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Agrometeorological Indices and the Weather Parameters Impact on Growth and Yield of Pearl Millet

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***Abstract*— *The experiment entitled "Studies on crop weather relation in pearl millet (Pennisetum glaucum L.) under experiment was carried out in FRBD (Factorial Random Block Design). Nine treatment combinations comprise of three sowing environments viz. crop sown on 28th June (G_1), 8th July (G_2) and 18th July (G_3) respectively along with three cultivars i.e., PC-701, HHB-67 and RHB-223 were used in the investigation. The minimum temperature and rainfall had a positive and significant effect on the grain yield. It had a strong negative correlation with evaporation and wind speed. During the research period, among cultivars the highest accumulated GDD had observed in HHB-67 from emergence to physiological maturity. The higher accumulated HTU had consumed by 18th July and lowest by 28th June and the highest HTU were observed in HHB-67 from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18th July). The Accumulated Heat use efficiency (HUE) was higher on 28th June treatment at 60 DAS. HHB-67 (0.61 g/m^2 °C/day) possess higher HUE followed by PC-701 and RHB-223 (0.50 g/m^2 °C/day).*

***Keywords*— GDD, HTU HUE, Pearl Millet.**

I. INTRODUCTION

Based on several kinds of research, in order to fulfill the demands of a growing population and changing dietary habits, the world's food supply will need to double by the year 2050 (Bruinsma, 2009; Tilman et al., 2011; OECD; Food and Agriculture Organization of the United Nations, 2012). Surface temperature is expected to increase over the 21st century under all evaluated emission scenarios, with a high probability of an increase in the severity and duration of heat waves and extreme precipitation events in many regions, according to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2023). Changes in the ordinary and extreme weather pose a major threat to governments and organizations worldwide. This study aimed to present data about the effects of meteorological factors on the development stages and yield of climate-resilient pearl millet. In this sense, millets might be selected as climate-smart crops in the future. Millets are hardy and varied crops that belong to the monocotyledon group of the Poaceae family (Maitra *et al.*, 2000, 2022). Since major cereals grown on soils that get a lot of fertilizer, irrigation, and pesticide inputs have attained an average level of productivity, the importance of millets has increased dramatically in India during the past several decades. In both rich and developing countries, millets may increase food output. Millets are a type of grain in addition to the mainstays of wheat, rice, and maize. Millions of people, especially those who live in hot, dry parts of the world, rely on millets as their main source of sustenance millions of Africans rely on millet as their main source of protein and energy. The nutritional and therapeutic advantages of millet have been documented (IIMR report 2017). Among the various types of millet, pearl millet stands out as a significant food grain cultivated in both Africa and India. As a C4 plant, it is well-suited for growth in semi-arid regions, and its unique genetic characteristics enable it to withstand high temperatures, moderate salinity, and moisture stress, making it highly adaptable (Arya *et al.*, 2014). In light of these considerations, the present study was conducted to assess the impact of crop-weather relationships on the physiological growth parameters and yield performance of pearl millet cultivars in the eastern plain zone of Uttar Pradesh.

II. MATERIAL AND METHODS

An experiment carried out during the 2023 Kharif season at the Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.). This chapter provides a detailed account of the supplies, procedures, and techniques used during the experiment.

Experiment site: The experiment was laid out at Agro-meteorological Research Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during Kharif season 2023-24 The farm is located at 26˚47′ N latitude and 82˚12′ E longitude and at an altitude of about 113 meter above the mean sea level. The field was well levelled having assured irrigation and drainage facilities.

Climatic condition of the experimental site: Geographically, the climate in this area is subtropical. This crop receives average 724.2 mm of rainfall. During the crop growing season, the average weekly maximum and lowest temperatures were 31.8 ºC to 36 ºC and 24.5 ºC to 27.6 ºC, respectively. The range of the average relative humidity was 61.05% to 91.04%, and the number of hours of bright sunshine were 1.6 to 7.8. During the study, the soil of the research plot was collected through random sampling, and the analysed physicochemical properties of the soil revealed that the experimental soil was sandy clay loam in texture with a soil pH of 8.1 and an organic carbon of 0.38%. The soil contained 189.25 kg ha-1, 18.20 kg ha-1 and 236.50 kg ha-1 of nitrogen, phosphorous and potassium respectively. The experiment was carried out in F.R.B.D (Factorial Random Block Design). Nine treatment combinations comprise of three sowing dates *viz.* 28th June (G_1); 8thJuly (G_2) and 18thJuly (G_3) respectively along with three cultivars *i.e.,* PC-701, HHB-67 and RHB-223 were used in the investigation. Pearl millet seeds were sown at a seed rate of 2-3 kg ha-1 on well-prepared seedbeds. The main field was harrowed and ploughed twice with a cultivator and rotavator and levelled with the levellers. Then, the experimental layout was divided into plots. Further, each plot was manually levelled, and one pre-planting irrigation was provided for better soil conditions during the transplanting to establish finger millet seedlings. All plots received the recommended fertilizer dose of 40:20:20 kg ha^{-1} of nitrogen, phosphate and potash, respectively.

During the experimental period, the plant height, dry matter accumulation, number of tillers and leaf area index were collected at 10-day intervals from 15 days after germination to harvest. The following equations calculated the Leaf area index, Harvest index, and relative index

Harvest index (%)- The harvest index is the ratio of grain yield and biological yield, it was calculated by following formula:

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Leaf area index-The leaf area of five plants was measured with an automatic leaf area meter at 30, 45, 60, 75, 90, and 105 DAS, as well as when the crop reached physiological maturity. The leaf area index was calculated using the formula.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Relative humidity (%)- Relative humidity is the ratio between the amount of water vapour required for saturation at a particular temperature and pressure. It can be expressed as percentage or ratio.

$$\text{RH (\%)} = \frac{\text{Water vapour present in air Relative himidity (\%)}}{\text{Water vapour required for saturation}} \times 100$$

GDD/heat units (°C Day) - were computed by summing the daily mean temperature above base temperature and expressed in day °C. For pearl millet crop, Tbase is considered as 10°C for computation of GDD (Ahmad et al., 2017). GDD was calculated for different phenological stages in pearl millet by using the following formula:

$$\text{GDD} = \sum_b^a \left\{\frac{Tmin.+Tmax.}{2} - Tbase\right\}$$

Where,

T max. is daily maximum temperature (°C)

T min is daily minimum temperature (°C)

Tb is base temperature

'a' is starting date of phenophase and 'b' is ending date of that phenophase

Base temperature for Pearl millet (kharif) crop 10-12°C

Helio-thermal units (°C Day hour)- The helio-thermal units (HTU) for a day represent the product of growing degree days and bright sunshine hours for that day and are expressed in day °C hour. The sum of HTU for each phenophase was determined by using the equation:

$$\text{HTU} = = \sum_b^a (GDD \times n)$$

Were,

n is actual sunshine hours.

GDD is growing degree day.

Heat use efficiency (HUE) (g m -2 °C Day)- the amount of dry matter produced per unit of growing degree days or thermal time and is expressed in g m-2 oC day. HUE was calculated between any two consecutive phenological stages of the crop as under

$$HUE = \frac{Total\ dry\ matter\ (g/m2)}{\sum GDD}$$

Were,

∑GDD is summation of growing degree day.

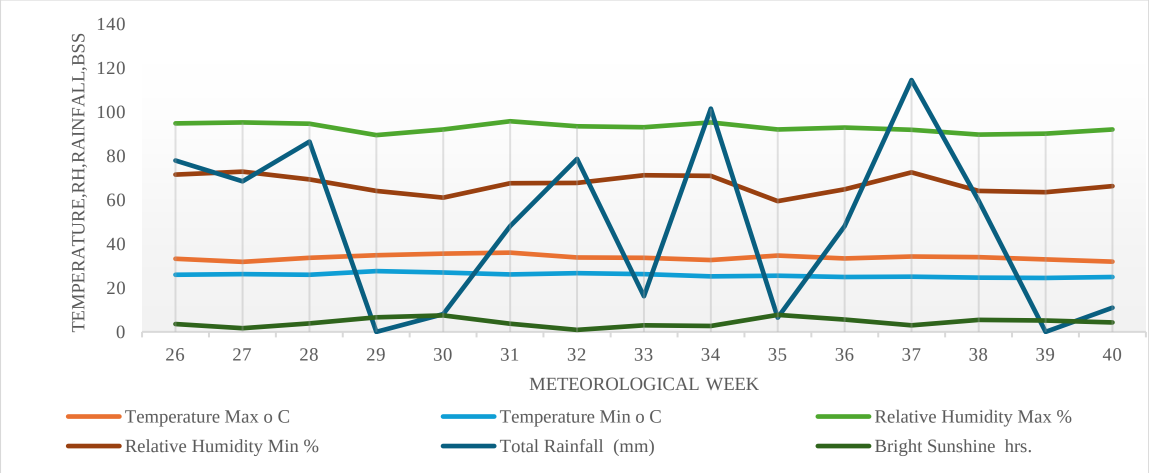

Fig.a Weather data during the experiment studies

III. RESULT AND DISCUSSION

Correlation analysis- Correlation between growth and weather parameters-shows the findings of correlation studies between meteorological parameters and growth during the vegetative and reproductive phases of pearl millet development. During the reproductive period of crop growth, there has been a strong but negative association seen between wind speed and plant height and dry matter. There is a significant positive link between the leaf area index (LAI) and the minimum temperature, and a strong negative correlation with the relative humidity in the morning.

Correlation between yield and it`s attributes with weather parameters- The minimum temperatures and rainfall have a substantial positive link with grain yield, but wind speed and evaporation have a large negative correlation. The number of effective tillers per plant was inversely connected with maximum temperature and hours of intense sunshine, and positively correlated with relative humidity in the morning and evening. The maximum and minimum temperatures and wind speed had a negative correlation with earhead length, while the two variables showed a positive correlation. Positive relationships have been observed between the test weight attribute and the lowest temperature, evening relative humidity, and rainfall; negative relationships have been observed with wind speed and evaporation. Wind speed and biological yield also had a negative correlation. Maximum temperature had a negative correlation with effective tillers per plant and a positive correlation with earhead length. The minimum temperature has been positively correlated with test weight, grain yield, and earhead length. Only the effective tillers per plant were impacted by morning relative humidity, whereas test weight and effective tillers per plant were impacted by evening relative humidity. Earhead length, test weight, grain yield, and biological yield have all been adversely affected by wind speed; also, effective tillers per plant have been found to be negatively correlated with bright daylight hours. Test weight, grain production, and the number of effective tillers per plant were all adversely affected by evaporation. Grain yield and test weight showed a favourable correlation with rainfall. There is no discernible relationship between the harvest index, earhead girth, and stover yield and meteorological data.

Agrometeorological indices - The agrometeorological observatory, located on the students' instructional farm, provided the meteorological data, which included the daily maximum and minimum air temperature, the amount of rainfall, and the number of brilliant sunshine hours. Directly recorded meteorological measurements were the source of the agrometeorological indicators. Agrometeorological indices are a highly helpful instrument for forecasting agricultural yield and determining the relationship between weather and crop productivity.

Growing Degree Days (°C Day) - Table 3 presents the data regarding the cumulative growing degree days (GDD) in relation to various treatments and phenological stages. Between the cultivars, HHB-(1241.50 °C Day) has used more GDD than PC-701 (1222.6 °C Day), RHB- 223 (1240.1°C Day), and RHB-223 has used less GDD overall at all phenological stages than PC-701 and HHB-67. Similar results had published by Andhale *et al*. (2001), and Anil Kumar *et al. (*2008).

Helio Thermal Unit (° C Day/ hours)- Table presents the information about the total number of helio-thermal units (HTU) for each treatment for each of the several phenophases. In compared to 28th June and 8th July, the crop growth environment on July 18th (PC-701) had the greatest HTU from emergence to milking stage (514.88 to 4850.40), except for the flag leaf stage, boot, dough stage, and physiological maturity stage. With each sowing delay from 28th June to 18th July, the HTU for emergence to dough stage (apart from the physiological maturity stage) rose. Among the crop growing environments for cultivar HHB-67, the 18th of July exhibited the highest HTU (518.88 to 5750.23°day/hr.) from emergence to physiological maturity, apart from the flag leaf, boot, dough, and physiological maturity stages. Another cultivar, RHB-223, is intended to be used in a range of agricultural producing settings. Every delay in seeding from 28th June to 18th July increased the HTU for physiological maturity. The 28th of June had the highest HTU values ranging from 510.75 to 5739.40 °C Day/hr. from emergence to milking stage, apart from the flag leaf stage, boot stage, dough stage, and physiological maturation as compared to 8th July and 18th July. Similar outcomes were reported by V.M.Londhe *et al.* (2020) & G. Aishwarya *et.al* (2022).

Accumulated Heat Use efficiency (HUE) **-**

Calculating the thermal usage efficiency (HUE) is crucial in determining the potential yield under various cultivars and sowing circumstances. It measures the quantity of dry matter generated every day per unit of growth degree. Table 5 presents the data that shows the HUE. The results show that as crop stages have increased, so too has the value of HUE. Maximum HUE values for the variety HHB-67 have been seen on 28th June sowing dates at all phases 15,30,45 and 60 DAS intervals, followed by 8th July and 18th July. Maximum HUE values for the cultivar PC-701 have been seen on 28th June sowing dates at all phases of 15,30,45 and 60 DAS intervals, followed by 8th July and 18th July. Another cultivar, RHB-223, exhibited the highest HUE values on 28th June sowing dates at all stages of 15,30,45 and 60 DAS, followed by 8th July and 18th July. Similar results were reported by Girijesh *et al.*in (2011), Ved Prakash *et al.*(2017), V.M.Londhe *et al.* (2020);

Table:1 Correlation coefficients of growth parameters with prevailing weather during vegetative and reproductive phases of pearl millet cultivers

Parameters	Plant height (cm)		Dry matter (g)		Leaf area index	
	Veg. phase	Rep. phase	Veg. phase	Rep. phase	Veg. phase	Rep. phase
Tmax	0.07	-0.02	0.08	-0.12	0.14	0.44
Tmin	-0.22	-0.14	-0.23	-0.32	-0.22	0.62*
RH(m)	0.04	0.21	0.03	0.34	-0.02	-0.60*
RH(e)	-0.24	0.08	-0.21	-0.14	-0.28	0.24
Wind speed	-0.08	-0.54**	-0.04	-0.50**	0.04	0.32
BSS	0.09	0.16	0.06	0.26	0.13	-0.42
Rainfall	0.05	0.2	0.02	-0.05	-0.05	0.27

Table: 2. Correlation coefficients of yield index with weather parameters in pearl millet cultivars

Parameters	Tillers/ plant	Ear head length/plant	Ear head girth/ plant	Test weight	Grain yield	Stover yield	Biological yield	Harvest index
T_{max}	-0.62**	0.43*	0.14	0.06	0.16	0.15	0.19	-0.05
T_{min}	-0.294	0.55**	0.11	0.46*	0.42*	0.27	0.32	0.14
RH(m)	0.56**	0.03	0.02	0.27	0.12	0.08	0.09	0.12
RH(e)	0.42*	0.25	0.04	0.44*	0.36	0.19	0.26	0.20
Wind speed	-0.05	-0.62**	-0.15	-0.55**	-0.52**	-0.37	-0.42*	-0.17
BSS	-0.55**	-0.06	0.02	-0.26	-0.16	-0.09	-0.12	-0.17
Evaporation	-0.43*	-0.41	-0.08	-0.42**	-0.41*	-0.24	-0.25	-0.23
Rainfall	0.28	0.34	0.06	0.40*	0.39*	0.22	0.24	0.20

*Significance at 1 %; **Significance at 5% Where, T_{max}= maximum temperature (°C), T_{min}= minimum temperature (°C), RH(m) = morning relative humidity (%), RH(e) = evening relative humidity (%), BSS= bright sunshine hours (hrs), Veg. phase = vegetative phase, Rep. phase= reproductive phase

Table: 3. AGDD/Heat unit at different phenophases (˚C/days) of pearl millet cultivars as affected by crop growing environments

Treatments	Emergence stage	5 leaf stage	Tillering stage	Flag leaf stage	Boot stage	50% flowering Stage	Milking stage	Dough stage	Physiological maturity stage
Crop growing environments									
PC-701									
28th June (33.2°C)	70.75	213.75	375.85	644.6	691.1	902.35	1041.1	1076.6	1222.6
8th July (31.8°C)	80	216.75	335.75	620.5	676.1	870.6	1031.6	1067.85	1196.35
18th July (34.8°C)	51	171.75	261	603.1	726.1	834.6	988.1	1019.1	1165.35
28th June (33.2°C)	70.75	213.75	375.85	644.6	691.1	902.35	1041.1	1076.6	1222.6
HHB - 67									
28th June (33.2°C)	82	221.75	367.85	638.5	726.1	910.35	1047.6	1076.6	1241.50
8th July (31.8°C)	71.25	215.75	330.75	634.6	691.1	880.6	1041.1	1062.85	1201.5
18th July (34.8°C)	67	188.75	296.25	599.1	679.1	839.6	992.4	1039.1	1175.5
RHB-223									
28th June (33.2°C)	77	212.75	365.85	640.6	736.1	899.5	1040.1	1076.6	1219.7
8th July (31.8°C)	69.75	210.75	332.75	597.1	688.1	875.5	1031.6	1067.85	1160.85
18th July (34.8°C)	51	165.5	261	610.5	679.1	844.6	988.1	1009.1	1190.5

Table: 4. Accumulated helio thermal unit (HTU) (°C /day/ hours) on different crop growing environments and cultivars

Treatments	Emergence stage	5 leaf stage	Tillering stage	Flag leaf stage	Boot stage	50% flowering stage	Milking stage	Dough stage	Physiological maturity stage
Crop growing environment									
PC -701									
28th June (33.2°C)	319.50	865.88	1261.38	3284.33	3338.33	3910.83	4298.08	4650.40	5744.40
8th July (31.8°C)	404.63	966.25	1952.88	3135.45	3233.83	3883.45	4782.65	5005.28	5604.03
18th July (34.8°C)	514.88	1626.25	2205.02	2781.20	3130.33	3910.40	4807.40	4881.90	5427.03
HHB - 67									
28th June (33.2°C)	325.50	888.50	1270.70	3280.32	3345.40	3915.25	4388.58	4690.46	5750.23

8th July (31.8°C)	406.63	970.30	1960.80	3140.42	3198.25	3908.15	4800.50	5047.25	5606.05
18th July (34.8°C)	518.88	1630.20	2216.20	2785.40	3150.50	3920.70	4855.23	4890.05	5430.02
RHB-223									
28th June (33.2°C)	315.25	860.85	1260.75	3282.25	3340.25	3889.59	4379.75	468 5.4	5739.40
8th July (31.8°C)	400.62	961.05	1905.50	3105.40	3230.25	3851.40	4777.05	4997.05	5598.25
18th July (34.8°C)	510.75	1610.20	2198.05	2777.29	3129.32	3893.34	4830.20	4870.25	5420.25

Table: 5. Accumulated heat use efficiency (HUE) (g /m-2 °C /day) on different crop growing environments and cultivars

Treatments	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**
PC-701				
28th June (33.2°C)	0.05	0.20	0.46	0.50
8th July (31.8°C)	0.04	0.14	0.44	0.48
18th July (34.8°C)	0.01	0.12	0.29	0.32
HHB-67				
28th June (33.2°C)	0.06	0.20	0.54	0.61
8th July (31.8°C)	0.04	0.17	0.51	0.48
18th July (34.8°C)	0.02	0.14	0.35	0.36
RHB-223				
28th June (33.2°C)	0.05	0.16	0.40	0.50
8th July (31.8°C)	0.03	0.12	0.41	0.49
18th July (34.8°C)	0.02	0.10	0.28	0.31

IV. CONCLUSIONS

During the reproductive period of pearl millet, there is a significant association between the morning relative humidity and minimum temperature and the leaf area index (LAI). Wind speed during the reproductive phase has a negative impact on plant height and dry matter. Although there was a negative correlation with wind speed and evaporation, there was a strong positive correlation between grain yield and test weight and minimum temperature and rainfall. Both evaporation and wind speed have been found to have a negative impact on grain yield and biological yield respectively. The higher accumulated GDD had consumed by 28th June (1241.50 ° C/day) to attain physiological maturity among different crop growing environments then after 18th July (1201.5 °C/day). 8th July (1190.5°C/day) utilized minimum accumulated GDD. Among cultivars, the highest accumulated GDD had observed in HHB-67 from emergence to physiological maturity. The higher accumulated HTU had consumed by 18th July and lowest by 28th June among different sowing dates at different phenophases with few exceptions. Among cultivars, the highest HTU were observed in HHB-67 from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18th July). The Accumulated Heat use efficiency (HUE) was higher on 28th June treatment at 60 DAS. HHB-67 (0.61 g/m^2 °C/day) possess higher HUE followed by PC-701 and RHB-223 (0.50 g/m^2 °C/day). Among cultivars, the highest AGDD were Fig-b Heat use efficiency of crop growing environment observed in HHB-67 (1241.50 °C/day) from emergence to physiological maturity and least RHB-223 (1160.85 °C/day). Among cultivars, the highest AHTU were observed in HHB-67 (5750.23°C/day/ hours) from emergence to milking stage (except flag leaf stage, boot stage, dough stage and physiological maturity on 18th July). Among cultivars, HHB-67 had higher HUE (0.61 g/m^2 °C/day) followed by PC-701 and RHB-223 (0.50 g/m^2 °C/day).

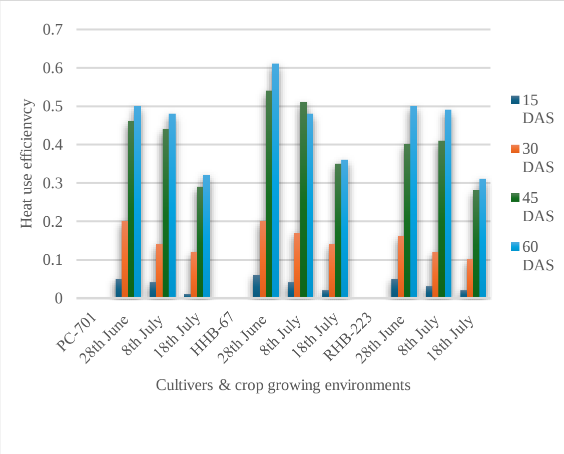

Fig-b Heat use efficiency of crop growing environment

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