperature and soil temperature at morning and afternoon hours with coefficient of determination 55.6% and 75.6%, respectively. Linear regression relationship depicted an increase in morning and afternoon soil temperature by 0.642 and 0.762 °C, respectively with increase in 1°C of morning and afternoon air temperature. There is a change in grain yield and oil content by 48.8 and 45.4% variation, respectively due to soil heat accumulation. While average soil temperature affected the grain yield and oil content by 55.4 and 24.5%, respectively. From the results, it has been concluded that grain yield and oil content in rapeseed and mustard was affected by soil temperature as an independent variable.

Key words: Detopping, mustard, grain yield, oil content and soil temperature

Rapeseed and mustard are the primary oilseed crops of our country, occupying important place next to groundnut in area and production, which fulfills the fat requirement of more than 50 per cent of human population in major states such as Uttar Pradesh, Punjab, Madhya Pradesh, Rajasthan, Assam and Bihar. The name rapeseed-mustard is used for the oilseeds produced from 3 genera i.e. *Brassica*, *Eruca* and *Sinepsis* of the *Brassicae* family, out of which *Brassica* is most important. The different types of *Brassica* genotypes used in India for oilseed production and are mostly grown above 20°N of latitude i.e. northern and eastern parts of India. *Brassica juncea* i.e. Indian mustard is the most important among all ecotypes in India due to its high seed yield and oil content and hardy nature as compared to all ecotypes of Brassica (Singh Chhida, 1996). Rapeseed contains about 42% oil and mustard contains about 38-40% oil. Rapeseed and mustard were grown on 43.9 thousand hectares with a production of 69.3 thousand tonnes during 2021-22 in the Punjab State. The average yield was 15.79 quintals per hectare (6.39 quintals per acre). Gobhi sarson are sown exclusively under irrigated conditions, whereas raya can be grown under both irrigated and rainfed conditions (Anonymous, 2023-24).

In present scenario, main challenge for the agricultural scientists is to increase the production of crops without enlarging the acreage of the crops to accomplish the food security. One of the reasonable ways to do the same, is by harvesting the natural resources like solar radiation i.e. photosynthetically active radiation to the maximum extent (Goyal *et al.,* 2018). The radiation use efficiency and photosynthetic active radiation interception depends on the planting geometry and have impact on the biological and economical yield

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(Jha *et al.*, 2015). Mustard is a source-limited plant in which, post flowering photosynthates are not enough to feed all the blossoming flowers, which results in filling of only some pods of the inflorescence, leaving the inflorescence-top siliqua unfilled. These unfilled pods at the inflorescence-top consumes a lot of assimilates but contribute nothing towards the grain yield. So, with removal of this unproductive top portion of the inflorescence, a scope of supplying more assimilates to the basal developing siliqua may arise. This may increase grain yield by increasing the weight of grains (Yeasmin *et al.,* 2014).

Soil is a key natural resource and soil temperature is one of the potential physical parameters that determines crop productivity and sustainability (Glinski and Walczak, 1998). Soil temperature controls biological and biochemical processes in the soil which, in turn, affect soil organic matter formation, fertilizer efficiency, seed germination, plant development, plant winter survival, nutrient uptake and decomposition, and disease and insect occurrence (Jacobs *et al.*, 2007; Verma *et al.*, 2011). In addition, soil temperature behaviour plays an especially important role in crop variety selection and farm management practices (Azadegan and Massah, 2011).

Materials and Methods

The field experiment was conducted at the research farm of Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana (30°54′ N latitude and 74°48′ E longitude and altitude of 247 m above mean sea level) during *rabi* of 2019-20. The experiment was laid out in a split plot design with three replications and 24 treatments (four cultivars: Giriraj, RLC-3, GSC-7 and GSC-6, three planting methods i.e. uni-directional (E-W), uni-directional (N-S) and bi-directional (E-W, N-S) with two growth alterations viz. detopping and no detopping in a 3.60 × 3.60 m plot size. Four cultivars and three planting methods were kept in main plots and growth alterations were kept in sub-plots. Sowing was done on 21st October by adopting kera method by keeping the sowing depth at 4-5 cm under good soil moisture conditions by using seed rate of 3.75 kg/ha. Row to row spacing was kept 30 cm for two cultivars of raya (Giriraj and RLC-3) and 45 cm for two cultivars of gobhi sarson (GSC-7 and GSC-6) and plant to plant spacing of 10 cm is maintained by thinning for both raya and gobhisarson. Uni-directional planting was done in east-west (E-W) (P_1) and north-south (N-S) (P_2) direction, separately and bi-directional planting (P_3) was done in both directions east-west (E-W) and north-south (N-S) using half seed rate in each directions.

The growth alteration treatments were applied at 40 DAS by cutting top 2-3 cm terminal portion of the plant *i.e.*, detopping (D_1), and other one is no detopping (D_2) treatment. Nitrogen was applied in the form of urea (46 per cent N) @ 90 kg/acre, phosphorus (P_2O_5) was applied as single superphosphate (16 per cent P_2O_5) @ 75 kg/acre and muriate of potash (60 per cent K_2O) @ 10 kg/acre in the field. Half dose of the urea, full dose of single superphosphate and muriate of potash was applied at the time of sowing and remaining half of the urea was applied during first irrigation at 21 DAS. The grain produce from each plot was weighed to record grain yield per net plot and then yield in quintal per hectare was calculated. The oil content was depicted with nuclear magnetic resonance (NMR) spectro-metery technique in the laboratory.

Daily soil temperature was measured at 5 cm soil depth at 07:30 and 14:30 hrs. This daily average soil temperature was then accumulated to determine soil heat accumulation/Soil degree days:

$$\text{Soil heat accumulation} = \Sigma \frac{\text{STmax} + \text{STmin}}{2} - \text{STb}$$

where, ST_{max}= daily maximum soil temperature, ST_{min}= daily minimum soil temperature and ST_b= Minimum threshold/Base soil temperature (5°C) (Morrison *et al.*, 1990)

This soil heat accumulation were correlated with the biophysical parameters (dry biomass production, grain yield and oil content) accumulated up to maximum/peak values to establish the functional relationship with cumulative soil temperature/soil heat accumulation.

Results and Discussion

The analysis of weather data during crop season indicated that monthly mean air temperature varied from 11.4 to 24.5°C and mean relative humidity was around 73%. Total rainfall of 205.8 mm was recorded with average sunshine hours of 5.4 hrs during crop season. Temporal variations in soil temperature as mean minimum and maximum soil temperatures with statistical analysis are presented in Table 1 and Table 2, respectively. Soil temperature showed variation among different planting methods as expressed in Table 1 and Table 2. Mean maximum soil temperature was higher by about 2.95 to 9.69°C, 2.93 to 9.89°C and 2.52 to 9.57°C in P_1, P_2 and P_3 treatments, respectively as compared to mean minimum soil temperatures.

Significant effect of air temperature on soil temperature was observed as shown in Fig. 1 and Fig. 2. A positive linear regression relationship was observed between these two temperatures. The linear trend results in minimum soil temperature = 0.642* minimum air temperature + 7.125 with a coefficient of determination of R^2 = 0.55, which means each unit change in minimum air temperature will increase the minimum soil temperature by 0.642 unit, whereas maximum soil temperature will increase by 0.762 unit with increase in each unit of maximum soil temperature (maximum soil temperature = 0.762* maximum air temperature + 3.644, R^2 = 0.75). This

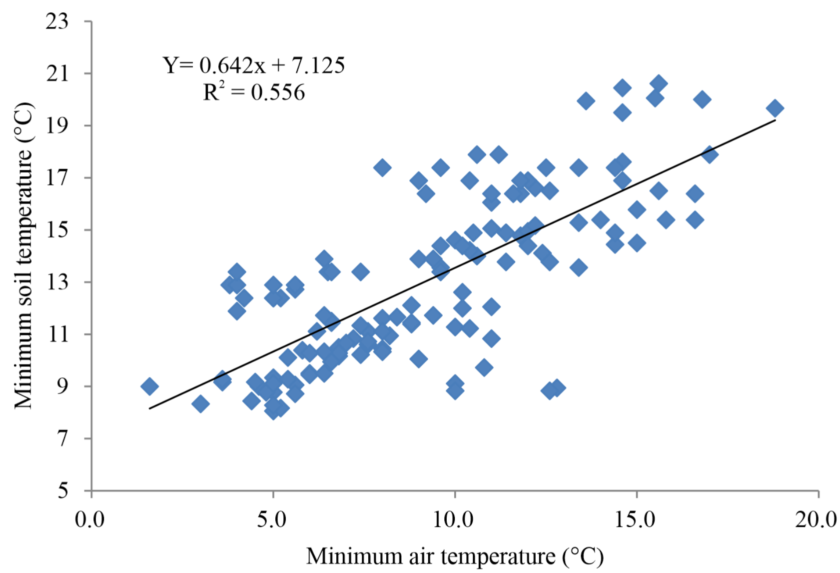

Fig. 1. Relationship between air and soil temperature at morning hours in rapeseed and mustard crop during *rabi* 2019-20

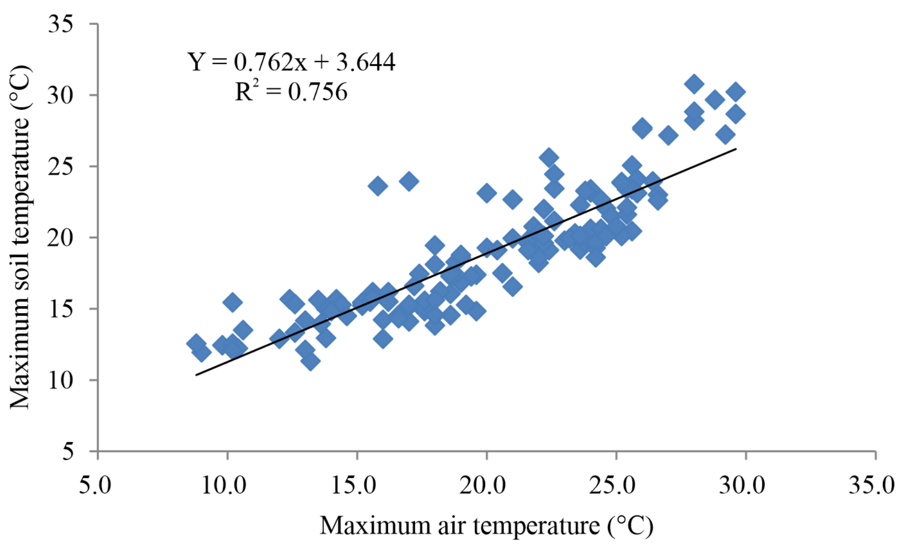

Fig. 2. Relationship between air and soil temperature afternoon hours in rapeseed and mustard crop during *rabi* 2019-20

Table 1. Statistical analysis of variation in minimum (morning) soil temperature during the crop season (2019-20)

Treatment									P1									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	20.33	17.95	15.71	14.57	13.48	10.17	9.79	11.38	9.4	8.38	9.88	10.83	10.07	12.45	13.26	14.05	15.4	16.19
SD	1.05	1.87	1.15	0.58	1.55	0.46	0.98	0.5	0.68	0.65	1.15	0.93	1.72	0.72	0.41	0.35	0.74	0.8
Variance	1.11	3.5	1.31	0.33	2.41	0.21	0.96	0.25	0.47	0.42	1.32	0.86	2.96	0.52	0.17	0.12	0.54	0.64
CV%	5.17	10.42	7.3	3.96	11.52	4.49	10.03	4.37	7.25	7.76	11.64	8.55	17.07	5.81	3.07	2.49	4.77	4.93
Kurtosis	0.29	-1.65	-0.43	-0.84	-0.49	-0.63	0.09	0.17	-1.1	-0.4	-0.95	0.02	-0.81	-0.15	-0.22	-0.76	0.39	-1.27
Skewness	1.3	0.28	0.84	0.13	-0.32	0.11	0.89	0.19	0.25	-0.4	-0.55	-0.45	0.72	-0.7	-0.08	-0.13	0.99	0.2
Treatment									P2									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	20.19	18	15.57	14.57	13.39	10.5	9.86	11.18	9.11	8.75	9.93	10.75	10.11	12.18	12.68	13.46	14.82	15.61
SD	0.53	1.72	1.36	0.58	1.48	0.52	0.79	0.42	0.68	0.51	1.17	0.78	1.75	0.61	0.42	0.37	0.75	0.81
Variance	0.28	2.96	1.84	0.34	2.2	0.27	0.63	0.18	0.47	0.26	1.38	0.61	3.05	0.37	0.18	0.13	0.56	0.66
CV%	2.63	9.56	8.71	4.01	11.07	4.94	8.06	3.77	7.52	5.82	11.83	7.24	17.27	4.99	3.32	2.71	5.06	5.21
Kurtosis	3.94	-1.6	-0.14	-0.44	-0.55	0.17	0.35	-0.18	-0.1	-0.9	-0.93	0.64	-1.12	-0.47	-0.18	-0.86	0.62	-1.24
Skewness	-1.96	0.04	0.88	0.02	-0.03	0	0.41	0.07	0.39	-0.2	-0.71	-1.14	0.73	-0.21	0.07	0.11	1.04	0.23
Treatment									P3									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	19.75	18.43	15.84	14.23	13.54	10.82	9.79	11.66	9.57	9.02	10.02	10.77	9.95	11.89	12.55	13.34	14.7	15.48
SD	0.61	1.66	1.26	0.8	1.64	0.85	1.11	0.72	0.8	0.54	1.09	0.73	1.59	0.75	0.64	0.61	0.89	0.94
Variance	0.37	2.75	1.58	0.64	2.7	0.73	1.23	0.51	0.64	0.29	1.19	0.53	2.52	0.56	0.41	0.37	0.78	0.88
CV%	3.07	9.01	7.92	5.61	12.14	7.87	11.33	6.15	8.38	5.94	10.91	6.74	15.98	6.3	5.12	4.57	6.03	6.06
Kurtosis	-0.47	-1.72	-0.8	-0.68	0.16	-0.91	0.86	-0.2	-0.7	-0.5	-1	0.02	-0.61	-0.59	-0.4	-0.57	0.11	-0.65
Skewness	-0.3	0.14	0.44	0.39	-0.34	0.17	1.2	-0.3	0.1	-0.4	-0.44	-0.66	0.95	0.25	0.46	0.54	0.73	0.27

P_1 : East-west (E-W), P_2: North-south (N-S) and P_3: bi-directional planting

Table 2. Statistical analysis of variation in maximum (afternoon) soil temperature during the crop season (2019-20)

Treatment									P1									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	28.13	27.64	21.69	19.5	16.43	19.5	16.43	16.07	12.79	14	14.29	14.86	15.61	16.98	19.24	20.55	19.52	21.43
SD	1.62	2.53	1.21	1.01	0.95	1.01	0.95	0.51	0.61	1.46	1.33	0.98	0.74	1.07	0.93	0.67	1.14	1.04
Variance	2.63	6.4	1.46	1.03	0.91	1.03	0.91	0.26	0.37	2.13	1.76	0.95	0.55	1.14	0.87	0.45	1.29	1.08
CV%	5.76	9.15	5.57	5.19	5.8	5.19	5.8	3.16	4.78	10.41	9.3	6.57	4.73	6.28	4.84	3.26	5.82	4.85
Kurtosis	-0.67	0	-1.57	0.24	-1.02	0.24	-1.02	-0.04	4.34	-0.75	-0.08	0.24	0.22	-0.54	0.45	-0.91	-0.82	-0.28
Skewness	-0.77	-0.62	0.11	-0.44	0.51	-0.44	0.51	0.01	1.87	-0.64	-0.55	0.22	-0.93	0.07	-0.89	-0.33	0.26	0.26
Treatment									P2									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	28.44	27.89	21.14	19.21	16.32	19.21	16.32	15.36	12.6	13.86	14.29	14.68	16	16.71	18.43	19.64	19.64	20.57
SD	0.9	2.68	0.97	1.17	1.22	1.17	1.22	0.5	0.42	1.46	1.09	0.93	1.02	0.95	0.51	0.36	0.77	0.85
Variance	0.82	7.2	0.94	1.37	1.48	1.37	1.48	0.25	0.18	2.13	1.18	0.87	1.05	0.9	0.26	0.13	0.59	0.73
CV%	3.18	9.62	4.58	6.1	7.47	6.1	7.47	3.24	3.32	10.54	7.61	6.35	6.39	5.69	2.79	1.85	3.92	4.14
Kurtosis	-0.35	0.2	-0.65	-1.33	-0.92	-1.33	-0.92	1.16	-0.61	-0.24	0.61	-0.72	-0.37	-1.14	-0.36	-0.73	-1.64	-0.84
Skewness	0.83	-0.82	-0.32	-0.15	0.34	-0.15	0.34	0.67	-0.51	-0.62	-0.61	-0.19	-0.92	-0.25	-0.67	-0.52	-0.26	-0.26
Treatment									P3									
DAS	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120	127	134
Mean	28.84	28	21.48	19.89	21.09	18.82	15.91	14.96	12.1	12.93	14.27	14.36	15.8	16.05	18.02	19.52	19.23	20.23
SD	0.72	2.22	1.6	2.38	1.33	1.27	0.9	0.51	0.7	1.05	1.1	0.73	0.89	1.24	1	1.14	1	1.15
Variance	0.52	4.94	2.56	5.65	1.76	1.62	0.82	0.26	0.49	1.11	1.21	0.53	0.78	1.55	1.01	1.29	1.01	1.32
CV%	2.51	7.94	7.45	11.95	6.29	6.75	5.68	3.39	5.79	8.13	7.72	5.09	5.6	7.75	5.57	5.82	5.22	5.69
Kurtosis	-0.87	0.16	-0.94	-0.55	-1.12	-0.76	-1.23	-0.65	-0.11	-0.54	-0.25	-0.53	0.06	-0.98	-0.61	-0.82	-0.36	-0.58
Skewness	-0.04	-0.76	-0.07	0.7	-0.13	0.08	0	-0.08	0.47	-0.03	-0.59	-0.3	-0.17	-0.1	0.12	0.26	-0.43	-0.43

P_1 : East-west (E-W), P_2: North-south (N-S) and P_3: bi-directional planting shows that heat capacity of soil is dependent on air temperature, as well as other soil characteristics.

Soil thermal regimes get changed as accumulated soil temperature will increased with time. So, a relation of soil heat accumulation/soil degree days with time variable is assessed which showed progressive increase in soil heat accumulation with time as crop moved towards maturity (Fig. 3). Soil heat accumulations were pooled and correlated with time to develop the following equation to predict soil heat accumulation:

Soil heat accumulation/soil degree days = 9.940 * time variable (day) + 189.4, (R^2= 0.98).

This means with increase in each unit of time variable (day)soil degree days will increase with 9.94 units. A sum of around 1700 soil degree days was observed during the experimental period. When soil heat accumulation was plotted against growing degree days, a positive linear trend was observed (Fig. 4).

Concept of soil heat accumulation was used to evaluate variability in grain yield and oil content. A

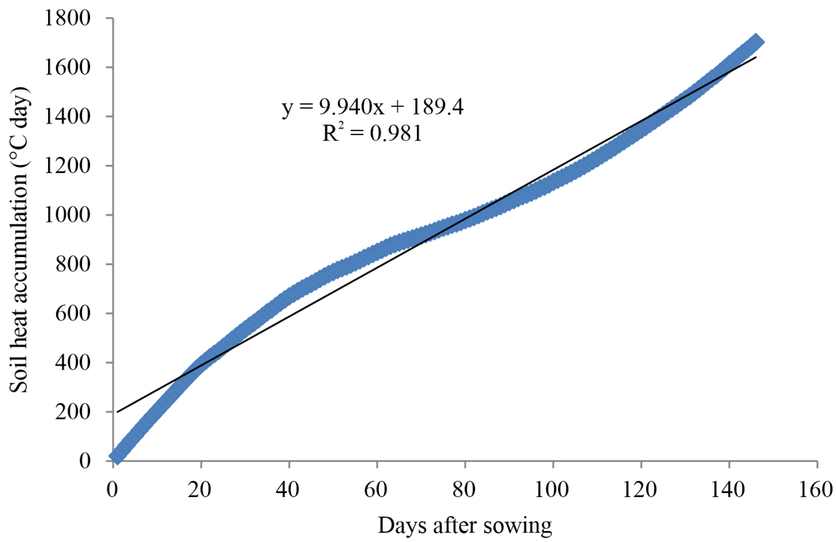

Fig. 3. Time variable soil heat accumulation in rapeseed and mustard crop during *rabi* 2019-20

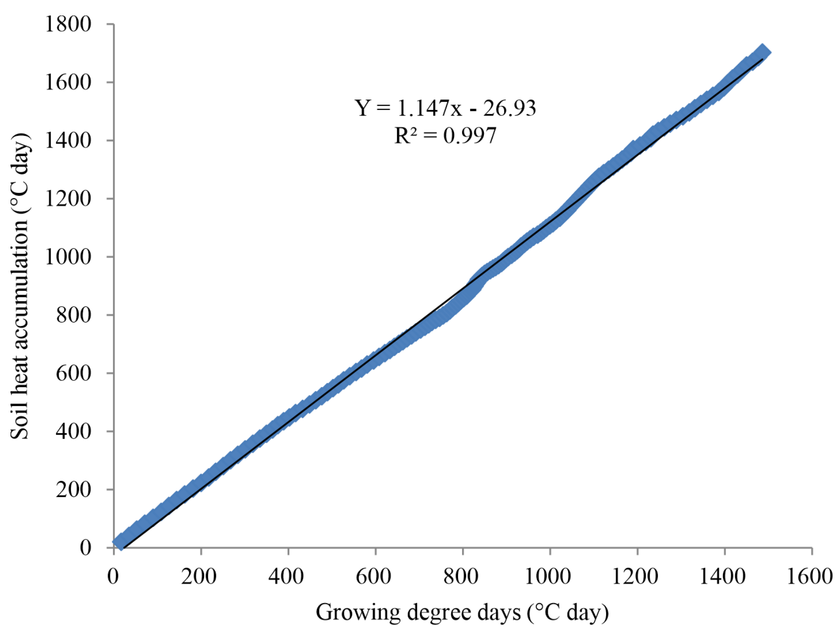

Fig. 4. Relationship between soil heat accumulation and growing degree days in rapeseed and mustard crop during *rabi* 2019-20

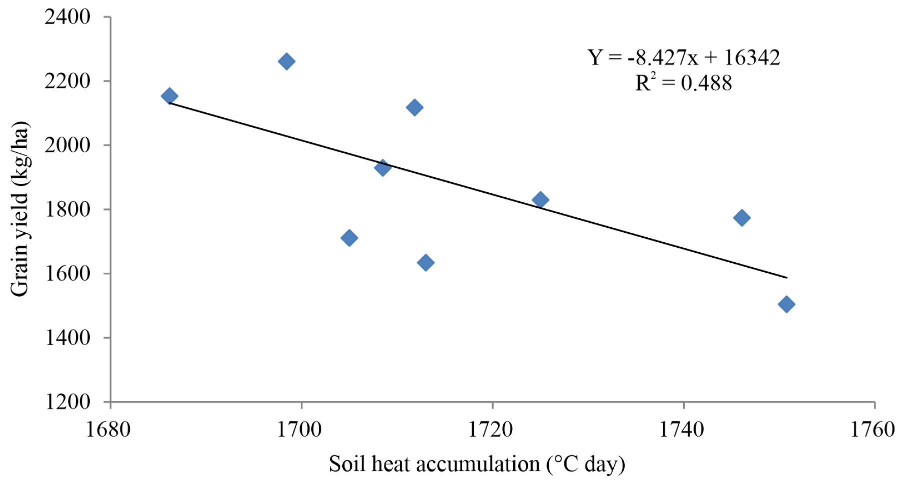

Fig. 5. Relationship between soil heat accumulation and grain yield in rapeseed and mustard crop during *rabi* 2019-20

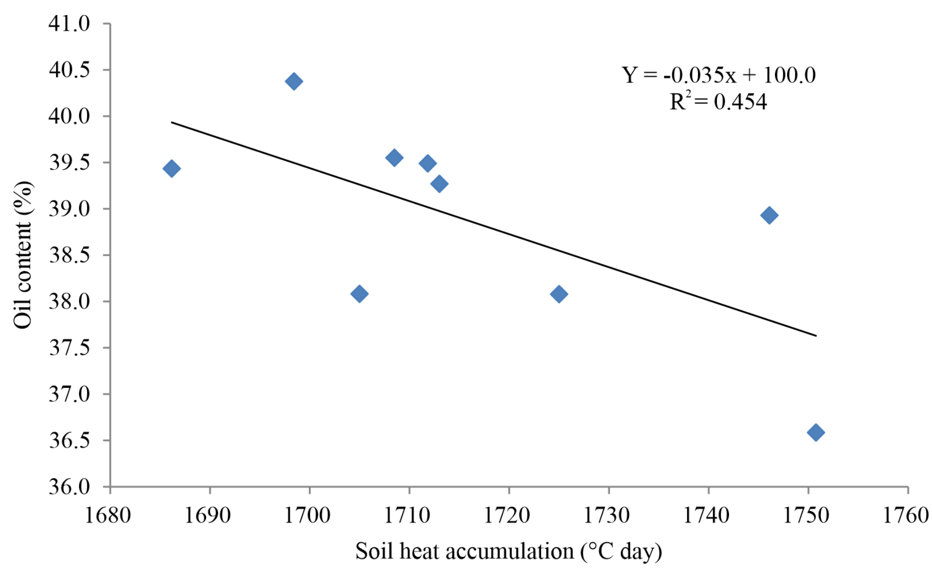

Fig. 6. Relationship between soil heat accumulation and oil content in rapeseed and mustard crop during *rabi* 2019-20

linear trend (grain yield = -8.427 * soil heat accumulation + 16342) was observed between grain yield and soil heat accumulation with a coefficient of determination of R^2 = 0.48, which means each unit change in soil heat accumulation will decrease the grain yield by 8.427 kg/ ha, whereas oil content will decrease by 0.035 unit with increase in each unit of soil heat accumulation (oil content = -0.035* soil heat accumulation + 100, R^2 = 0.45). To conclude, a 48.8 and 45.4% variation in grain yield and oil content, respectively, was observed due to soil heat accumulation. Average soil temperature was also used to evaluate variability in grain yield and oil content. A linear trend (grain yield = -1423 * average soil temperature + 25115) with a coefficient of determination of R^2 = 0.55, which means each unit change in average soil temperature will decrease the grain yield by 1423 kg/ ha. To conclude, a 55.4 and 24.5% variation in grain yield and oil content respectively was observed due to change in average soil temperature.

The results show that grain yield and oil content was affected by soil temperature as an independent variable. Linear and non-linear statistical analysis by using different regression models also confirmed

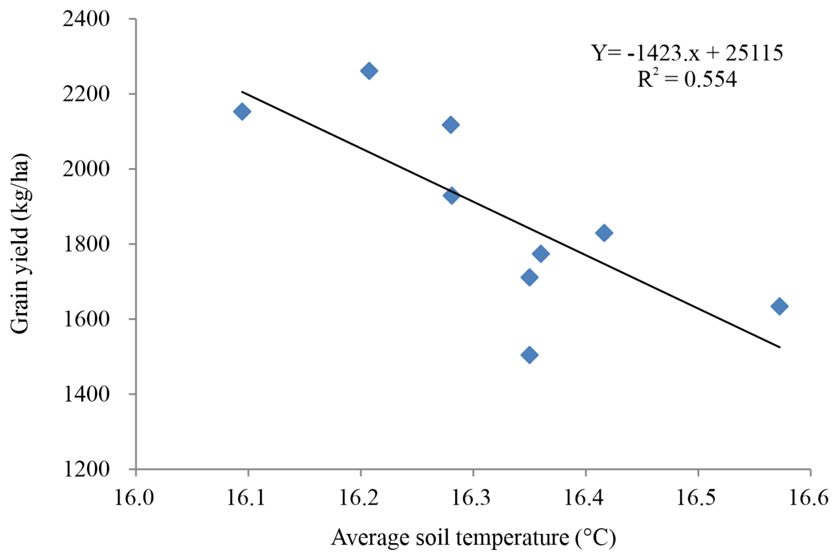

Fig. 7. Relationship between average soil temperature and grain yield in rapeseed and mustard crop during *rabi* 2019-20

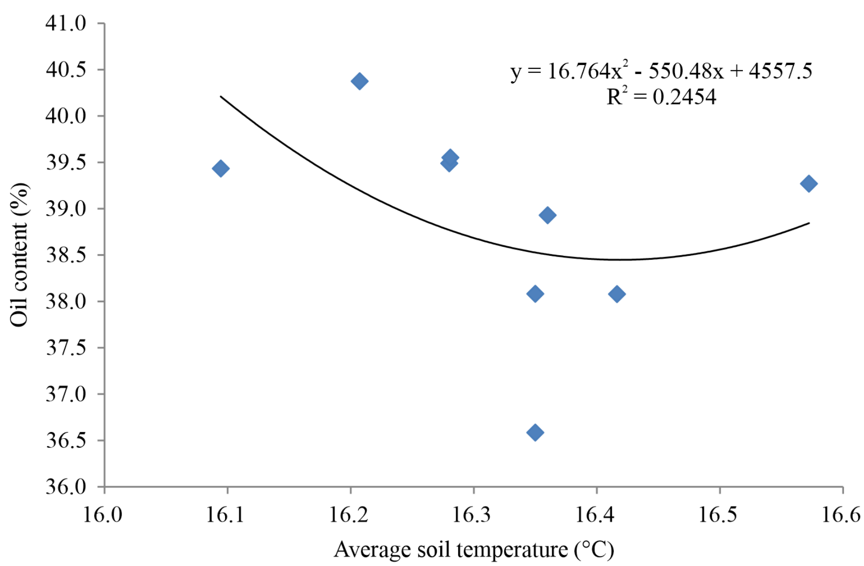

Fig. 8. Relationship between average soil temperature and oil content in rapeseed and mustard crop during *rabi* 2019-20

a negative correlation of soil heat accumulation with grain yield and oil content (Table 3).

Conclusions

A linear and positive relationship was observed between air temperature and soil temperature at morning and afternoon hours with coefficient of determination 55.6% and 75.6%, respectively. It indicates that if air temperature will change, a change in soil temperature will be sure. Linear relation indicated that with each °C change in minimum air temperature will change the minimum soil temperature by 0.642 °C, whereas maximum soil temperature will change by 0.762 °C with increase in each °C of maximum soil temperature. Near about 50% variation in grain yield and oil content is due to soil heat accumulation and it revealed that grain yield and oil content is a function of soil temperature as an independent variable in rapeseed and mustard crop.55.4 and 24.5% variation in grain yield and oil

Table 3. Regression models for predicting grain yield and oil content as a function of soil heat accumulation in rapeseed and mustard during 2019-20

Models	Regression relationship	R^2
	Grain yield	
Linear	$Y = -58.81x + 15277$	0.41
Polynomial	$Y = 5.321x^2 - 2475.x + 28967$	0.44
Logarithmic	$Y = -1338\ln(x) + 74514$	0.41
Exponential	$Y = 2E{+}06e^{-0.03x}$	0.40
Power	$Y = 2E{+}19x^{-6.80}$	0.40
	Oil content	
Linear	$Y = -0.035x + 100.0$	0.45
Polynomial	$Y = -0.000x^2 + 1.333x - 1078$	0.47
Logarithmic	$Y = -61.2\ln(x) + 495.2$	0.45
Exponential	$Y = 191.5e^{-9E-0x}$	0.45
Power	$Y = 6E{+}06x^{-1.59}$	0.45

content, respectively is due to average soil temperature and it also confirms these crop parameters are function of soil temperature as in case of soil heat accumulation.

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