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Response of Pearl Millet to Weather Health Indices under Different Spacings and Sowing Windows in Coastal Agro- Ecosystem of Andhra Pradesh, India

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A field experiment was conducted during k*harif,* 2018 at Agricultural College Farm, Bapatla to study the phenology and various weather health indices of pearlmillet grown under different spacings and dates of sowing. The crop sown on 2nd fortnight of July accumulated maximum growing degree days, photo thermal units, heat use efficiency, helio thermal use efficiency and photo thermal use efficiency whereas the highest helio thermal units were recorded under 2nd fortnight of August sowing to attain different phenological stages till maturity. Among different spacings, 45 × 15 cm treatment accumulated highest growing degree days, helio thermal units and photo thermal units, heat use efficiency, helio thermal use efficiency and photo thermal use efficiency as compared to other.

Introduction

Pearl millet (*Pennisetum glaucum*), which belongs to the family poaceae, is one of the most important among the major millets which are generally referred as nutritious coarse grain cereals. It is one of the oldest food crops known to man and possibly first cereal grain to be used for domestic purposes (Railey, 2006). It is grown mostly in marginal areas under where major cereals fail to give substantial yields.

Among the cereals of the world, its rank is sixth which is next to rice, wheat, corn, barley, and sorghum. In Andhra Pradesh, area under pearl millet is 0.042 million ha and its production is 0.072 million tonnes with an average productivity of 1718 kg ha^{-1} (www.Indiastat.com, 2016-17).

Temperature is an important environmental factor influencing the growth and development of crop plants. It influences the crop phenology and yield of crop. The optimum range of air temperature for vegetative growth of pearl millet is 33 to 34^0c. Soil temperatures should be at least 18°C or warmer before pearl millet is sown and it germinates well at soil temperatures of 21 to 31°C. Grain production in pearl millet is known to be adversely affected when flowering and grain setting coincide with rains and low temperatures, respectively. Generally, low yields of pearlmillet are noticed under late sown situations coupled with aberrant monsoon behavior of its early cessation.

Sowing window and weather are the most important non - monetary inputs which influence crop yield even in photo and thermo- insensitive crops. A decline in both temperature and length of photo period over successive sowing dates from July to September had a drastic effect on phenology and yield potentials of the pearl millet (Mass *et al*., 2007). Late sowing beyond October may result in poor germination and plant stand due to low soil temperatures.

Besides weather factors *viz.*, temperature and rainfall, inadequate plant population also attributes to the lower yields of pearl millet. As the yield of a crop depends on its stand establishment and final plant density which in turn depends on the germination percentage and the survival rate. Yield can be increased by optimizing the plant population. Hence, a field experiment was carried to study the effect of different spacings and sowing dates on the phenology, heat units and heat efficiencies required for pearlmillet.

Materials and Methods

The present research was carried on sandy loamy soils of Agricultural College Farm, Bapatla, during *kharif*, 2018. The experimental soil was sandy loam having pH 6.80 and organic carbon of 0.21 per cent. The available nitrogen, phosphorus and potassium contents were 240, 12.8, and 188.1 kg ha^{-1}, respectively. The experiment was conducted in factorial RBD with three replications.

Twelve treatment combinations were formed considering different spacings i.e., 45 × 15 cm (S_1), 45 × 30 cm (S_2), 60 × 15 cm (S_3) and 60 × 30 cm (S_4) and sowing windows i.e., 2^{nd} fortnight of July (D_1), 1^{st} fortnight of August (D_2) and 2^{nd} fortnight of August (D_3).

During the crop growth period, the weekly mean maximum temperature ranged from 29.9^o C to 37.6^o C with an average of 33.3^oC and weekly mean minimum temperature ranged from 18.77^oC to 26.80 ^{o}C with an average of 24.2 ^{o} C. The weekly mean relative humidity (8.30 hrs.) ranged from 65.8 to 86.7% with an average of 80.3% and weekly mean relative humidity (17.30 hrs.) ranged from 47.1 to 83.7% with an average of 71.5%. A total rainfall of 387.4 mm was received in 25 rainy days during the crop growth period. The weekly mean bright sunshine hours ranged from 0.78 to 6.89 hours day^{-1} with an average of 5 hours day^{-1}. The weekly mean day length ranged from 11.26 to 12.89 hours day^{-1}. All the data recorded in the study were subjected to statistical analysis using ANOVA for factorial RBD suggested by Panse and Sukkhatme (1985).

The growth stages (phenophases) of pearl millet were divided as follows to have a better understanding of the influence of weather health indices on pearlmillet.

Phase 1: GS1 – Sowing to panicle differentiation
Phase 2: GS2 – Panicle initiation to flowering
Phase 3: GS3 - Flowering to grain maturity
Growing degree days (GDD)

A degree day or a heat unit is the departure from the mean daily temperature above the threshold temperature of the crop. Growing degree days were computed from date of sowing to harvesting of the crop to give accumulated growing degree days. This was expressed as ^{0}C day. The GDD were calculated by using the following equation (Iwata, 1984).

$$\text{Growing Degree Days (GDD)} = \frac{T_{max} + T_{min}}{2} - T_b$$

Where,
T_{max} = Maximum temperature
T_{min} = Minimum temperature
T_b = Base temperature

Helio thermal units (HTU)

Heliothermal unit (HTU) was measured daily with the help of Campbell-stokes sunshine recorder. This was expressed as ^{0}C day hour. This was calculated by using the formula given by Rajput (1980).

$$\text{Helio Thermal Units (HTU)} = \text{GDD} \times \text{Bright Sunshine Hours}$$

Photo thermal units (PTU)

Nuttonson (1956) made an attempt to improve GDD concept applying day length factor and used Photothermal unit (PTU) concept in climatic analogue studies. This was expressed as ^{0}C day hour and calculated by using the formula

$$\text{Photo Thermal Units (PTU)} = \text{GDD} \times \text{Day length}$$

Heat use efficiency (HUE)

Heat use efficiency defined as yield per day ^{0}C on growing day concept or per unit of day ^{0}C hours on Helio thermal units indicating the efficiency with the available heat utilized for grain yields. This was expressed as kg ha^{-1} ^{0}C^{-1} day^{-1} and was calculated by using the following formula (Haider *et al.*, 2003).

$$\text{Heat Use Efficiency (HUE)} = \frac{\text{Total drymatter or seed yield (kg ha}^{-1})}{\text{Accumuated heat units (°C day)}}$$

Helio thermal use efficiency (HtUE)

It is defined as total drymatter yield per hours ^{0}C on growing day concept or per unit of ^{0}C day hours on helio thermal units indicating the efficiency with the available sunshine hours utilized for drymatter yields. This was expressed as kg ha^{-1} ^{0}C^{-1} day^{-1} hour and was calculated using the formula (Rajput, 1980)

$$\text{HTUE} = \frac{\text{Total drymatter or seed yield (kg ha}^{-1})}{\text{Helio thermal units (HTU)}}$$

Photo thermal use efficiency (PtUE)

It is defined as total drymatter yield per hour ^{0}C on growing day concept or per unit of ^{0}C day hours on Photo thermal units which indicate the efficiency with the available day length utilized for drymatter yields. This was expressed as kg ha^{-1} ^{0}C^{-1} day^{-1} hour. This was calculated using the formula as suggested by Rajput (1980).

$$\text{PtUE} = \frac{\text{Total drymatter or Seed yield (kg ha}^{-1})}{\text{Photo Thermal Units (PTU)}}$$

Results and Discussion

Pearlmillet phenology

The number of days taken to attain different phenophases from sowing to maturity ranged from 30 to 90 days for different spacings and dates of sowing. Among dates of sowing, 2nd fortnight of July (D_1) took the maximum number of days of 90 to maturity (Table 1).

Among the spacings, the mean maximum days to attain all the phases were recorded with 45 × 15 cm (S_1) followed by 60 × 15cm (S_3) and 45 × 30 cm (S_2) and the least were recorded with 60 × 30 cm (S_4).

Growing degree days (GDD)

For different spacings and dates of sowing, the accumulated GDD from sowing to maturity during different phenophases ranged from 419 to 745. Among the sowing dates, D_1 recorded the highest GDD (1903) followed by D_2 (1888) and least were accumulated with D_3 treatment (Table 1).

This might be due to longer crop duration with early sowing in July along with optimum temperatures and bright sunshine hours during vegetative and reproductive stage that favoured crop growth for accumulating higher GDD and thereby yield. Similar results were also reported by Bhuva and Detroja (2018) and Wankhede *et al.,* (2018).

Helio thermal units (HTU)

The accumulated HTU from sowing to maturity during different phenophases for different spacings and dates of sowing ranged from 1244 to 4505.

Among the four spacings and three dates of sowing, the accumulated HTU of spacing 45 × 15 cm at 2^{nd} FN of August sowing recorded highest (10320). This might be due to higher GDD accumulation during reproductive stage and also by the combined effect of higher bright sunshine hours and optimum temperatures during crop duration. Similar results were also reported by Padma and Subbaiah (2016) and Revathi and Sree Rekha (2016).

Photo thermal units (PTU)

The photo thermal units for different phenophases revealed that the accumulated photo thermal units from vegetative to maturity ranged from 4825 to 8724 ^{o}C day hr. for different spacings at different dates of sowing. The total accumulated PTU were highest during 2^{nd} FN of July (D_1) sowing (23428) compared to other sowing dates (Table 1).

This might be due to the crop duration, higher bright sunshine hours, longer photoperiods, optimum temperatures during crop growth period and higher GDD and HTU during reproductive stage. The results are in agreement with Girijesh *et al.,* (2011) and Patidar (2013).

Thermal use efficiencies of pearl millet under different dates of sowing and spacings

Pearlmillet sown on 2^{nd} fortnight of July recorded highest HUE, HtUE and PtUE with total drymatter accumulation and grain yield at different spacings. Maximum HUE of 5.45 kg ha^{-1}°C^{-1} day^{-1} for drymatter accumulation of 10373 kg ha^{-1} and 1.52 kg ha^{-1} °C^{-1} day^{-1} for grain yield of 2875 kg ha^{-1} was recorded with 45 × 15 cm (S_1) when sown on 2^{nd} fortnight of July (D_1) (Table 2).

The highest helio-thermal use efficiency of 1.27 kg ha^{-1} °C^{-1} day^{-1} hour for drymatter accumulation of 10373 kg ha^{-1} and 0.35 kg ha^{-1} °C^{-1} day^{-1} hour for grain yield of 2875 kg ha^{-1} were recorded with 45 × 15 cm (S_1) when pearl millet was sown on 2^{nd} fortnight of July (D_1).

With regard to photo-thermal use efficiency, pearl millet with spacing 45 × 15 cm (S_1) when sown on 2^{nd} fortnight of July (D_1) recorded the maximum PtUE of 0.44 kg ha^{-1} °C^{-1} day^{-1} hour for drymatter accumulation and 0.12 kg ha^{-1} °C^{-1} day^{-1} hour for grain yield and was followed by S_3, S_2 and S_4 spacings (Table 2).

Table.1 Growing degree days (^{0}C) (GDD), Helio thermal units (^{0}C day hours) (HTU) and Photo thermal units (^{0}C day hours) (PTU) required for attainment of phenophases for pearlmillet at different spacings and dates of sowing

Growth Stages	2nd fortnight of July				1st fortnight of August				2nd fortnight of August			
	Phenology	**GDD**	**HTU**	**PTU**	**Phenology**	**GDD**	**HTU**	**PTU**	**phenology**	**GDD**	**HTU**	**PTU**
S_1 (45 × 15 cm)												
GS_1	35	688	1356	8724	33	669	2605	8326	31	624	3117	7884
GS_2	68	691	3977	8538	66	726	4102	8685	63	745	4505	8822
GS_3	90	524	2773	6166	87	493	3186	5713	83	444	2698	5081
Total		1903	8106	23428		1888	9893	22724		1813	10320	21787
S_2 (45 × 30 cm)												
GS_1	33	647	1244	8210	32	649	2476	8084	30	604	2962	7652
GS_2	66	667	3440	7652	63	675	4230	8090	60	605	4239	8299
GS_3	88	528	3108	6244	85	474	2663	5774	81	454	2686	4825
Total		1842	7792	22106		1798	9369	21948		1663	9887	20776
S_3 (60 × 15 cm)												
GS_1	34	667	1356	8643	32	649	2476	8084	31	624	3117	7884
GS_2	67	672	3581	7946	64	700	4230	8387	62	726	4427	8563
GS_3	89	527	2995	6219	86	494	2843	5735	82	423	2588	5090
Total		1866	7932	22628		1843	9549	22206		1773	10132	21537
S_4 (60 × 30 cm)												
GS_1	33	647	1244	8210	31	629	2304	7484	30	605	2962	7652
GS_2	65	643	3235	7353	62	619	3884	7435	61	681	4025	8051
GS_3	86	507	3003	6005	82	461	2220	5378	79	419	2900	5331
Total		1797	7482	21568		1709	8408	20297		1705	9887	21034

Table.2 Heat use efficiency (kg ha^{-1} ^{0}C^{-1} day^{-1}) (HUE), Helio thermal use efficiency (kg ha^{-1} ^{0}C^{-1} day^{-1} hour) and Photo thermal use efficiency (kg ha^{-1} ^{0}C^{-1} day^{-1} hour) (PtUE) of pearlmillet at different spacings and dates of sowing

Dates of sowing	Total Drymatter	Grain yield	HUE		HtUE		PtUE	
			TDM	GY	TDM	GY	TDM	GY
S_1 (45 × 15 cm)								
D_1 (2nd FN of July)	10373	2875	5.45	1.52	1.27	0.35	0.44	0.12
D_2 (1st FN of August)	9599	2813	5.08	1.51	0.97	0.97	0.42	0.12
D_3(2nd FN of August)	9018	2764	4.97	1.48	0.87	0.26	0.41	0.12
S_2 (45 × 30 cm)								
D_1 (2nd FN of July)	8545	1929	4.63	1.04	1.09	0.24	0.38	0.08
D_2 (1st FN of August)	7570	1632	4.21	0.90	0.80	0.17	0.34	0.07
D_3(2nd FN of August)	6511	1283	3.91	0.77	0.65	0.12	0.31	0.06
S_3 (60 × 15 cm)								
D_1 (2nd FN of July)	9658	2710	5.17	1.45	1.21	0.34	0.42	0.11
D_2 (1st FN of August)	9339	2574	5.06	1.39	0.97	0.26	0.42	0.11
D_3(2nd FN of August)	8557	2447	4.82	1.38	0.84	0.24	0.39	0.11
S_4 (60 × 30 cm)								
D_1 (2nd FN of July)	7660	1675	4.26	0.93	1.02	0.22	0.35	0.07
D_2 (1st FN of August)	6750	1245	3.94	0.72	0.80	0.14	0.33	0.06
D_3(2nd FN of August)	5787	1087	3.39	0.63	0.58	0.10	0.27	0.05

From the above study, it can be concluded that 2nd fortnight of July sown crop at 45 × 15 cm spacing performed well by recording maximum GDD, PTU, HUE, HtUE and PtUE with maximum drymatter and grain yields and it could be the optimum time of sowing and optimum spacing for coastal Andhra Pradesh. The present study indicated that the application of heat units provided a scientific basis for determining the effect of temperature and radiation or photo period on phenological behavior of the crop and these indicated very clear picture on the amount, pattern and efficiency of heat energy consumption at different sowing windows and the phenological stages of the crops.

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