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ENERGY INDICES FOR PEARLMILLET [*PENNISETUM GLAUCUM* (L.) R BR.] CROP

1. Periodic occurrence of phenophases is very sensitive to weather conditions particularly to temperature and day length. Growing degree days and photothermal units have been widely used in relation to phonological events and maturity dates in crops (Bishnoi *et al.*, 1986). With the development of day neutral varieties, the rates of crop development can be considered as functions of the energy recipients and temperature conditions prevailing in a season. Choi *et al.* (1990) observed that the duration for heading decreased with late sown pearl millet crop but growing degree day remained the same (697° C days). Panicle initiation in pearl millet was found to be strongly influenced by day length (Begg and Burt, 1971). Crauford and Bidinger (1988a) noticed that the duration of growth phases from panicle initiation to the flowering and from flowering to maturity was 320 and 390° C days, respectively. The objective of the study is to compare the different energy summation indices during different phenophases.

2. Field experiments were conducted during 1992 and 1993 *kharif* seasons on pearl millet crop on sandy loam soils of research farm of Indian Agriculture Research Institute, New Delhi. Three pearl millet varieties, Pusa-23, HHB-60 and HHB-67 were sown on 21st July 1992 and 16th July 1993 in east-west and north-south row directions. The experiment was replicated thrice in a randomized block design. All agronomic practices were applied as per recommended package of practices for the crop. Dates of growth stages as defined by Maiti and Bidinger, 1981: seedling emergence to panicle initiation, panicle initiation to anthesis and anthesis to maturity for different varieties were noted. The meteorological data were recorded at agro meteorological observatory situated on north side in adjacent field. The following indices were computed with respect to panicle initiation, anthesis and maturity.

TABLE 1

Summation, standard deviation and coefficient of variation of energy indices for pearl millet varieties: Pusa 23, HHB 60 and HHB 67

Energy	Pusa 23			HHB 60			HHB 67		
Indices	Mean	S.D.	C.V. (%)	Mean	S.D.	C.V. (%)	Mean	S.D.	C.V. (%)
Seedling emergence to panicle initiation									
GDD	477.2	60.2	12.6	486.9	50.0	10.2	401.6	44.7	11.1
PTU	6549.4	625.6	9.6	6936.7	740.1	10.7	5557.3	418.0	7.5
HTU	2585.5	325.8	12.6	2677.0	354.5	13.2	2285.5	251.0	11.1
PET	135.0	8.1	6.0	141.8	9.9	7.0	114.5	8.5	7.4
PAR	190.1	8.6	4.5	197.9	15.6	7.9	160.0	10.5	6.6
TIR	245.0	13.0	5.3	2151.5	6.5	2.5	289.5	13.5	6.4
Panicle initiation to anthesis									
GDD	314.7	12.9	4.1	314.9	12.7	4.0	267.8	7.6	2.8
PTU	4101.3	98.0	2.4	4178.0	100.0	2.4	3539.5	101.0	2.9
HTU	2313.5	410.5	17.7	2328.5	425.5	18.2	1912.5	446.5	23.3
PET	71.6	6.3	8.7	78.4	7.9	10.0	67.6	4.5	6.6
PAR	110.2	3.0	2.7	115.0	7.0	6.1	102.0	13.0	12.7
TIR	176.0	14.0	8.0	177.0	14.5	8.2	165.0	3.0	1.8
Anthesis to maturity									
GDD	504.1	38.1	7.6	541.6	17.2	3.2	448.4	10.9	2.4
PTU	6242.1	496.8	8.0	6447.6	514.0	8.0	5094.6	444.0	8.7
HTU	3384.0	351.0	10.4	3669.0	219.0	14.1	2624.0	205.0	7.8
PET	141.3	2.1	1.5	136.6	4.0	2.9	119.3	4.6	3.9
PAR	213.0	10.0	4.7	228.0	8.0	3.5	178.0	6.0	3.4
TIR	255.0	4.5	1.7	273.0	5.5	2.0	211.0	8.0	3.8
Seedling emergence to maturity									
GDD	1296.0	111.4	8.5	1343.4	79.9	5.9	1117.8	156.6	14.0
PTU	16892.8	1120.4	7.2	17562.3	1354.1	7.7	14191.4	963.0	6.8
HTU	8283.0	1087.3	13.2	8674.5	1290.0	14.9	6822.0	902.5	13.2
PET	347.9	16.5	4.7	356.8	21.8	6.1	301.4	17.6	5.8
PAR	513.3	24.9	4.9	540.9	30.6	5.7	440.0	30.0	6.7
TIR	676.0	32.0	4.6	701.5	26.5	3.7	585.5	24.5	4.1

Where,

GDD = Growing degree days (°C days)
PTU = Photothermal units (°C days hours)
HTU = Heliothermal units (°C days hours)
PET = Potential evapotranspiration (mm)
PAR = Photosynthetically active radiation (MJ m^{-2})
TIR = Thermal interception rate (MJ °C/plant)
SD = Standard deviation
CV = Coefficient of variation

2.1. *Growing Degree Days (GDD)* - Growing degree day between two phenological stages, a and b is defined as :

$$\text{GDD}(^{\circ}\text{C day}) = \sum_{a}^{b}\left[\frac{(T_{\max} + T_{\min})}{2} - T_b\right]$$

Where, $T_{\max}$ and $T_{\min}$ represent the daily maximum and minimum temperatures (°C) and T_b is the base temperature taken to be 10° C (Ong, 1983a).

2.2. *Photothermal Unit (PTU)* - The PTU is the product of growing degree day and day length. The sum of

PTU for each growth cycle was worked out by using the formula:

$$\text{PTU}(^{\circ}\text{C day hour}) = \sum_{a}^{b}[\text{GDD} \times \text{D}]$$

Where, D = day length (hour)

2.3. *Heliothermal Unit (HTU)* - The HTU is the product of growing degree days and daily hours of bright sun shine. The sum of HTU for each phenophase was worked using the formula:

$$\text{HTU}(^{\circ}\text{C day hour}) = \sum_{a}^{b}[\text{GDD} \times \text{S}]$$

Where, S = Bright sunshine hours

2.4. *Thermal Interception Rate (TIR)* - Thermal interception rate was calculated for each growth cycle as per procedure adopted by Ong and Squire (1984) using the formula :

$$\text{TIR}(\text{MJ}\,^{\circ}\text{C plant}^{-1}) = \sum_{a}^{b}[S_i / n(\text{GDD})]$$

Where,

S_i = Photosynthetically active radiation incident on the crop canopy MJ m^{-2} day^{-1}

n = Number of plants m^{-2}

2.5. *Photosynthetically Active Radiation (PAR)* - The incoming photosynthetically active radiation was then calculated by multiplying solar radiation by 0.45 (Rosenthal and Gerik, 1991). Daily PAR absorbed by the canopy was then determined from the calculated extinction coefficient, incoming and reflected PAR and interpolated leaf area index estimated between radiation measurements.

2.6. *Potential Evapotranspiration (PET)* - Potential evapotranspiration has been calculated over weekly periods using Penman's equation (1948). The values of the six indices mentioned above were accumulated over the seedling emergence to panicle initiation, panicle initiation to anthesis and anthesis to maturity and seedling emergence to maturity period of crop growth. Coefficients of variation and standard deviation of the accumulated values were computed by pooling the data across the row directions and two *kharif* seasons.

3. The data on summation, standard deviation and coefficient of variation of six different energy indices for Pusa-23, HHB-60 and HHB-67 pearl millet varieties for growth stages: seedling emergence to panicle initiation, panicle initiation to anthesis, anthesis to maturity and whole growth period are presented in Table 1.

3.1. *Seedling emergence to panicle initiation period* - Among the six different indices computed, accumulated thermal interception rate (TIR) yielded the lowest coefficient of variation (C.V.) with 5.3, 2.5 and 6.4 for three pearl millet cultivars Pusa-23, HHB-60 and HHB-67, respectively. The thermal indices (GDD, PTU and HTU) gave relatively higher coefficient of variation for this growth stage. However, for the semi arid, monsoonal climate of Delhi region, C.V. was highest in the case of HTU ranging from 11.1 to 13.2% during this growth period for three varieties of pearl millet. Among all the energy indices TIR proved to be better for this growth stage.

3.2. *Panicle initiation to anthesis* - When the different indices were accumulated over the Panicle initiation to anthesis stage, again HTU showed the highest variability. For the three varieties, C.V. ranged between 17.7 and 23.7%. The PTU showed lowest coefficient of variation. The GDD and TIR showed relatively higher variability as compared to PTU for all the three varieties for this growth period. Sastry and Chakarvarty (1982) reported that PAR showed minimum variability when accumulated from sowing to anthesis in wheat.

3.3. *Anthesis to maturity* - During this period TIR and PET showed lowest variability, ranging from 1.5 to 3.8% for all three varieties. GDD and PTU showed relatively higher C.V. as compared to other indices. HTU again yielded highest C.V. ranging from 7.8 to 14.1% during this growth stage.

3.4. *Seedling emergence to maturity period* - When the different energy units were accumulated over the entire crop period, HTU showed the highest variability. For the three cultivars, coefficient of variation ranged from 13.2 to 14.9%, like the highest variability observed in other growth stages. The lowest coefficient of variation was observed in case of TIR over the whole growth season. The radiation based indices showed relatively lower variability as compared to temperature based indices.

The thermal indices such as growing degree day, photothermal unit, and heliothermal unit were higher than

that of other growth stages during anthesis to maturity in all the three cultivars. This might be due to more days were taken by the pearl millet cultivars for completion of this growth stage. The cumulative value of the potential evapotranspiration of pearl millet cultivars was highest during anthesis to maturity and it was lowest during panicle initiation to anthesis. The pearl millet cultivars absorbed maximum photosynthetically active radiation during reproductive phase *i.e*., anthesis to maturity fallowed by seedling emergence to panicle initiation and panicle initiation to anthesis. The pearl millet cultivars showed higher thermal interception rate during anthesis to maturity as compared to other growth cycles. All the three pearl millet cultivars used maximum energy indices during anthesis to maturity. It means that this growth phase is most important in respect of use of energy resources.

Among the pearl millet cultivars, all the agro meteorological indices were highest in HHB 60 and were lowest in HHB 67, during all the growth cycles. This might be explained by the fact that HHB 67 completed all the growth cycles in less period and matured earlier about 12 days in comparison to HHB 60.

TIR, PAR, PET and PTU gave consistent values for all the three varieties and depending on the data availability, any of the four indices could have been used. However, TIR proved to be better predictor due to minimum coefficient of variation observed at all the growth stages and for whole growth period. HTU showed highest year to year variability. This could be probably due to erratic distribution of monsoonal rainfall.

4. Based on the above results these conclusions are drawn:

(*i*) The pearl millet cultivar HHB-60 used maximum and HHB 67 used minimum energy indices during crop growth period.

(*ii*) The pearl millet utilized maximum energy indices during anthesis to maturity stage. It means this phase is most important in respect of use of energy resources.

(*iii*) TIR, PAR, PET and PTU gave consistant values for all the three cultivars.

(*iv*) These results obtained could not be compared with those for other semi arid regions as the results were location and crop specific.

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