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Effect of Soil Moisture on Growth and Yield of Pearl Millet (*Pennisetum glaucum* L.) under Different Dates of Sowing

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ABSTRACT

Water that is stored in the soil pore as soil moisture is very important for pearl millet under rainfed conditions. This study aims to evaluate the effect of soil moisture on the growth and yield of pearl millet. PASM of soil depth up to 60 cm during milking to maturity found a positive influence on LAI and plant height of pearl millet. The PASM has a significant positive influence on dry matter, grain, and stover yield. The crop phase from flag leaf to maturity was more sensitive to soil moisture availability than the early vegetative stage and hence, the availability of soil moisture at the reproductive stage determines the growth and development of pearl millet and ultimately the yield. At the early growth stage yield negatively correlated with soil moisture and thereafter positively. The soil moisture shows a high correlation with the yield at the milking stage.

Keywords Pearl millet, PASM, Correlation and regression, Growth parameters, Yield.

INTRODUCTION

Challenges associated with sustainable food production are being intensified by climate change, which is expected to have relatively higher effects in semi-arid and arid regions than in any other region (Hirooka *et al*. 2021). Soil moisture is a key climatic variable in the hydrological cycle and influence water and energy exchanges occurring in the terrestrial surface (Pal *et al*. 2016, Srivastava *et al*. 2015). In agriculture, rainfall influences the edaphic factors, viz., soil moisture, soil temperature, and aeration (Niwas *et al*. 2006). In India, approximately 56% of the total cultivated area comes under rainfed agriculture and it produces nearly half of the total agricultural output (Sharma *et al*. 2015). This area occupies 67% of net sown area, contributing 44% of food grain production and supporting 40% of the population (CRIDA 1997). Water extremely influences the biochemical process and uptake of mineral nutrients in plants (Anonymous 2016). Its shortage and excess both affect the growth and development of a plant directly and consequently, yield and quality. The production potential of rainfed system is continued to be low as a result of frequent drought (Sharma *et al*. 2009, Sahrawat *et al*. 2010). Changes in climate make drought stresses even more

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severe in the future (Yadav 2014). To meet the crop's water demands and optimum crop production correct amount and timing of water application is desirable for irrigation scheduling (Mehta *et al*. 2016). Declining soil moisture related to climate change can greatly affect social, economic, environmental and hydrological processes and extreme weather events. Hence, it is imperative to understand the timing of significant soil moisture drying under future climate change.

Pearl millet (*Pennisetum glaucum* L.R.Br) is a diploid species (2n=14). It is the sixth most important cereal grown worldwide followed by rice, wheat, corn, barley, and sorghum (Kumar *et al*. 2014) and in India, it is the fourth most important cereal crop after rice, wheat, and sorghum (Maurya *et al*. 2016). It is a staple food of 90 million poor people and extensively grown on 30-million-ha area in the arid and semi-arid tropical regions of Asia and Africa. It is also used for feed and fodder and accounts for almost half of the global millet production (Srivastava *et al*. 2020). It possesses the huge capability to eliminate micronutrient deficiency among developing countries (Rai *et al*. 2012, Anuradha *et al*. 2017, Singhal *et al*. 2018) as it supplies 30–40% of inorganic nutrients and Millets are also rich in health promoting phytochemicals which are act as antioxidants, immune modulators, detoxifying agents and hence protect against age-related degenerative diseases like cardiovascular diseases (CVD), diabetes, cancer (Sireesha *et al*. 2011, Dayakar Rao *et al*. 2017). It have a high potential as food for humans because they are gluten-free, higher in dietary fiber content than rice, similar in lipid content to maize and higher content of essential amino acids (leucine, isoleucine and lysine) than other traditional cereals, such as wheat and rye (Martins *et al*. 2018). It is more resilient to extreme climatic events such as drought and water scarcity and can play a vital role in ensuring food and nutritional security in changing climatic scenarios (Satyavathi *et al*. 2021). Its development divided into 3 phases i.e. the vegetative phase (GS1), the panicle development phase (GS2) and the grain filling phase (GS3). The impact of moisture deficiency is more felt during the period just after germination, flowering, and milking stages of the crop and result in yield reduction, both quantitatively and qualitatively (Chandrasekar and Sesha Sai 2015).

MATERIALS AND METHODS

Experimental details

The field experiment was conducted at Research Farm, Dept of Agricultural Meteorology, CCS HAU, Hisar (Haryana), India. The experiment was comprised of three dates of sowing and three varieties (GHB 558, HHB 67 Improved, and HHB 272) and laid out in factorial RBD with four replications. Hisar is situated in the sub-tropical, semi-arid climatic zone of India. Daily weather data were obtained from the record of the Agro-meteorological observatory.

Soil moisture

The gravimetric method involves taking soil samples from the field and determining the weight of water contained in a soil sample, relative to the weight of dry soil. Weekly soil moisture measured at four different depths i.e. 0-15 cm, 15-30 cm, 30-45 and 45-60 cm. The moisture contained in the soil is measured in terms of percentage.

$$\text{Soil moisture (\%)} = \frac{\text{Weight of wet soil (g)} - \text{Weight of dry soil (g)}}{\text{Weight of dry soil (g)}} \times 100$$

Percent available soil moisture (PASM)

PASM is based on daily water balance and is defined as the ratio of the difference between the current soil moisture (SMc) and the permanent wilting point (PWP) to the field capacity (FC) and the Permanent wilting Point (Saxena *et al*. 2019).

$$\text{PASM (\%)} = \frac{\text{SMc - PWP}}{\text{FC-PWP}}$$

Growth parameters

Leaf area index, plant height, dry matter accumulation, and its partitioning were recorded at 7 days intervals from crop establishment to the harvest. Three plants from each plot were selected for the green leaf

Table 1. Effect of sowing time on plant height (cm) in pearl millet varieties during crop season 2019.

Treatments	Days after sowing							
	14	21	28	35	42	49	56	PM
Factor A (Sowing dates)								
30th June	27.0	61.2	114.7	154.3	178.0	200.8	204.5	204.5
10th July	24.1	67.9	101.8	140.8	180.7	189.3	190.9	190.9
30th July	20.2	42.2	64.7	89.0	105.7	144.5	152.4	152.4
CD at 5%	1.9	2.7	7.5	5.6	8.6	6.4	6.2	6.2
SE (m)	0.6	0.9	2.6	1.9	2.9	2.2	2.1	2.1
Factor B (Varieties)								
GHB-558	20.6	48.4	59.5	82.7	144.4	182.9	188.4	188.4
HHB-67 Improved	25.9	63.3	98.3	135.6	162.3	174.4	181.8	181.8
HHB-272	24.8	59.6	97.3	131.8	157.7	174.3	177.6	177.6
CD at 5%	1.9	2.7	7.5	5.6	8.6	6.4	6.2	6.2
SE (m)	0.6	0.9	2.6	1.9	2.9	2.2	2.1	2.1

area, plant height and dry matter.
LAI = L/S

Where, L = Leaf area (m^2)
S = Land area (m^2)

Statistical analysis

The observations recorded for PASM, growth parameters, and yield were put to statistical analysis in accordance with the analysis of variance technique as suggested by Fisher (1950) for factorial RBD. The critical difference was calculated to assess the significance of treatment means, whenever, the F; test was found significant at 5% levels of probability.

CD = 2 EMS/ n × t value at 5%

Where, CD = critical difference, EMS = error mean sum of square, n = number of observations.

Correlation and regression analysis

To assess the relationship, correlation and regression coefficients between the dependent variable (Y) and independent variables (X) were computed using the method given by Snedecor and Cochran (1968). The regression equations were also fitted and tested at 5 and 1% levels of significance. Multiple regression equations were developed by taking two or more significant parameters together using the stepwise regression technique.

Table 2. Effect of sowing time on leaf area index (LAI) in pearl millet varieties.

Treatments	Days after sowing								
	14	21	28	35	42	49	56	63	PM
Sow factor A (Sowing dates)									
30th June	0.06	0.70	1.61	3.20	3.95	4.28	4.17	3.79	3.55
10th July	0.05	0.67	1.58	3.04	3.56	3.92	3.79	3.53	3.35
30th July	0.04	0.59	1.12	2.12	2.44	2.86	2.81	2.52	2.52
CD at 5%	0.005	0.013	0.031	0.048	0.081	0.131	0.049	0.075	0.088
SE (m)	0.002	0.004	0.011	0.016	0.028	0.045	0.017	0.025	0.03
Factor B (Varieties)									
GHB- 558	0.04	0.62	1.41	2.58	3.41	4.03	4.26	3.99	3.70
HHB-67 Improved	0.05	0.65	1.44	2.85	3.23	3.40	3.17	2.85	2.79
HHB-272	0.06	0.68	1.46	2.93	3.32	3.63	3.33	2.99	2.92
CD at 5%	0.005	0.013	0.031	0.048	0.081	0.131	0.049	0.075	0.088
SE (m)	0.002	0.004	0.011	0.016	0.028	0.045	0.017	0.025	0.03

RESULTS AND DISCUSSION

Crop growth

Maximum average height, LAI and dry matter accumulation were recorded in crop sown on 30th June followed by 10th July and 30th July. The findings of Nwajei *et al*. (2019) and Aggarwal *et al*. (2016) support the result related to plant growth. This is due to high temperature which causes shorting of the GS2 phase and maximum numbers of leaves produced were largely controlled by day length and temperature. GS2 directly influences canopy development, interception of radiation, transpiration, and photosynthetic process. In case of varieties GHB-558 recorded higher plant height as compare to HHB-67 Improved and HHB-272 (Table 1). Maximum LAI, and dry matter accumulation were obtained by the variety GHB-558 and minimum by HHB-67 Improved (Tables 2-4). This might be due to the more height, more no. of leaves per plant, thick stem, and long growth period of GHB-558.

Yield and yield attributes

The highest grain yield, stover, and biological yield were recorded by 30th June sown crop followed by 10th July and 30th July sown crops. The crop sown on 30th June received higher amount of rainfall as compared to subsequent sowing and being the rainfed crop the rainfall contributed to the yields. it was supported by findings of Detroja *et al*. (2018) and Bisht *et al*. (2019). Among the varieties, the grain yield of GHB-558 was highest followed by HHB-and HHB-67 Improved at crop harvest. The GHB-558 took advantage of its comparatively longer duration

Table 3. Effect of sowing time on plant dry matter accumulation (g/plant) in pearl millet varieties from 14 to 42 DAS.

Treatments	Days after sowing								
	14			21			28		
	L	S	T	L	S	T	L	S	T
Factor A (Sowing dates)									
30th June	0.6	0.6	1.2	1.7	1.2	2.8	5.2	4.5	9.7
10th July	0.6	0.5	1.1	3.0	0.9	3.9	4.2	3.7	7.9
30th July	0.5	0.4	0.9	2.5	0.7	3.2	3.8	3.1	6.9
CD at 5%	0.07	0.10	0.13	0.14	0.18	0.20	0.37	0.41	0.53
SE (m)	0.02	0.04	0.04	0.05	0.06	0.07	0.13	0.14	0.18
Factor B (Varieties)									
GHB- 558	0.5	0.4	0.9	2.1	0.8	2.9	4.0	3.0	7.1
HHB-67 Improved	0.6	0.5	1.1	2.5	0.9	3.3	4.5	4.0	8.4
HHB-272	0.7	0.6	1.3	2.6	1.1	3.6	4.7	4.3	9.0
CD at 5%	0.07	0.10	0.13	0.14	0.18	0.20	0.37	0.41	0.53
SE (m)	0.02	0.04	0.04	0.05	0.06	0.07	0.13	0.14	0.18

Table 3. Continued.

Treatments	Days after sowing						
	35			42			
	L	S	T	L	S	P	T
Factor A (Sowing dates)							
30th June	8.8	13.6	22.4	10.6	22.5	5.6	38.8
10th July	5.8	12.2	18.0	8.0	19.5	4.1	31.5
30th July	5.3	8.8	14.0	6.5	16.7	5.1	28.3
CD at 5%	0.44	1.05	1.18	0.58	0.81	1.35	1.92
SE (m)	0.15	0.36	0.40	0.20	0.28	0.46	0.66
Factor B (Varieties)							
GHB- 558	6.3	9.7	16.1	9.3	21.4	1.9	32.5
HHB-67 Improved	6.7	11.6	18.3	7.7	18.2	6.1	32.0
HHB-272	6.9	13.2	20.1	8.1	19.1	6.8	34.1
CD at 5%	0.44	1.05	1.18	0.58	0.81	1.35	NS
SE (m)	0.15	0.36	0.40	0.20	0.28	0.46	0.66

Table 4. Effect of sowing time on plant dry matter accumulation (g/plant) in pearl millet varieties from 49 to harvest. L= leaf, S= stem, P= panicle, T= total.

Treatments	Days after sowing							
	49				56			
	L	S	P	T	L	S	P	T
Factor A (Sowing dates)								
30th June	11.5	25.3	16.4	53.2	9.3	26.4	28.7	64.3
10th July	9.0	21.7	13.0	43.7	8.6	22.9	22.4	53.9
30th July	6.9	18.0	13.4	38.3	6.5	20.2	18.8	45.4
CD at 5%	0.44	1.19	1.19	2.00	0.68	1.39	1.32	1.74
SE (m)	0.15	0.40	0.40	0.68	0.23	0.47	0.45	0.59
Factor B (Varieties)								
GHB- 558	9.9	25.4	12.2	47.6	9.4	28.2	20.9	58.4
HHB-67 Improved	8.6	19.0	14.5	42.1	7.2	19.8	23.3	50.3
HHB-272	8.9	20.6	16.0	45.4	7.8	21.5	25.6	54.9
CD at 5%	0.44	1.19	1.19	2.00	0.68	1.39	1.32	1.74
SE (m)	0.15	0.40	0.40	0.68	0.23	0.47	0.45	0.59

Table 4. Continued.

Treatments	Days after sowing							
	63				Harvest			
	L	S	P	T	L	S	P	T
Factor A (Sowing dates)								
30th June	7.3	28.6	37.4	73.3	6.4	28.3	42.9	77.5
10th July	6.4	23.8	31.1	61.3	5.1	24.7	36.4	66.2
30th July	5.2	20.8	26.3	52.4	4.5	21.9	28.7	55.1
CD at 5%	0.69	2.15	2.80	2.69	0.82	2.13	2.45	3.04
SE (m)	0.24	0.73	0.95	0.92	0.28	0.73	0.84	1.04
Factor B (Varieties)								
GHB- 558	7.9	28.1	32.2	68.2	6.3	29.1	40.2	75.6
HHB-67 Improved	5.4	21.0	30.3	56.7	4.8	21.2	32.7	58.7
HHB-272	5.7	24.2	32.2	62.0	4.90	24.6	35.1	64.6
CD at 5%	0.69	2.15	NS	2.69	0.82	2.13	2.45	3.04
SE (m)	0.24	0.73	0.95	0.92	0.28	0.73	0.84	1.04

Table 5. Effect of different dates of sowing on yield attributes in pearl millet varieties at physiological maturity.

Treatments	Total no. of tillers/plant	Effective no. of tillers/ plant	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})
Sowing dates					
30th June	3.78	3.22	3589.3	11386.8	14976.1
10th July	4.36	3.88	2753.0	9261.8	12015.8
30th July	4.00	2.36	1484.3	4946.4	6431.7
CD at 5%	0.28	0.21	258.57	789.42	1032.00
SE (m)	0.10	0.07	88.06	2.68	351.40
Varieties					
GHB- 558	3.75	3.32	2904.7	9208.3	12113.0
HHB-67 Improved	4.06	3.51	2332.0	7791.6	10449.3
HHB -272	4.33	3.74	2589.9	8595.2	11185.0
CD at 5%	NS	0.21	258.57	789.42	1032.00
SE (m)	0.10	0.07	88.06	2.68	351.4

Table 6. Correlation coefficients of growth parameters with PASM at different depths during different growth phases. *Significant at 0.05 p level, n=70, GS1= Emergence to tillering, GS2= flag leaf to flowering, GS3= milking to maturity, TDM=total dry matter, PWC= plant water content.

Growth parameter	Growth phase	Depth (cm)			
		0-15	15-30	30-45	45-60
LAI	GS1	0.00	-0.19	-0.11	-0.23
	GS2	-0.13	0.04	0.07	0.23
	GS3	0.46*	0.62*	0.61*	0.57*
	Total duration	-0.45*	-0.56*	-0.56*	-0.52*
Plant height	GS1	0.03	-0.19	-0.13	-0.21*
	GS2	0.09	0.24	0.29	0.42*
	GS3	0.72*	0.82*	0.68*	0.51*
	Total duration	-0.39*	-0.53*	-0.54*	-0.51*
TDM	GS1	0.04	-0.1	-0.06	-0.17
	GS2	-0.29	-0.13	-0.13	0.04
	GS3	0.63*	0.37	0.33	0.11
	Total duration	-0.40*	-0.61*	-0.64*	-0.64*
PWC	GS1	-0.24	-0.4	-0.26	-0.46*
	GS2	0.42*	0.35	0.20	0.16
	GS3	-0.30	-0.20	-0.18	0.04
	Total duration	-0.28*	-0.32*	-0.25*	-0.25*

with superior yield attributes.

10th July had the highest number of total tillers plant^{-1} (4.36 tillers) as compared to 30th July (4.00 tillers) and 30th June (3.78 tillers). Low temperature during GS1 causes a reduction in the number of tillers and results corroborated with the findings of Joshi *et al*. (2016). Among the varieties, the highest number of total tillers plant^{-1} at harvest was produced by HHB-272 (4.33 tiller) followed by HHB-67 Improved (4.06 tillers) and GHB-558 (3.75 tillers) during the crop season (Table 5). The effective tillers plant^{-1} has followed a similar trend.

Relationship studies

Soil moisture strongly influences the growth parameters and yield. Less availability of soil moisture causes a reduction in LAI, plant height, and dry matter. At GS1 growth phase plant height showed a negative correlation with PASM at depth 45-60 cm. At GS2 plant height shown a positive correlation with PASM at depth 45-60 cm as the plant water requirement is increased with increasing canopy and crop need to extract more water available at deeper layers. At the GS3 phase, LAI and height have shown a positive correlation with PASM at depth 0-60 cm (Salter *et al*. 1967). At GS3 dry matter shows a positive correlation with PASM at 0-15 cm depth while total duration LAI and height showed a negative correlation with PASM at all four depths (Rostamza *et al*. 2011). The growth parameters like LAI, plant height, and TDM highly positively correlated with PASM at 42 DAS (Table 6). PASM has a positive correlation with grain, stover, and biological yield at almost all crop stages (Table

Table 6. Continued.

Growth parameter	Depth	Days after sowing							
		14	21	28	35	42	49	56	63
LAI	0-15	-0.70*	0.31	0.81*	-0.42	0.88*	0.64	0.47	0.37
	15-30	-0.61	-0.19	0.73*	0.24	0.94*	0.74*	0.57	0.39
	30-45	-0.67*	-0.17	0.78*	0.73*	0.89*	0.78*	0.45	0.94*
	45-60	-0.42	-0.17	0.68*	0.82*	0.95*	0.78*	0.51	0.64
	Total	-0.78*	-0.03	0.80*	0.59	0.96*	0.81*	0.54	0.7
Plant height	0-15	-0.61	0.51	0.75*	-0.22	0.91*	0.84*	0.67	0.82*
	15-30	-0.36	0.14	0.69*	0.32	0.90*	0.89*	0.85*	0.83*
	30-45	-0.44*	0.11	0.63	0.81*	0.79*	0.84*	0.77*	0.5
	45-60	0.04	0.13	0.34	0.81*	0.91*	0.76*	0.76*	0.07
	Total	-0.49	0.29	0.67*	0.67*	0.91*	0.91*	0.82*	0.88*
TDM	0-15	-0.59	0.32	0.54	-0.15	0.56	0.65	0.38	0.78*
	15-30	-0.43	0.62	0.55	0.43	0.75*	0.68*	0.59	0.48
	30-45	-0.56	0.62	0.41	0.58	0.71*	0.63	0.57	0.77*
	45-60	-0.3	0.08	0.09	0.63	0.75*	0.47	0.52	0.25
	Total	-0.62	0.49	0.46	0.56	0.73	0.66	0.54	0.9

Table 7. Correlation coefficients of different yield and yield attributes with PASM at different intervals during the crop season. *Significant at 0.05 p level, n=9.

Days after sowing	Yield and yield attributes			
	Grain	Stover	Biological	Harvest Index
7	-0.64*	-0.74*	-0.71*	0.15
14	-0.56*	-0.62*	-0.61*	-0.03
21	0.19	0.22	0.21	-0.04
28	0.89*	0.88*	0.88*	0.41*
35	0.53*	0.58*	0.57*	0.03
42	0.85*	0.85*	0.85*	0.37
49	0.72*	0.74*	0.74*	0.27
56	0.67*	0.71*	0.70*	0.10
63	0.71*	0.62*	0.65*	0.67*
70	-0.20	-0.21	-0.21	-0.11

7). PASM at different depths collectively explained the variability in LAI, plant height, dry matter and PWC at different growth phases. The PASM based regression models developed are presented in Table 8.

CONCLUSION

The percent available soil moisture of depth up to 60 cm during milking to maturity positively influences LAI and plant height of pearl millet. GS2 and GS3 phases are more sensitive to soil moisture availability than GS1. The PASM has a significant positive influence on grain and stover yield, hence, availability of soil moisture at later stages determines the growth and development of pearl millet and ultimately the yield than the early stage.

Table 8. PASM based multiple regression equations for growth parameters. Depth 0-15 cm = X1, 15-30 cm = X2, 30-45 cm =X3, 45-60 cm = X4. LAI= Leaf area index, TDM= Total dry matter, PWC= Plant water content. GS1= Emergence to tillering, GS2= Flag leaf to flowering, GS3= Milking to maturity. TD= Total duration.

Multiple regression equations	R2
LAI (GS3)= 2.21 + 0.70X1 + 1.92X4	0.66
LAI = 4.54 - 0.26X1 - 1.45 X2 -1.03 X3 - 0.58 X4	0.58
Height (GS3)= 136.25 + 22.69 X1 + 82.34 X2 + 25.49 X3 - 16.72 X4	0.86
Height (TD) = 217.35 + 12.17 X1 - 44.53 X2 - 66.36 X3 - 42.99 X4	0.58
TDM (GS3) = 42.88 + 23.52 X1	0.63
TDM (TD) = 66.94 + 12.18 X1 - 27.19 X2 - 17.25 X3 - 25.11 X4	0.67
PWC(GS1) = 136 -51.69 X4	0.46
PWC(GS2) = 90.45 + 5.12 X1	0.42
PWC (TD) = 96.46 -1.38 X1 - 19.85 X2 + 12.62 X3 -5.54 X4	0.35

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