Journal of Agrometeorology 9(2) : 223 - 230 (Dec. 2007)

Thermal requirement and heat use efficiency of sunflower (*Helianthus annus L.)* in Punjab

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ABSTRACT

Field experiments were carried out on the sandy loam soil of the Agronomy and Agromet farm of Punjab Agricultural University, Ludhiana. The experiment was laid out with two cultivars of sunflower (V_1 -PSFH 118 and V_2 - SH 3322) under three dates of sowing during *rabi* 2003-04 and *rabi* 2004-05 following the recommended agronomic practices. The crop was sown on three dates in both the years to expose the crop to different weather conditions during its various phenological stages. The thermal units required to attain a given phenological stage increased as sowing was delayed in both the cultivars and seasons. The phenothermal index gradually increases from emergence to physiological maturity in all three dates of sowing in both years being the lowest at emergence and the highest during grain filling and physiological maturity stages.

Key words: *Helianthus annus*, sunflower, GDD, HTU, PTU, PTI, HUE

Sunflower (*Helianthus annus L.*) is a short duration important oilseed crop. Sunflower ranks fourth amongst oilseed crops next to soybean, cotton and rapeseed/ mustard in the world. Temperature and light combination plays a key role in influencing sunflower production. The occurrence of different phenological events during crop growth period in relation to temperature can be estimated by using accumulated heat units or growing degree-days (GDD) (Gouri *et al*, 2005). Knowledge of accumulated GDD can provide an estimate of harvest date as well as crop development stage (Ketring and Wheless, 1989; Bonhomme, 2000; Wurr *et al*, 2002; Roy *et al* 2005). Thermal time is an independent variable to describe plant development (Dwyer and Stewart, 1986). It can be used as a tool for characterizing thermal responses in different crops.

Heat use efficiency (HUE), i.e., efficiency of utilization of heat in terms of dry matter accumulation, depends on crop type, genetic factors and sowing time and has great practical application (Rao *et al*, 1999). The duration of each phenophase determines the accumulation and partitioning of dry matter in different organs.

In view of this, an attempt was made to work out the thermal requirement and to compute phenothermal index and heat use efficiency for different phenological stages of two sunflower cultivars as influenced by different dates of sowing during two crop seasons.

MATERIALS AND METHODS

The field experiments were conducted during *Rabi* 2003-04 and 2004-05 at Ludhiana (30 °-54' N and 75°-48' E, 247m above mean sea level). The average maximum and minimum temperature and rainfall during the *rabi* season are 24.4 °C, 9.5 °C and 129 mm, respectively at Ludhiana (Hundal and Prabhjyot-Kaur, 2002).

The experiment was laid out with two cultivars of Sunflower (V_1 -PSFH 118 and V_2 - SH 3322) under three dates of sowing (*rabi* 2003-04: D_1 -9th Jan 2004,D_2 - 27th Jan 2004, D_3 –13th Feb 2004 & *rabi* 2004-05: D_1 –9th Dec 2004, D_2 -–10thJan 2005, D_3 – 11thFeb 2005). The crop received 60kg N and 30 kg P_2O_5 ha^{-1}. Half nitrogen and full phosphorus was applied as a basal dose while remaining half nitrogen was applied 30 days after sowing. Plant samples were collected periodically at 15-day interval and leaf area index and dry matter accumulation were recorded. The indices namely growing degree-days, heliothermal units, photothermal units, phenothermal index and heat use efficiency were computed. Growing degree-days (GDD) were determined as per Nuttonson (1955) using a base temperature of 4 °C (Villalobos *et al.*, 1996)..

Heliothermal units (HTU), the product of GDD and corresponding actual sunshine hours for that day were computed on daily basis. Photothermal units (PTU), the product of GDD and corresponding day length for that day were computed on daily basis.

All thermal units were accumulated from the date of sowing to each date of sampling and a particular date of phenophase to give accumulated indices.

Phenothermal index (PTI), the ratio of degree-days to the number of days between two phenological stages was calculated as:

$$\text{PTI} = \frac{\text{Degree days consumed between two phenological stages}}{\text{Number of days between two phenological stages}}$$

Heat use efficiency (HUE) for seed and total dry matter was obtained as under:

$$\text{Heat use efficiency} = \frac{\text{Seed yield / Total dry matter}}{\text{Accumulated heat units}}$$

RESULTS AND DISCUSSION

Growing degree days (GDD)

Growing degree days required for different phenophases of sunflower cultivars for different sowing dates for two crop seasons are shown in Table1. In general, earlier sown crop availed lesser growing degree days during both the crop seasons

Table 1 : Accumulated growing degree day (°C day) availed for different phenological stages of sunflower cultivars under three dates of sowing and two crop seasons

Phenological stages	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
Rabi (2003-04)						
Start emergence	142	142	86	86	90	116
Complete emergence	224	224	138	138	170	204
4 leaf stage	294	253	225	172	305	275
6 leaf stage	347	294	335	252	372	320
8 leaf stage	415	371	424	384	422	387
Star stage	545	545	649	629	583	588
Bud formation	847	930	776	754	919	994
Start flowering	908	1110	873	893	1101	1257
Complete flowering	1172	1478	1250	1327	1382	1478
Grain filling	1243	1685	1327	1602	1504	1584
Physiological maturity	1451	1974	1577	1907	1786	1935
Rabi (2004-05)						
Start emergence	103.	78	104	97	107	969
Complete emergence	208	135	176	160	182	156
4 leaf stage	264	247	222	204	205	193
6 leaf stage	342	318	328	300	347	318
8 leaf stage	407	374	440	415	396	378
Star stage	743	706	692	654	945	908
Bud formation start .	800	783	794	765	1081	10368
Bud formation complete	880	895	893	839	1179	1129
Start flowering	908	939	979	1095	1227	1269
Complete flowering	1068	1112	1149	1184	1496	1577
Grain filling	1345	1371	1438	1547	1780	1835
Physiological maturity	1666	1741	1637	1754	2031	2088

and with each delay in sowing, growing degree day requirement increased. Amongst the two cultivars, cv. SH-3322 required more heat units to complete different phenological stages during both the crop growth seasons. For different sowing dates and crop seasons, AGDD from emergence to physiological maturity ranged between 1451 to 2031 °C day and 1741 to 2088 °C day for cv. PSFH-118 and cv. SH-3322, respectively.

Heliothermal units (HTU)

Heliothermal units (HTU) required to attain different phenological stages are shown in Table 2. Earlier sown crop availed lesser HTU during both the crop seasons

Table 2 : Accumulated heliothermal units (°C day hour) availed for different phenological stages of sunflower cultivars under three dates of sowing and the two crop seasons

Phenological stages	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
Rabi (2003-04)						
Start emergence	654	654	613	613	750	1018
Complete emergence	1037	1037	965	965	1605	1932
4 leaf stage	1629	1342	1695	1312	3045	2711
6 leaf stage	2126	1629	2836	1955	3775	3223
8 leaf stage	2635	2358	3783	3324	4283	3929
Star stage	3973	3973	6146	5934	5951	5950
Bud formation	7196	8057	7278	7244	8962	9732
Start flowering	7836	9638	8153	8365	10739	12189
Complete flowering	10178	13189	11810	12619	12937	13966
Grain filling	10848	14662	12619	14792	14195	14754
Physiological maturity	12896	17443	14513	17821	17098	18892
Rabi (2004-05)						
Start emergence	773	586	661	634	627.6	511
Complete emergence	1090	905	1252	1113	1117	1039
4 leaf stage	1229	1133	1419	1406	1146	1117
6 leaf stage	1756	1560	1893	1820	2185	1940
8 leaf stage	2147	2022	2620	2543	2687	2514
Star stage	4106	3925	4523	4188	7749	7299
Bud formation start	4342	4284	4920	4806	9291	8764
Bud formation complete	4928	5016	5966	5386	9725	9673
Start flowering	5173	5503	6996	8135	10080	10379
Complete flowering	6292	6586	8620	9012	12541	13421
Grain filling	9255	9508	11227	12125	15824	16601
Physiological maturity	12482	12713	12919	14044	18445	18907

and with delay in sowing, HTU consumption increased. Amongst the cultivars, cv. SH-3322 required more HTU to complete different phenological stages during both the crop growing seasons. For different sowing dates and seasons, accumulated HTU from emergence to physiological maturity ranged between 12896 to 18445 °C day hour and 12919 to 18907 °C day hour for cv. PSFH-118 and cv. SH-3322, respectively.

Photothermal units (PTU)

The accumulated PTU required to attain different phenological stages in

Table 3 : Accumulated photothermal units (°C day hour) availed for different phenological stages of sunflower cultivars under three dates of sowing and two crop seasons

Phenological stages	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
Rabi (2003-04)						
Start emergence	1437	1437	921	921	1006	1295
Complete emergence	2343	2343	1492	1492	1908	2302
4 leaf stage	3103	2657	2460	1864	3464	3121
6 leaf stage	3691	3103	33713	2762	4256	3645
8 leaf stage	4446	3956	4735	4267	4841	4431
Star stage	5922	5922	7393	7146	6781	6781
Bud formation	9479	10483	8930	8656	10935	11884
Start flowering	10222	12700	10117	10360	13253	15274
Complete flowering	13480	17367	14867	15856	16909	18179
Grain filling	14376	20064	15856	15540	18530	19593
Physiological maturity	17024	23919	19126	23558	22320	24363
Rabi (2004-05)						
Start emergence	1051	795	1077	949	1185	1063
Complete emergence	2114	1373	1845	1675	2048	1751
4 leaf stage	2679	2513	2343	2151	2311	2176
6 leaf stage	3481	3234	3514	3197	3976	3635
8 leaf stage	4156	3820	4789	4492	4555	4344
Star stage	7868	7443	7753	7295	11381	10895
Bud formation start	8526	8326	8985	8635	13134	12550
Bud formation complete	9455	9633	10195	9536	14431	13768
Start flowering	9796	10163	11271	12731	15052	15613
Complete flowering	11714	12247	13425	13865	18661	19672
Grain filling	15149	15469	17175	18616	22537	23714
Physiological maturity	19268	20251	19821	21403	26025	26816

sunflower cultivars are shown in Table 3. It was observed that sowing dates had marked influence on photothermal units accumulation. Earlier sown crop availed lower PTU during both the seasons and with delay in sowing, PTU consumption increased. Amongst the cultivars, cv. SH-3322 required more PTU to complete different phenological stages during both the crop growing seasons. For different sowing dates and crop seasons, accumulated PTU from emergence to physiological maturity ranged between 17024 to 26025 °C day hour and 20251 to 26816 °C day hour for cv. PSFH-118 and cv. SH-3322, respectively.

Phenothermal index (PTI)

The phenothermal index for consecutive phenophases of sunflower

Table 4 : Phenothermal index (ºC days day^{-1}) for Sunflower cultivars sown on three dates of sowing and two crop seasons

Phenological stages	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
Rabi (2003-04)						
Start emergence	10.89	10.89	8.59	8.59	15.05	14.50
Complete emergence	8.25	8.25	10.44	10.44	13.28	14.73
4 leaf stage	8.75	7.27	12.44	11.23	14.99	14.20
6 leaf stage	10.66	10.22	13.75	13.38	16.87	15.00
8 leaf stage	13.54	11.03	14.90	14.67	16.47	16.70
Star stage	14.14	14.46	17.3	16.32	20.19	20.11
Bud formation	16.77	17.49	21.17	20.85	20.96	21.33
Start flowering	20.50	20.03	19.36	19.84	26.0	26.33
Complete flowering	20.32	24.53	23.53	24.09	25.55	24.55
Grain filling	23.73	25.89	25.57	25.09	24.50	21.18
Physiological maturity	25.96	22.27	25.01	23.42	23.44	27.00
Rabi (2004-05)						
Start emergence	12.9	13	7.98	8.33	10.7	11.95
Complete emergence	8.73	11.42	7.22	6.85	10.8	8.66
4 leaf stage	9.27	8.64	9.20	8.84	11.35	12.30
6 leaf stage	7.83	7.83	11.80	11.90	15.8	15.6
8 leaf stage	7.20	8.07	9.36	8.85	16.23	14.95
Star stage	9.36	8.73	15.73	14.97	18.3	18.25
Bud formation start	15.7	12.78	16.98	18.55	22.5	21.37
Bud formation complete	14.66	15.94	16.40	14.76	24.7	23.3
Start flowering	14.4	14.9	17.26	19.65	23.55	23.32
Complete flowering	17.77	17.27	21.29	17.76	22.46	23.68
Grain filling	17.3	18.47	22.19	22.71	25.78	26.19
Physiological maturity	21.35	21.76	22.13	23	27.94	27.87

cultivars for different sowing dates and two crop seasons was also computed and are presented in Table 4. The phenothermal index is expressed as degree-days per growth day (Sastry and Chakravarty, 1982). It was observed that the index gradually increases from emergence to physiological maturity in all three dates of sowing in both years being lowest at emergence and highest during grain filling and physiological maturity stages indicating an increase in daily heat consumption toward maturity. Amongst the dates of sowing, the value of phenothermal index was found to be highest in D_3 (first fortnight of February) than the other two dates of sowing during both the crop years.

Heat use efficiency (HUE)

Heat use efficiency was computed for different phenological stages of sunflower and is presented in Table 5. Amongst the

Table 5 : Heat use efficiency (kg ha^{-1} $°C^{-1}$ day^{-1}) for sunflower cultivars for three dates of sowing and two crop seasons at different phenophases

Phenological stages	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
Rabi (2003-04)						
Vegetative stage	0.28	0.41	0.08	0.09	0.21	0.22
Star stage	0.39	0.53	0.68	0.80	0.20	0.20
Bud formation	1.15	1.88	1.14	1.29	0.90	0.94
Start flowering	1.84	2.38	1.55	1.46	1.96	2.91
Complete flowering	3.02	3.6	3.05	2.94	2.67	2.79
Grain filling	3.24	5.70	3.08	2.61	2.81	3.07
Physiological maturity	3.8	6.02	4.18	3.49	2.96	2.73
Rabi (2004-05)						
Vegetative stage	0.06	0.06	0.18	0.35	0.07	0.14
Star stage	2.23	1.89	0.80	1.61	1.52	1.78
Bud formation	3.36	3.91	3.43	3.77	1.80	2.73
Flowering	3.62	3.99	3.81	4.07	2.55	2.89
Grain filling	4.51	4.82	3.78	3.76	2.82	3.03
Physiological maturity	3.94	4.47	3.97	3.88	3.05	3.34

dates of sowing heat use efficiency was found to be higher for early sown crop and it decreased with delay in sowing.

The application of thermal time indices provides a basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of the crop. These provide very clear picture of amount, pattern and efficiency of heat energy consumption at different phenological stages of the crops. These can also be used very effectively for forecasting the occurrence of different phenophases of the crops.

ACKNOWLADGEMENT

The present study was funded by Department of Science and Technology (DST), New Delhi under an adhoc research project entitled, "Evaluation of potential productivity of major oilseed crops in Punjab using crop simulation models" in the Agrometeorology section of the Department of Agronomy, Agrometeorology & Forestry, Punjab Agricultural University, Ludhiana.

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