LR-5308
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RESEARCH ARTICLE

Legume Research- An International Journal

Weather based Yield Prediction of Pigeonpea Crop with the Resource Use Efficiency under Varied Sowing Windows

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10.18805/LR-5308

ABSTRACT

Background: Sowing of crops at the optimal time is a non-cash input, which maximizes yield by effectively utilizing available resources. Choosing the best sowing time is crucial for exploiting a crop's fullest potential in a specific environment with good agronomic management.

Methods: A long term experiment (2004-2020) was conducted at research farm under AICRP on Agro meteorology field unit, University of Agricultural Sciences, GKVK, Bengaluru from 2004-2020 to find out the different sowing windows on the performance and resource use efficiencies in pigeonpea.

Result: Long term (2004-2020) pooled data analysis reveals that, among the different sowing windows, early sown pigeonpea produced higher seed yield with effective utilization of the resources compared to the normal and late sown crops.

Key words: Pigeonpea, Resource use efficiencies, Sowing windows.

INTRODUCTION

Agriculture is crucial for the economy and food security of tropical nations like India, where rainfed agriculture dominates. India ranks first globally in rainfed agriculture, producing significant quantities of yield of various crops *viz*., 44% rice, 87% coarse cereals, 85% food legumes, 72% oilseeds, 65% cotton and 90% minor millets in rainfed regions (Ghosh *et al.* 2023). Among the pulse crops, pigeonpea is India's primary crop, constituting 63% of the total pulse production in India and characterized by its drought-tolerant nature.

Lower yield and higher variability of crop yield under rainfed condition, combined with the fast demographic increase caused recurrent food crises. Many reasons explain the weakness and spatiotemporal variability in yield of pulses (Lingaraj *et al.* 2019). Pigeonpea crop faces various constraints including water stress (drought and water logging), lack of suitable varieties, untimely sowing, poor input management, inappropriate planting geometry, inadequate technology transfer *etc.* The major determinants of pigeonpea production is the environmental factors such as rainfall, temperature, humidity, sunshine hours, *etc.*, which are influencing crop performance differently (Kuri *et al.,* 2018). Crop growth and development are heavily influenced by weather during the crop season, accounting for 67% of the variation in productivity. Other factors such as soil and nutrient management account for 33% (Kumar *et al.,* 2023). Agro-climatic conditions influence crop selection and productivity, as well as production sustainability (Ramachandrappa *et al.,* 2019). Weather conditions of the rainfed agriculture are highly uncertain and unpredictable. The Indian rainfed agriculture relies heavily on South-West monsoon and it decides the availability of soil moisture during crop season, which greatly depends on the rainfall amount and distribution.

The potential yield of a particular crop under a given agro climatic condition greatly depends on the ideal sowing time. The dry matter accumulation and its partitioning into various organs are determined by the duration of crop growth and development, finally the crop yield. Crop duration can be used to determine the ideal time of sowing. Delayed sowing led to early maturity and makes the sharp decrease in yield compared to a timely sowing, which has a longer growth period and as a result, offers a chance to accumulate more biomass (Nandini *et al.,* 2019). The key for improving the crop growth and productivity is to harness more solar radiation, which allows for the efficient use of available natural resources. Pigeonpea being a qualitatively short day plant exhibits the growth elasticity. Hence, finding a suitable time of sowing plays a predominant role in deciding plant vigour and finally the yield.

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How to cite this article: Thimmegowda, M.N., Manjunatha, M.H., Sathisha, G.S., Huggi, L., Jayaramaiah, R., Soumya, D.V. and Nagesha, L. (2024). Weather Based Yield Prediction of Pigeonpea Crop with the Resource Use Efficiency under Varied Sowing Windows. Legume Research. doi: 10.18805/LR-5308.

Submitted: 21-02-2024 **Accepted:** 05-09-2024 **Online**: 15-10-2024

In the present study, the results of the long term experiment (2004-2020) of different sowing dates on pigeonpea performance and resource use efficiency under Eastern Dry Zone of Karnataka is analysed and correlated with the derived agro meteorological indices.

MATERIALS AND METHODS

The data related to the study has collected from the AICRP on Agro meteorology field unit, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, from the field experiment conducted during *kharif* 2004-2020. The study area represents the Eastern Dry Zone of the Karnataka, where pigeonpea is one of the important pulse crop growing as sole and also intercrop with many of the cereals and pulses during *kharif* season.

The experiment was designed in factorial randomized complete block design with three dates of sowing, three spacing and two varieties. Dates of sowing were categorized as early (May 15th to 30th), normal (June 1st to 30th) and late (July 1st onwards) because the experiment was conducted under rainfed situation from 2004 to 2020. The three spacing includes S_1: 60 cm×22.5 cm, S_2: 90 cm ×22.5 cm and S_3: 120 cm×22.5 cm as second factor. Two varieties (V_1: TTB-7 and V_2: BRG-1) were taken as the third factor of the study.

The five plants from each plot were selected randomly and tagged for recording different phenology and yield attributing components using standard protocol and subjected for analysis.

Some of the important daily meteorological parameters like Tmax (°C), Tmin (°C), sun shine hours (hr day^{-1}), day length (hrs), average relative humidity (%) and rainfall (mm) from 2004-2020 were used to calculate the different derived agro meteorological indices and resource efficiencies *viz*., growing degree days (GDD), photo thermal units (PTU), helio thermal units (HeTU), hydro thermal units (HyTU), heat use efficiency (HUE), photo thermal use efficiency (PTUE), helio thermal use efficiency (HeTUE), hydro thermal use efficiency (HyTUE) and radiation use efficiency (RUE) for the corresponding cropping period from sowing to harvest.

$$\text{GDD (°days)} = \sum [(T_{max} + T_{min}/2)-T_b] \text{ (Monteith, 1984).}$$

Where:

T_{max} and T_{min}= Maximum and minimum temperature, respectively.

T_b= Base temperature and it is 10°C for pigeonpea (Nihalani, 1989).

$$\text{PTU (°days hours)} = \text{GDD} \times \text{Day length (Wilsie, 1962).}$$

$$\text{HeTU (°days hours)} = \text{GDD} \times \text{Sun shine hour (Bright SSH)}$$
(Ram *et al.* 2012).

$$\text{HyTU (°days)} = \sum_{i=1}^{n} = [\text{GDD} \times \text{Average relative humidity (\%)}]$$
(Ram *et al.* 2012)

Where:

n= Daily average RH.

Accumulated value of these indices were used from sowing to harvest of the crop.

$$\text{HUE (kg °days}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Accumulated growing degree days (°day)}}$$

$$\text{PTUE (kg °days hour}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{PTU (°days hours)}}$$

$$\text{HeTUE (kg °days hour}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{HeTU (°days hours)}}$$

$$\text{HyTUE (kg °days}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{HyTU (°days}}$$

$$\text{RUE (kg MJ}^{-1}) = \frac{\text{Grain yield (kg)}}{\text{Solar radiation (MJ)}}$$

Statistical analysis and the interpretation of data

Fisher's method of analysis of variance (ANOVA) was used for analysis and interpretation of the data as outlined by Gomez and Gomez (1984). Factorial RBD was exploited with date of sowing as first factor, variety as second factor and spacing as third factor for assessment of critical difference amongst the treatments. The level of significance used in 'F' tests was p=0.05. Critical differences were calculated wherever 'F' test was significant. For calculation of correlation coefficients with heat map and multiple linear regression between interested parameters of the study conducted by using R studio software.

RESULTS AND DISCUSSION

The pooled ANOVA data from 2004-2020 pertaining to the growth and yield attributing parameters of pigeonpea as influenced by the date of sowing, spacing and varieties presented in the Table 1. One of the most important non-cash input for pigeonpea crop's effective production is the time of sowing. Among the three categories of the sowing significantly higher seed yield (1849 kg ha^{-1}) was recorded in the early date of sowing. While, significantly lower seed yield observed in normal (1146 kg ha^{-1}) and late (841 kg ha^{-1}) sowing windows compared to the early sowing. Significantly higher seed yield of early sown category was attributed to significantly higher number of pod per plant (196.3), pod weight (113.7 g), husk weight (43.3 g) and 1000 seed weight (72.8 g) compared to the normal (121.1, 91.1 g, 34.8 g and 54.1 g, respectively) and late (111.8, 75.8 g, 29.0 g and 543.4 g, respectively) sowing windows. The similar results of significant effect of early sowing on the crop yield were reported by Sharma *et al.* (2023) and Mukherjee *et al.* (2023).

Significantly superior yield parameters of pigeonpea is directly related to the significant increase in the growth parameters *viz*., plant height at harvest (190.6 cm), leaf area at 120 DAS (6032.8 cm^2 plant^{-1}) and total dry matter at

Table 1: Effect of sowing dates on seed yield, growth and yield attributing parameters of pigeonpea varieties sown under different spacing (Pooled data).

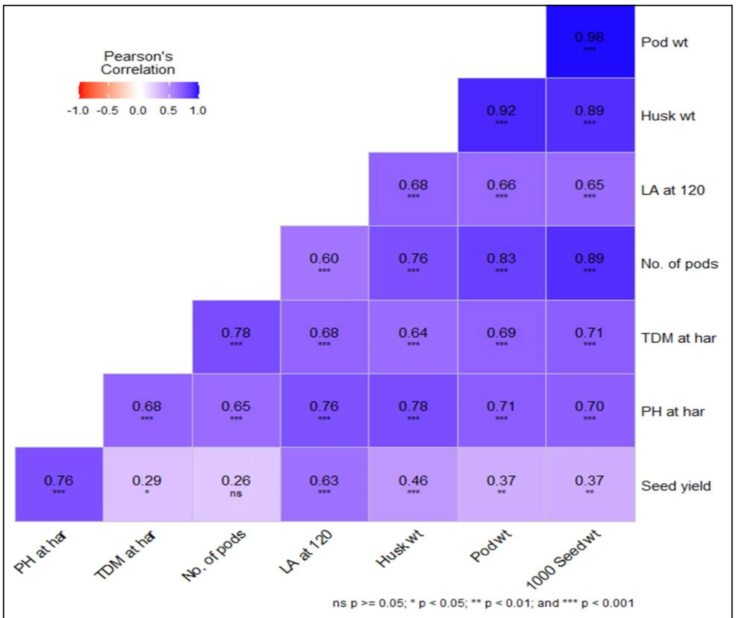
Date of sowing (D)	Seed yield (kg ha^{-1})	Plant height at harvest (cm)	Leaf area at 120 DAS (cm^2 plant^{-1})	Total dry matter at harvest (g plant^{-1})	Number of pods per plant	Pod weight (g)	Husk weight (g)	1000 seed weight g)
Early	1849	190.6	6032.8	189.4	196.3	113.7	43.3	72.8
Normal	1146	154.7	3148.0	136.8	121.1	91.1	34.8	54.1
Late	841	136.3	3251.6	152.2	111.8	75.8	29.0	43.4
S.Em.±	34.77	3.88	109.30	3.55	3.11	2.22	0.84	1.34
CD (P=0.05)	99.95	11.16	314.15	10.22	8.95	6.39	2.41	3.85
Spacing (S)								
S_1 (60 cm×22.5 cm)	1355	158.3	3210.9	140.9	134.5	80.3	32.8	48.5
S_2 (90 cm×22.5 cm)	1312	158.2	4812.9	164.3	134.5	92.7	34.8	55.9
S_3 (120 cm×22.5 cm)	1170	165.2	4408.6	173.2	160.2	107.6	39.6	65.9
S.Em.±	34.77	3.88	109.30	3.55	3.11	2.22	0.84	1.34
CD (P=0.05)	99.95	NS	314.15	10.22	8.95	6.39	2.41	3.85
Variety (V)								
V_1 (BRG-1)	1386	165.6	4339.3	186.3	182.8	102.5	37.2	64.3
V_2 (TTB-7)	1171	155.5	3949.0	132.6	103.4	84.6	34.2	49.2
S.Em.±	28.39	3.17	89.24	2.90	2.54	1.81	0.68	1.09
CD (P=0.05)	81.60	9.11	256.50	8.34	7.31	5.21	1.97	3.14
D×S								
S.Em.±	60.23	6.72	189.32	6.16	5.39	3.85	1.45	2.32
CD (P=0.05)	NS	NS	544.12	17.71	15.51	11.07	4.18	6.67
S×V								
S.Em.±	49.18	5.49	154.58	5.03	4.40	3.14	1.18	1.89
CD (P=0.05)	NS	NS	NS	14.46	NS	9.04	NS	5.44
D×V								
S.Em.±	49.18	5.49	154.58	5.03	4.40	3.14	1.18	1.89
CD (P=0.05)	141.35	NS	NS	14.46	12.66	9.04	3.41	5.44
D×S×V								
S.Em.±	85.186	9.51	267.74	8.715	7.63	5.44	2.05	3.28
CD (P=0.05)	NS	NS	NS	NS	21.93	15.65	5.91	9.43

harvest (189.4 g plant^{-1}) in early sowing windows compared to the normal (154.7 cm, 3148.0 cm^{2} plant^{-1} and 136.8 g plant^{-1}, respectively) and late (136.3 cm, 3251.6 cm^{2} plant^{-1} and 152.2 g plant^{-1}, respectively) sowing windows. Early sowing provides the ideal environmental conditions for better crop growth and development, thereby increased leaf area which helps in effective harnessing of the solar radiation and produced higher biomass till the reproductive stage of pigeonpea crop (Singh *et al.,* 2023). More primary and secondary branches were recorded under the early sown crop, which in turn led to the production of higher pods per plant, which also increased the seed yield. A delayed sowing caused early blooming, which reduced vegetative growth and earliness in maturity might resulted in reduced final output (Jaybhaye *et al.,* 2023).

Among the three spacing tested, the seed yield was found significantly higher (1355 kg ha^{-1}) under 60 cm row spacing which was at par with the 90 cm row spacing (1312 kg ha^{-1}). Whereas120 cm row spacing recorded significantly lower seed yield (1170 kg ha^{-1}). But, significantly higher yield parameters at harvest *viz*., number of pods (160.2), pod weight (107.6 g), husk weight (39.6 g) and 1000 seed weight (65.9 g) were recorded in 120 cm row spacing compared to 90 cm row spacing (134.5, 92.7, 107.6 g, 34.8 g and 55.9 g, respectively) and 60 cm row spacing (134.5, 80.3, 32.8 g and 48.5 g, respectively).It might be due to the less competition between the plants for the resources at wider row spacing thereby it makes the plant to produce superior yield parameters. But the total seed yield is higher in 60 cm followed by 90 cm row spacing due to higher plant population. Similar results were reported by the Math *et al.* (2023) and Amoako *et al.* (2023). Among the growth parameters, the plant height was found at par. Where, 120 cm row spacing recorded 165.2 cm of plant height, followed by 60 cm (158.3 cm) and 90 cm (158.2 cm). While, leaf area at 120 days after sowing (DAS) recoded higher value in 90 cm row spacing (4812.9 cm^{2} plant^{-1}) and it was at par with 120 cm row spacing (4408.6 cm^{2} plant^{-1}). Because of higher leaf area per plant in 120 cm and 90 cm row spacing, significantly higher total dry matter was recorded in 120 cm (173.2 g plant^{-1}) and 90 cm (164.3 g plant^{-1}) as compared to 60 cm (140.9 g plant^{-1}) row spacing.

Varieties differed significantly with respect to growth and yield parameters. The variety BRG-1 recorded significantly higher (1386 kg ha^{-1}) seed yield compared to TTB-7 (1171 kg ha^{-1}). The significantly higher yield in BRG-1 than TTB-7 was mainly due to significantly superior growth and yield attributing components. The plant height at harvest (165.6 cm), leaf area at 120 DAS (4339.3 cm^{2} plant^{-1}), total dry matter at harvest (186.3 g plant^{-1}), number of pods (182.8), pod weight (102.5 g), husk weight (37.2 g) and 1000 seed weight (64.3 g) was higher with BRG-1 compared to TTB-7 (155.5 cm, 3949.0 cm^{2} plant^{-1}, 132.6 g plant^{-1}, 103.4, 84.6 g, 34.2 g and 49.2 g, respectively). The difference in grain yield of pigeonpea varieties was also reported by Kumar *et al.* (2023) and Amoako *et al.* (2023).

The pigeonpea seed yield significantly correlated with the plant's growth and yield parameters (Fig 1). Where, grain yield shows a positive and significant correlation at 0.1% level of significance with husk weight (0.46), leaf area



(PH at har-Plant height at harvest, TDM at har-Total dry matter at harvest, No. of pods-Number of pods, LA at 120-Leaf area at 120 days after sowing, Husk wt.-Husk weight, Pod wt.-Pod weight and 1000 seed wt.-1000 seed weight).

Fig 1: Heat map on person's correlation coefficient between the growth and yield parameters of the pigeonpea as influenced by the date of sowing, spacing and varieties.

at 120 DAS (0.63) and plant height at harvest (0.76). Similarly, at 1% level of significance it is positively correlated with the 1000 seed weight (0.37), pod weight (0.37) and at 5% level of significance with the total dry matter at harvest (0.29). The number of pods (0.26) shows a non significant relation with the seed yield.

Resource use efficiencies and derived agro meteorological indices

Among the three different sowing windows based on the cumulative average values from 2004-2020, the higher heat use efficiency (0.7181 kg °days^{-1}), photo thermal use efficiency (0.0578 kg °days hour^{-1}), helio thermal use efficiency (0.1401 kg °days hour^{-1}), hydro thermal use efficiency (0.0099 kg °days^{-1}) and radiation use efficiency (0.5862 kg MJ^{-1}) were recorded in the early sowing windows followed by normal sowing window (0.5018 kg °days^{-1}, 0.0406 kg °days hour^{-1}, 0.0927 kg °days hour^{-1}, 0.0069 kg °days^{-1} and 0.3845 kg MJ^{-1}, respectively) and late sowing window (0.4104 kg °days^{-1}, 0.0340 kg °days hour^{-1}, 0.0722 kg °days hour^{-1}, 0.0057 kg °days^{-1} and 0.2988 kg MJ^{-1}, respectively) (Table 2). The increased resource use efficiencies in the early date of sowing was due accumulation of the higher dry matter which helps for the better photosynthesis and ultimately produces higher seed yield. The derived agro meteorological indices guides in planting schedules for an orderly harvest of crops and as an index in making crop zonation maps for undeveloped agricultural land and multiple cropping system for effective land use (Banerjee *et al.* 2023). Where, among the different sowing windows highest derived meteorological indices *viz*., growing degree days (2.584 °days), photo thermal units (32.082 °days hours), helio thermal units (13.534 °days) and hydro thermal units (188.224 kg °days^{-1}) were higher in the early sowing window followed by the normal sowing window (2.304 °days, 28.395 °days hours, 12.524 °days, 167.307 kg °days^{-1}, respectively) and late sowing window (2.059 °days, 24.749 °days hours, 12.090 °days, 149.296 kg °days^{-1}, respectively) (Table 2).

The increased agro meteorological indices was mainly due to the increased seed yield under the early date of sowing. The early sown crop might have experienced the suitable or optimum weather conditions during the crop growing period as compared to the normal and late sowing windows. Which was supported by the most favourable (2004-2020) meteorological parameters during the first sowing window's growth period of pigeonpea (Table 3). Where, the coefficient of variation for the early, normal and late sowing windows for the rainfall amount (30.6%, 27.0% and 39.3%, respectively) and the number rainy days (21.2%, 31.6% and 29.6%, respectively) were maximum. Whereas, the other observed meteorological parameters *viz*., maximum temperature (1.47%, 9.76 % and 7.30%, respectively), minimum temperature (1.80%, 4.82% and 4.10%, respectively), sunshine hours (9.84%, 0.001% and 13.07%, respectively), solar radiation (6.77%, 8.40% and 8.26%, respectively), day length (0.78%, 0.90% and 0.71%, respectively) and average

Table 2: Effect of sowing windows on accumulated agro meteorological indices and resource use efficiencies of pigeonpea crop (Pooled data).

Sowing window	Yield (kg ha^{-1})	GDD* (°days)	PTU* (°days hours)	HeTU* (°days)	HyTU* (kg°days^{-1})	HUE* (kg°days^{-1})	PTUE* (kg°days hour^{-1})	HeTUE* (kg°days hour^{-1})	HyTUE* (kg°days^{-1})	RUE (kg MJ^{-1})
Early	1849	2.584	32.082	13.534	188.224	0.7181	0.0578	0.1401	0.0099	0.5862
Normal	1146	2.304	28.395	12.524	167.307	0.5018	0.0406	0.0927	0.0069	0.3845
Late	841	2.059	24.749	12.090	149.296	0.4104	0.0340	0.0722	0.0057	0.2988

*Values for the given indices and efficiencies are in multiples of 1000.

relative humidity (1.65%, 2.46% and 2.88%, respectively) were not much varied across the year. The less variation in the rainfall amount and its distribution in the early sowing window might have positively impacted the soil to store the moisture for the longer period of time during the crop growing period. Thereby the crop might have not experienced the moisture stress at critical phenophases of crop under the early sowing window compared to the late sowing window. And these effects were positively influenced the highest number of days taken from sowing to harvest in early (191.5) compared to the normal (178.5) and late sowing (167.7). Hence, the early sown crop produces a highest crop yield due to the favourable environmental condition experienced during the growth period of crop. Similar results were obtained by the Amoako *et al.* (2023) and Appiah *et al.* (2023).

Correlation and multiple linear regression studies

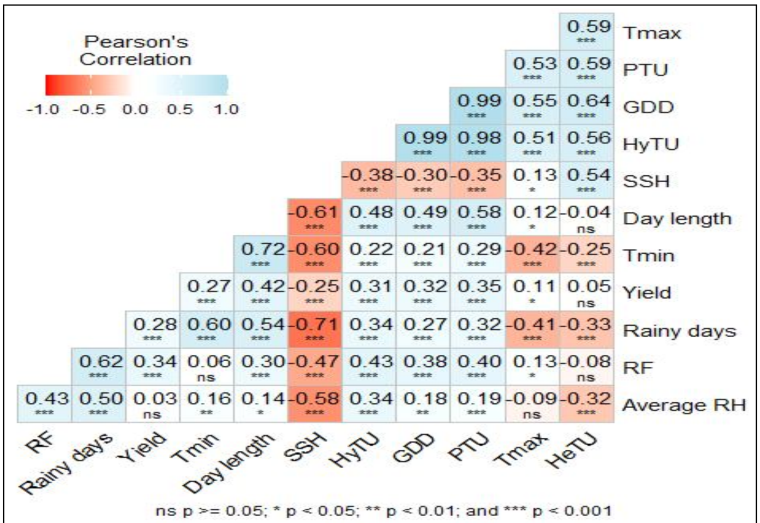
Pigeonpea seed yield shows positive correlation with the rainfall (0.34), rainy days (0.28), minimum temperature (0.27), day length (0.42), hydro thermal units (0.31), growing degree days (0.32) and photo thermal units (0.35) at 0.1% level of significance. Maximum temperature shows a correlation co efficient of 0.11 at 5% level of significance with yield.

Helio thermal use efficiency and average relative humidity shows a non-significant correlation coefficient of about 0.05 and 0.03, respectively at 5% level of significance with the seed yield (Fig 2).

The multiple linear regression between the pigeonpea seed yield with the observed meteorological parameters (2004-2020) was analysed. The results revealed coefficient

Table 3: Normal (2004-2020) meteorological parameters during the different sowing window's cropping period of pigeonpea.

	T max (°c)	T min (°c)	SSH (hr day^{-1})	SRAD (MJ m^{-2} day^{-1})	Day length(hrs)	Average RH(%)	RF (mm)	Rainy days	Crop duration (Days)
					Early				
Average	28.26	18.85	5.17	3179	12.46	73.45	731.4	45.2	191.5
SD	0.42	0.34	0.51	215.40	0.10	1.21	224.0	9.6	14.5
CV (5%)	1.47	1.80	9.84	6.77	0.78	1.65	30.6	21.2	7.6
					Normal				
Average	27.28	18.66	5.41	2999	12.37	73.07	579.3	42.6	178.5
SD	2.66	0.90	0.54	254.21	0.11	1.80	153.2	13.3	13.7
CV (5%)	9.76	4.82	0.001	8.40	0.90	2.46	27.0	31.6	7.6
					Late				
Average	27.01	17.68	5.97	2838	12.05	72.85	513.2	31.4	167.7
SD	1.98	0.73	0.76	232.56	0.09	2.10	199.5	2.3	11.42
CV (5%)	7.30	4.10	13.07	8.26	0.71	2.88	39.3	29.6	6.81



(Tmax-Maximum temperature, Tmin-Minimum temperature, RH-Relative humidity, SSH-Sun shine hours, RF-Rainfall, HeTU-Helio thermal units, HyTU-Hydrothermal units, GDD-Growing degree days, PTU-Photo thermal units).

Fig 2: Heat map on person's correlation coefficient between the pigeonpea seed yield, observed meteorological parameters and derived agro meteorological indices.

Table 4: Multiple linear regression model with significant meteorological parameters for the prediction of seed yield of pigeonpea under different sowing windows.

Regression equation		R^2 value
Early	Yield = -293204.10 + 2150.53(T_{max}) + 8621.03(T_{min}) - 15497.33(SSH) + 21.20(RF) + 25.50(SRAD) - 1698.51(RHI) + 801.47(RHII) + 17135.54(DL) - 1030.37(NRD).	0.75
Normal	Yield = -48537.81 + 283.16(T_{max}) -77.78(T_{min}) + 824.10(SSH) -2.76(RF) -0.3593(SRAD) -2.19(RHI) + 61.80(RHII) + 2914.34(DL) + 57.32(NRD).	0.24
Late	Yield = -30212.60 + 41.43(T_{max}) + 196.70(T_{min}) + 143.76(SSH) + 1.29(RF) + 0.3029(SRAD)+ 110.51(RHI) -59.74(RHII) + 1418.61(DL) -0.06(NRD).	0.49

Where, T_{max}: Maximum temperature (°C), T_{min}: Minimum temperature (°C), SSH: Sunshine hours (hr day^{-1}), RF: Rainfall (mm), SRAD: Solar radiation (MJ m^{-2} day^{-1}), RHm: Relative humidity morning (%), RHe: Relative humidity evening (%), DL = Day length (hrs) and NRD = Number of rainy days.

of determination (R^2) was significant between the seed yield with the significant meteorological parameters *viz*., maximum temperature, minimum temperature, sunshine shine hours, rainfall, solar radiation, morning relative humidity, evening relative humidity, day length and number of rainy days contributed directly the pigeonpea yield to the extent of 75%, 24% and 49% in the early, normal and late sowing windows (Table 4).

CONCLUSION

Based on the long-term data analysis of the different sowing windows on the pigeonpea crop performance in eastern dry zone of the Karnataka, early sowing of the pigeonpea is performed well by producing a higher seed yield with the better resource use efficiency as compared to the normal and late sowing windows. Where, the early sown crop gets a good amount of the rainfall at various growth stages with better distribution during the cropping period and enables the soil to store the moisture for the longer period of time thereby reduces the chance of facing the dry spell at different crop growth stages. Whereas, late sown crop recorded lower yield due to the less amount of the rainfall received during the cropping period with the poor distribution of the rainfall compared to the early and normal sowing windows.

Conflict of interest

All authors declare that they have no conflict of interest.

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