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Research Article

Effect of Dates of Sowing on Thermal Utilisation and Heat Use Efficiency of Groundnut Cultivars in Central Punjab

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ABSTRACT

Field experiments were carried out on the sandy loam soil of the research farm, Department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana. Two groundnut cultivars (V_1: M-522 and V_2: M-548) were sown on three dates (D_1 - 1st June, D_2 - 20th June and D_3 - 10th July) during *kharif* 2004, 2005 and 2006 following the recommended agronomic practices. The crop was sown on three dates during all the years to expose the crop to different weather conditions during its various phenological stages. The thermal units required to attain a particular phenological stage decreased as the sowing was delayed in both the cultivars during all the three crop seasons. The phenothermal index gradually decreased from emergence to maturity in all the three dates of sowing during all the years being the highest at emergence and lowest during maturity of the crop.

Key words: Thermal Index, Heat Use Efficiency, Growth, Groundnut

Introduction

The crop growth response is influenced largely by the microclimate environment in the crop. Microclimate in the crop varies from top of the canopy to the soil surface and affects crop development and yield. Various environmental factors influencing growth are interception of photosynthetically active radiation, air and leaf temperature, relative humidity, prevailing wind speed, CO_2 concentration and soil moisture availability. Temperature and light play a key role in influencing crop 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). 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. Knowledge of accumulated GDD can provide an estimate of harvest date as well as crop development stage (Ketring and Wheles, 1989; Bonhomme, 2000; Wurr *et al.*, 2002; Roy *et al.*, 2005).

Dynamic crop growth simulation models are being used extensively for predicting growth and yield of crops, but these being very detailed models require large input data besides being very complex to use (Whisler *et al.*, 1986). Therefore, simplified models, with less input data requirement, would be quite useful. Agroclimatic models based on thermal indices can possibly meet these objectives. Attempts have therefore, been made to predict phenology (Hundal *et al.*, 1997), leaf area index (Benbi 1994), growth rate (Singh *et al.*, 1996), yield (Tripati *et al.*, 1999)

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and growth and yield (Hundal *et al.*, 2001) of crop using thermal based indices.

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*). Initiation as well as duration of crop phenophases is an essential component of weather based dynamic crop growth and yield simulation models. Crop phenology can be used to specify the most appropriate date and time of specific development process. The duration of each phenophase determines the accumulation and partitioning of dry matter in different organs (Dalton, 1967). Wang (1960) reported that the duration of a particular stage of growth was directly related to temperature and this duration of particular species could be predicted using the sum of daily air temperature.

In the present study, an attempt is made to predict the growth and yield of groundnut (*Arachis Hypogea L.*) with agroclimatic models based on growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU). Heat use efficiency of two cultivars of groundnut was evaluated from the crops grown under three dates of sowing in three consecutive *kharif* crop growing seasons.

Material and Methods

A field experiment was conducted with two cultivars of groundnut (V_1: M-522 and V_2: M-548) sown under three dates (D_1: 1st June; D_2: 20th June and D_3: 10th July) during *kharif* 2004, 2005 and 2006 at Ludhiana (30°54′ N and 75°48′ E, 247m above mean sea level). All the recommended agronomic management practices were followed except for the treatments. The crops received recommended doses of fertilizer. The crop was raised with a row to row spacing of 30 cm and plant to plant spacing of 22.5 cm. A seed rate of 38 kg/acre (kernels) and 36 kg/acre (kernels) was kept for M-522 and M-548, respectively, as recommended for these varieties. The seed was treated with 5 g Thiram / kg of kernels before sowing.

Ludhiana has a semi-arid climate with hot summer and mild winter seasons. The normal and actual weekly weather conditions during the three crop seasons are depicted in Figs. 1-3. The mean maximum temperature during the entire growing period of the crop was 33.4, 33.0 and 34.0°C during *kharif* 2004, 2005 and 2006, respectively, as compared to a normal value of 34.3°C. The mean minimum temperature for the corresponding seasons during the crop growing period was 23.0, 23.3 and 23.8 °C against a normal value of 22.4. The data indicates that the crop received below normal maximum temperature and above normal minimum temperature during all the years. Similarly, the sunshine hours received by the crop were also less than normal, but they were close to normal during *kharif* 2004 and 2005 (8.1 and 8.2 hrs, respectively) and were much less than normal during *kharif* 2006 (7.0 hrs.) as compared to normal (8.5 hrs.).

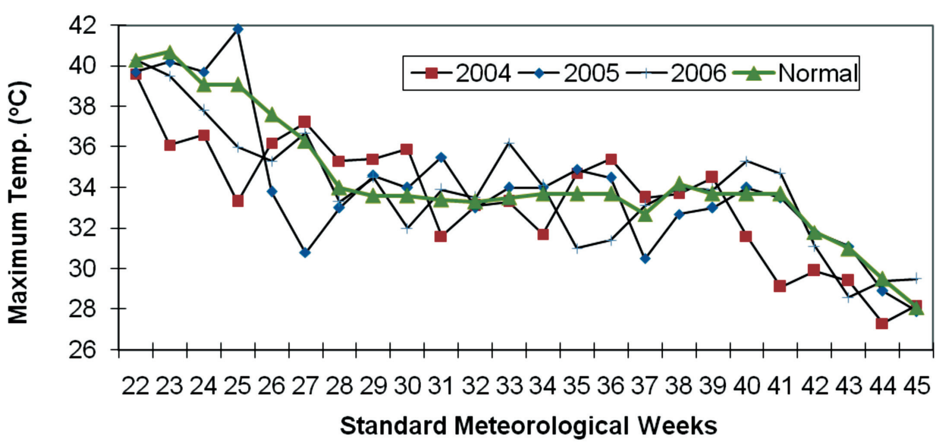

Fig. 1. Normal and actual maximum temperature during *kharif* 2004, 2005 and 2006

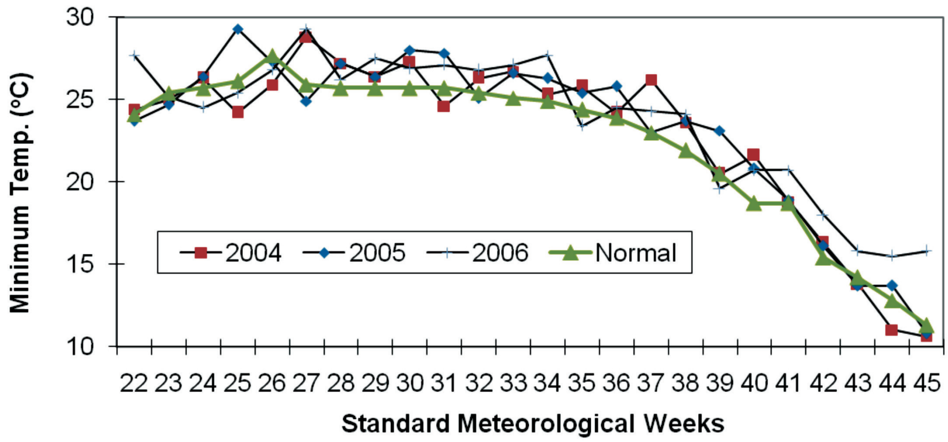

Fig. 2. Normal and actual minimum temperature during *kharif* 2004, 2005 and 2006

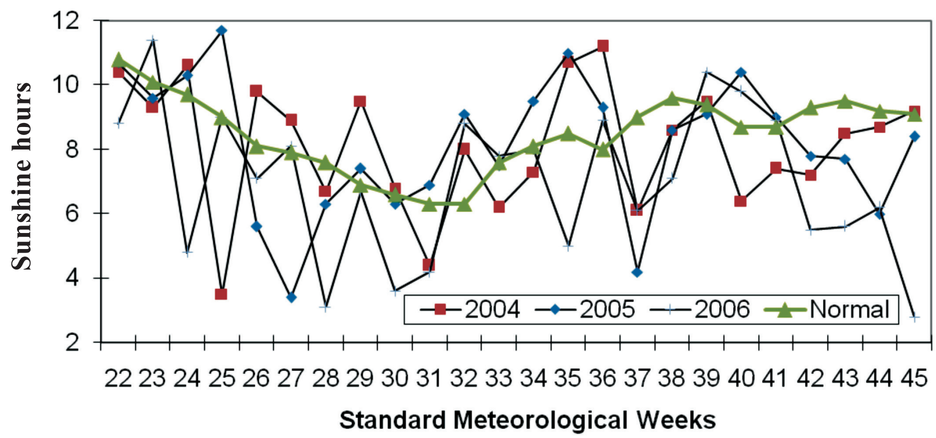

Fig. 3. Normal and actual sunshine hours during *kharif* 2004, 2005 and 2006

Plant samples were collected periodically at 15-days interval and leaf area index and dry matter accumulation were recorded. The agroclimatic indices, namely, growing degree-days, heliothermal units and photothermal units, phenothermal index and heat use efficiency were worked out. Growing degree-days (GDD) were determined as per Nuttonson (1955).

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base} \qquad \ldots(1)$$

where,

T_{max} = Daily maximum temperature (°C)

T_{min} = Daily minimum temperature (°C)

T_{base} = Base temperature of 10°C

Heliothermal units (HTU), the product of GDD and corresponding actual sunshine hours for that day were computed on daily basis as:

$$HTU = GDD \times \text{Actual Sunshine hours} \qquad \ldots(2)$$

Photothermal units (PTU), the product of GDD and corresponding day length for that day were computed on daily basis as follows:

$$PTU = GDD \times \text{Day Length} \qquad \ldots(3)$$

where, day length refers to maximum possible sunshine hours.

Growing degree-days, heliothermal units and photothermal 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:

$$\text{PTI} = \frac{\text{Degree days consumed between two phenological stages}}{\text{Number of days between two phenological stages}} \quad \ldots(4)$$

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

$$\text{Heat use efficiency (kg/ha/}^{o}\text{C day)} = \frac{\text{Seed yield / Total dry matter (kg/ha)}}{\text{Accumulated heat units (}^{o}\text{C day)}} \quad \ldots(5)$$

Results and Discussion

Growing Degree Days (GDD)

Growing degree-days required for different phenophases of groundnut for three crop seasons (*Kharif* 2004, 2005 and 2006) have been shown in Table 1. In general, earlier sown crop availed

Table 1. Accumulated growing degree days (^{o}C day) for different phenological stages of groundnut cultivars sown under three dates during three crop seasons

Phenological stage	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
***Kharif* 2004**						
Start emergence	114.2	114.2	92.3	92.3	107.0	107.0
Complete emergence	227.2	315.0	147.9	147.9	170.0	170.0
Flower initiation	547.2	663.1	569.7	590.3	615.1	631.9
Needle formation	989.6	1032.0	881.5	934.5	1001.3	1043.9
Pod initiation	1095.5	1141.1	1132.6	1173.1	1261.2	1302.9
Full pod formation	1205.4	1280.8	1232.1	1271.1	1492.5	1528.2
Seed initiation	1333.8	1393.8	1329.8	1363.2	1580.3	1616.0
Full seed formation	1922.3	1960.8	1877.0	1895.4	1785.1	1823.0
Physiological maturity	2101.3	2199.7	1983.0	1983.0	1871.7	1912.8
Harvest maturity	2488.1	2503.4	2205.3	2255.4	1951.4	1974.8
***Kharif* 2005**						
Start emergence	139.7	139.7	153.9	173.3	80.0	80.0
Complete emergence	181.8	223.2	311.5	311.5	178.9	178.9
Flower initiation	648.2	707.5	579.5	579.5	594.3	632.1
Needle formation	914.5	914.5	828.9	893.2	796.5	836.6
Pod initiation	1033.0	1033.0	996.3	996.3	937.1	999.0
Full pod formation	1202.7	1221.3	1157.4	1157.4	1395.2	1428.7
Seed initiation	1350.7	1350.7	1297.2	1297.2	1575.7	1630.4
Full seed formation	1731.9	1731.9	1678.9	1678.9	1835.3	1850.4
Physiological maturity	1931.5	1931.5	1848.1	1848.1	2011.6	2038.7
Harvest maturity	2502.0	2520.2	2370.7	2382.4	2129.2	2138.4
***Kharif* 2006**						
Start emergence	158.2	181.6	157.3	157.3	133.9	133.9
Complete emergence	278.4	278.4	281.3	281.3	218.0	218.0
Flower initiation	565.2	583.5	638.4	700.1	396.7	439.2
Needle formation	866.6	904.4	835.5	878.0	500.8	556.2
Pod initiation	980.6	1046.3	920.0	939.5	725.0	764.7
Full pod formation	1265.5	1285.9	1248.0	1288.9	1237.9	1349.8
Seed initiation	1365.6	1402.8	1351.1	1391.4	1619.3	1672.6
Full seed formation	1779.6	1856.9	1807.7	1848.7	1927.3	1938.2
Physiological maturity	2141.0	2178.6	2255.2	2287.8	2048.8	2061.1
Harvest maturity	2555.4	2574.5	2349.9	2376.9	2160.6	2199.7

D_1 – 1st June; D_2 – 20th June; D_3 – 10th July; V_1 – M-522; V_2 – M-548

Table 2. Accumulated heliothermal units (°C day hour) for different phenological stages of groundnut cultivars sown under three dates during three crop seasons

Phenological stage	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
***Kharif* 2004**						
Start emergence	1122.0	1122.0	423.4	423.4	789.9	789.9
Complete emergence	2057.3	3039.6	805.0	805.0	1254.3	1254.3
Flower initiation	4424.0	5812.3	4432.1	4648.4	4431.6	4524.0
Needle formation	8267.4	8654.4	6935.3	7078.1	7387.4	7853.9
Pod initiation	9356.3	9800.0	8617.4	9027.1	10144.0	10461.4
Full pod formation	10149.8	10554.3	9236.3	9447.0	11805.4	12183.8
Seed initiation	10697.1	11138.8	9996.4	10098.5	12708.1	13003.2
Full seed formation	15444.3	15876.0	14869.1	15034.7	14244.0	14482.5
Physiological maturity	17311.3	17888.5	15923.2	15923.2	14893.2	15210.7
Harvest maturity	20260.0	20260.0	17638.1	17937.6	15433.0	15653.6
***Kharif* 2005**						
Start emergence	1546.2	1546.2	1688.4	1758.2	442.9	442.9
Complete emergence	1862.0	2340.3	2426.0	2426.0	1097.2	1097.2
Flower initiation	6666.5	6946.5	3975.0	3975.0	3873.2	4226.4
Needle formation	7996.7	7996.7	5684.0	6031.5	5634.8	6040.1
Pod initiation	8744.9	8744.9	6781.0	6781.0	7015.3	7617.1
Full pod formation	9986.3	10032.8	8450.2	8450.2	10899.1	11179.4
Seed initiation	10878.2	10878.2	9464.8	9464.8	12504.3	13061.6
Full seed formation	14088.1	14088.1	13303.7	13303.7	15090.3	15626.7
Physiological maturity	16128.9	16128.9	14203.8	14203.8	16488.7	16679.2
Harvest maturity	20893.0	21088.3	19044.8	19140.8	17250.7	17329.3
***Kharif* 2006**						
Start emergence	1551.4	1820.5	1558.2	1558.2	686.4	686.4
Complete emergence	2598.8	2598.8	2300.6	2300.6	1157.1	1157.1
Flower initiation	4870.7	4932.9	4529.5	5131.1	2166.4	2449.4
Needle formation	6820.7	6973.6	5630.9	5913.9	2755.7	2968.0
Pod initiation	7463.4	7842.0	6210.4	6220.1	4454.5	4743.8
Full pod formation	9201.9	9226.4	8653.6	8912.8	8427.0	9250.3
Seed initiation	9563.6	9745.0	9311.6	9653.2	11601.1	12126.9
Full seed formation	12768.7	13497.2	12839.6	13120.3	14258.0	14268.9
Physiological maturity	15672.4	15852.9	16888.7	17188.2	14893.0	14988.1
Harvest maturity	19250.6	19426.3	17722.5	17733.4	15505.8	15565.9

D_1 – 1st June; D_2 – 20th June; D_3 – 10th July; V_1 – M-522; V_2 – M-548

higher degree-days during all the seasons and with delay of each day in sowing, degree-day consumption decreased. Both the cultivars consumed 2488.1 to 2574.5 °Cd, 2205.3 to 2382.4 °Cd and 1951.4 to 2199.7 °Cd to reach harvest maturity for 1st June, 20th June and 10th July sown crop, respectively during the three crop growth seasons. Among the cultivars, V_2 i.e. M-548 consumed slightly more heat units to reach maturity during all the crop growth seasons. For different sowing dates and seasons, AGDD to reach harvest maturity ranged between 1951.4 to 2555.4 °Cd and 1974.8 to 2574.5 °Cd for M-522 and M-548, respectively.

Heliothermal Units (HTU)

Heliothermal units (HTU) required for different phenophases of groundnut for three crop seasons have been shown in Table 2. Earlier sown crop availed higher heliothermal units during all the seasons and with delay in sowing, HTU consumption decreased. Both the cultivars consumed 19250.6 to 21088.3 °C d hr, 17638.1 to 19140.8 °C d hr and 15433.0 to 17329.3 °C d hr to reach harvest maturity by 1st June, 20th June and 10th July sown crops, respectively during the three crop growth seasons. Between the cultivars, M-548 required comparatively more heliothermal units to complete different phenological stages during all the crop growing seasons. For different sowing dates and seasons, AHTU to reach harvest maturity ranged between 15433.0 to 20893.0 °C d hr and 15565.9 to 21088.3 C d hr for M-522 and M-548, respectively.

Photothermal Units (PTU)

The APTU required to attain different phenological stages in groundnut cultivars have been shown in Table 3. It was observed that

Table 3. Accumulated photothermal units (°C day hour) for different phenological stages of groundnut cultivars sown under three dates during three crop season

Phenological stage	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
			***Kharif* 2004**			
Start emergence	1603.0	1603.0	1306.1	1306.1	1498.0	1498.0
Complete emergence	3195.6	4438.3	2093.2	2093.2	2376.1	2376.1
Flower initiation	7725.0	9362.5	8023.4	8310.4	8477.1	8702.8
Needle formation	13942.2	14532.0	12328.0	13049.1	13564.2	14112.3
Pod initiation	15412.1	16041.8	15711.5	16257.5	16863.0	17383.4
Full pod formation	16927.1	17959.9	17029.0	17541.3	19711.7	20143.2
Seed initiation	18681.0	19492.5	18308.7	18743.3	20768.6	21194.9
Full seed formation	26430.1	26919.7	25211.6	25435.6	23184.3	23622.5
Physiological maturity	28685.6	29904.6	26492.7	26492.7	24181.5	24648.2
Harvest maturity	33385.2	33566.0	29118.6	29697.3	25082.5	25343.7
			***Kharif* 2005**			
Start emergence	1960.8	1960.8	2179.5	2454.0	119.3	1119.3
Complete emergence	2553.3	3137.9	4407.5	4407.5	2498.0	2498.0
Flower initiation	9192.9	9991.5	8162.9	8162.9	8191.4	8700.1
Needle formation	12903.1	12903.1	11608.0	12486.6	10888.6	11416.5
Pod initiation	14555.0	14555.0	13883.5	13883.5	12730.3	13532.9
Full pod formation	16902.8	17158.5	16040.6	16040.6	18529.2	18939.6
Seed initiation	18927.0	18927.0	17883.3	17883.3	20717.6	21369.4
Full seed formation	24013.7	24013.7	22773.2	22773.2	23767.9	23942.5
Physiological maturity	26598.3	26598.3	24866.2	24866.2	25766.9	26068.0
Harvest maturity	33634.4	33850.6	31018.3	31150.0	27059.4	27159.6
			***Kharif* 2006**			
Start emergence	2221.9	2551.9	2227.4	2227.4	1872.3	1872.3
Complete emergence	3919.2	3919.2	3979.7	3979.7	3042.0	3042.0
Flower initiation	7979.7	8238.7	8983.1	9838.2	5505.8	6086.6
Needle formation	12228.0	12757.6	11702.3	12283.1	6923.9	7673.2
Pod initiation	13821.1	14735.5	12855.6	13120.4	9933.7	10459.1
Full pod formation	17757.0	18035.4	17243.6	17780.9	16555.3	17942.4
Seed initiation	19119.4	19622.1	18594.1	19119.0	21200.0	21829.8
Full seed formation	24615.3	25615.8	24375.0	24877.3	24769.5	24892.5
Physiological maturity	29207.0	29671.9	29700.3	30075.0	26125.1	26261.2
Harvest maturity	34202.3	34425.4	30783.8	31089.0	27342.8	27763.0

D_1 – 1st June; D_2 – 20th June; D_3 – 10th July; V_1 – M-522; V_2 – M-548

Table 4. Phenothermal index (°C days day^{-1}) for different phenological stages of groundnut cultivars sown under three dates during three crop seasons

Phenological stage	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
***Kharif* 2004**						
Start emergence	28.6	28.6	23.1	23.1	26.8	26.8
Complete emergence	18.8	20.1	18.5	18.5	21.0	21.0
Flower initiation	16.0	20.5	22.2	22.1	20.2	20.1
Needle formation	22.1	21.7	20.8	20.2	19.3	19.6
Pod initiation	21.2	21.8	19.3	19.9	20.0	19.9
Full pod formation	22.0	20.0	19.9	19.5	19.3	18.8
Seed initiation	18.3	18.8	19.5	18.4	17.6	17.6
Full seed formation	19.6	19.6	19.5	19.7	17.1	15.9
Physiological maturity	19.9	19.9	17.7	17.5	12.3	12.8
Harvest maturity	17.6	19.0	17.1	16.0	13.3	12.4
***Kharif* 2005**						
Start emergence	27.8	27.8	30.8	28.9	26.7	26.7
Complete emergence	21.1	20.9	19.7	19.7	19.8	19.8
Flower initiation	23.3	23.1	19.1	19.1	20.8	20.6
Needle formation	19.0	18.8	20.8	20.9	20.2	20.5
Pod initiation	19.8	19.8	20.9	20.6	20.1	20.3
Full pod formation	21.2	20.9	20.1	20.1	19.1	18.7
Seed initiation	21.1	21.6	20.0	20.0	18.1	18.3
Full seed formation	20.1	20.1	20.1	20.1	17.3	16.9
Physiological maturity	20.0	20.0	16.9	16.9	13.6	13.5
Harvest maturity	17.8	19.0	16.3	17.2	11.8	11.1
***Kharif* 2006**						
Start emergence	26.4	25.9	26.2	26.2	22.3	22.3
Complete emergence	24.0	24.2	20.7	20.7	21.0	21.0
Flower initiation	20.5	20.3	21.0	20.9	19.9	20.1
Needle formation	21.5	21.4	19.7	19.8	20.8	19.5
Pod initiation	19.0	20.3	21.1	20.5	20.4	20.9
Full pod formation	20.4	20.0	20.5	20.6	19.0	18.9
Seed initiation	20.0	19.5	20.6	20.5	18.2	17.9
Full seed formation	20.7	20.6	18.3	18.3	17.1	16.6
Physiological maturity	18.1	17.9	17.9	17.6	12.2	12.3
Harvest maturity	18.1	18.0	15.8	14.9	12.4	12.6

D_1 – 1st June; D_2 – 20th June; D_3 – 10th July; V_1 – M-522; V_2 – M-548

sowing dates had marked influence on photothermal accumulation. Earlier sown crop availed higher photothermal units during all the seasons and with delay in sowing, PTU consumption or availability during the left over crop season decreased. Both the cultivars consumed 33385.2 to 34425.4 °C d hr, 29118.6 to 31150.0 °C d hr and 25082.5 to 27763.0 °C d hr to reach harvest maturity by 1st June, 20th June and 10th July sown crops, respectively during the three crop growth seasons. Among the cultivars, M-548 required more PTU to complete different phenological stages during both the crop growing seasons. For different sowing dates and seasons, APTU to reach harvest maturity ranged between 25082.5 to 34202.3 °Cd and 25343.7 to 34425.4 °Cd for M-5222 and M-548, respectively.

Phenothermal Index (PTI)

The phenothermal index for consecutive phenophases was also computed and is presented in Table 4. The phenothermal index is expressed

Table 5. Heat use efficiency (g m^{-2} $^{o}C^{-1}$ day^{-1}) for different phenological stages of groundnut cultivars sown under three dates during three crop seasons

Phenological stage	D_1		D_2		D_3	
	V_1	V_2	V_1	V_2	V_1	V_2
			***Kharif* 2004**			
Flower initiation	0.10	0.08	0.04	0.05	0.03	0.06
Needle formation	0.11	0.08	0.12	0.13	0.05	0.06
Full pod formation	0.16	0.13	0.15	0.21	0.12	0.13
Full seed formation	0.30	0.28	0.22	0.25	0.25	0.25
Physiological maturity	0.43	0.37	0.34	0.36	0.28	0.26
			***Kharif* 2005**			
Flower initiation	0.06	0.08	0.05	0.06	0.03	0.05
Needle formation	0.14	0.11	0.13	0.13	0.09	0.10
Full pod formation	0.21	0.19	0.22	0.24	0.10	0.15
Full seed formation	0.45	0.42	0.32	0.33	0.24	0.24
Physiological maturity	0.50	0.44	0.43	0.40	0.25	0.24
			***Kharif* 2006**			
Flower initiation	0.14	0.13	0.07	0.07	0.14	0.13
Needle formation	0.31	0.31	0.13	0.13	0.33	0.25
Full pod formation	0.29	0.29	0.22	0.14	0.18	0.13
Full seed formation	0.60	0.53	0.48	0.42	0.25	0.25
Physiological maturity	0.55	0.52	0.45	0.36	0.29	0.28

D_1 – 1st June; D_2 – 20th June; D_3 – 10th July; V_1 – M-522; V_2 – M-548

as degree-days per growth day (Sastry and Chakravarty, 1982). It was observed that the phenothermal index gradually decreased from emergence to physiological maturity in all three dates of sowing during all the years, being highest at emergence and lowest during grain filling and maturity stages indicating a decrease in daily heat consumption towards maturity. Among the dates of sowing, the value of phenothermal index was found to be highest for 1st June and lowest for the 10th July sown crop for both the cultivars during all the three years of crop seasons.

Heat Use Efficiency (HUE)

Heat use efficiency was also computed for different phenological stages of groundnut and is presented in Table 5. The heat use efficiency went on increasing from vegetative growth to grain filling and physiological maturity of the crop. Among the dates of sowing, heat use efficiency was found to be higher for earlier sown crop and it decreased with delay in sowing for both the cultivars during all the three seasons.

Conclusions

The present study indicates that the application of agroclimatic indices provides a scientific basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of a standing crop. These provide very clear picture of the 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.

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