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Research Paper

Crop-weather relationship of soybean in Marathwada region of Maharashtra

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ABSTRACT

A long-term experiment was conducted during *kharif* seasons of2013 to 2020 at AICRP on Agrometeorology, VNMKV, Parbhani, to study the crop-weather relationship of soybean grown under four environments (27th SMW, 28th SMW, 29th SMW and 30th SMW) with three soybean varieties (MAUS-158, MAUS-71, and JS-335). Results indicated that soybean yield was significantly highest in (1541.4 kg ha^{-1}) in the early sown crop, and it decreased with delay in sowing with the lowest yield (803.8 kg ha^{-1}). Among the cultivars, MAUS-158 produced significantly the highest yield (1321.3 kg ha^{-1}). Correlation analysis between weather parameters during different phases with the yield revealed that the vegetative and grain formation period of soybean were found to be the most sensitive to weather parameters, as the correlation coefficients with most of the weather parameters. Rainfall, number of rainy days, humidity and soil moisture had favorable effects while temperatures and sunshine duration had negative effects on the yield of soybean in the Marathwada region. Individual weather parameters during 50% flowering to maturity period could explain 40 to 55% variation in the soybean yield while the multiple regression developed all weather parameters during grain formation to physiological maturity period could explain up to 82% variation which could be used the predict the soybean yield in Marathwada region

Keywords: Soybean, Sowing environment, Crop weather relationship, Soil moisture, Rainy days, Prediction equations

Every crop/cultivar has its climatic requirements in terms of temperature, sunshine hours, rainfall, etc. for attaining potential yield. The responses and requirements of these variables determine the growth and development of a plant in a given environment. The growth and yield of crops are dependent upon the integrated effects of weather phenomena prevailing during different growth stages (Bal *et al.,* 2023). Understanding the thresholds of weather variables and their interactions with crop phenology and yield is the key to enhancing crop production (Sattar *et al*., 2017). Soybean (*Glycine max*) is one of the most important food crops being rich in protein, and also a valuable source of edible oil (Medic *et al*., 2014). Planting a crop on different dates during a year exposes the crop to different temperature regimes during its growing season, allowing an understanding of crop responses to temperature without the artificial conditions imposed by controlled environments (Vijaya Kumar, 2015). Such experiments help us to understand how the changes in thermal and moisture regimes during different growth stages influence crop productivity (Bal *et al.,* 2018). Soybean cultivation is highly sensitive to environmental conditions (Bhagat *et al.,* 2017), and temperature plays a critical role in various stages of its growth cycle, from germination to flowering and pod development. Under climate change scenario Balvanshi, and Tiwari. (2019) had reported that the delay in sowing would be beneficial for soybean in Madhya Pradesh. Khan *et al.* (2023) applied various statistical and machine-learning techniques to predict the soybean yield in Uttarakhand using different weather parameters. Soil moisture levels also significantly impact soybean growth and yield, affecting nutrient uptake, root development, and overall plant health. Therefore, an attempt has been made to understand the intricate relationship between weather parameters during different phases of the soybean crop and its yield using long-term experiments conducted as Parbhani, Maharashtra.

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MATERIALS AND METHODS

The study aimed to evaluate the influence of weather parameters and soil moisture on soybean grain yield by conducting field experiments at AICRP on Agrometeorology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during the kharif seasons from 2013 to 2020. Treatments consisted of four sowing environments (27th SMW, 28th SMW, 29th SMW and 30th SMW) in the main plot and three varieties (MAUS-158, MAUS-71, and JS-335) in sub-plots, laid out in a split plot design with three replications. The crops were grown under recommended package of practices for rainfed conditions, with diligent weed control and pesticide application as needed. Phenological events such as sowing, flower initiation, pod formation, grain formation, and physiological maturity were recorded and averaged over the years to determine the timing of these phases. The daily weather data such as rainfall, rainy days, maximum and minimum temperatures, relative humidity, bright sunshine hours, and soil moisture were collected from the nearby Agrometeorological Observatory. Phenophase-wise weather parameters were correlated with the yield of soybean and simple and multiple regression equations were developed to understand the extent of influence of weather on soybean crop yield.

RESULT AND DISCUSSION

Effect of sowing environment and cultivar

The yield of soybean as influenced by sowing environment (27th SMW, 28th SMW, 29th SMW and 30th SMW and cultivar (MAUS-158, MAUS-71, and JS-335) is presented in Table 1. Among the four sowing environments, soybeans sown in 27th SMW exhibited the highest grain yield (1541.4 kg ha^{-1}), with yields gradually decreasing as sowing was delayed. The lowest yield (803.8kg ha^{-1}) is obtained under the last date of sowing (30th SMW). Among the cultivars tested, MAUS-158 demonstrated the highest yield (1321.3 kg ha^{-1}), followed by MAUS-71 and JS-335.

Influence of weather parameters on soybean yield

The correlation analysis worked out between grain yield and weather parameters during different phases of soybean using 8 years data (2013-2020) shows the differential effect of various weather parameters during different growth stages on soybean yield (Table 2). Rainfall exhibited a highly significant positive correlation with grain yield during the sowing to flower initiation stage (0.57**) and grain formation to physiological maturity stage (0.81**). However, it showed a negative significant correlation during the flower initiation to pod formation stage (-0.38*). This suggests that adequate rainfall during certain growth stages positively influences soybean seed yield, while excess or deficient rainfall during other stages may have adverse effects. Similar correlations were obtained with number of rainy days, relative humidity and soil moisture. The morning relative humidity (RH-I) had positive correlations 0.40* and 0.58**respectively during sowing to flower initiation stage and grain formation to physiological maturity stages while afternoon relative humidity (RH-II) showed positive significant correlations with grain yield 0.50* and 0.61** respectively during sowing to flower initiation stage and grain formation to physiological maturity stage. The soil moisture percent also influence soybean seed yield similar to rainfall that during flower initiation stage and grain formation to physiological maturity stages, it positively influenced the soybean yield.

Table 1: Yield of soybean under different treatments (pooled for 2013 to 2020)

Treatments	Grain yield (kg ha^{-1})
Sowing environments	
27th SMW	1,541.4
28th SMW	1,360.3
29th SMW	1,331.8
30th SMW	803.8
SE±	11.9
CD (0.05)	42.0
Varieties	
MAUS-158	1321.3
MAUS-171	1230.9
JS-335	1225.8
SE±	10.2
CD (0.05)	30.9
Interaction (D x V)	
SE±	20.5
CD (0.05)	65.5

Contrary to moisture regimes as discussed above, the weather parameters of thermal regimes like maximum temperature, minimum temperature, and bright sunshine hours (BSS) displayed negative correlations with grain yield from sowing to maturity. Maximum temperature had significant negative correlations -0.54* and-0.81** respectively, during sowing to flower initiation stage and grain formation to the physiological maturity stage of soybean while the minimum temperature had significant negative correlations -0.33* and-0.43* respectively, during sowing to flower initiation stage and pod formation to grain formation stages. The bright sunshine hours (BSS) had similar effect as that of maximum temperature (Table 2).Thus, it is seen that the different weather parameters during different stage of the soybean crop had differential effect on the yield.

An attempt has also been made to understand the extent to which weather parameters influence the soybean yield, simple regression equations were developed between rainfall, rainy days, maximum temperature and soil moisture during 50 % flowering to maturity stage of soybean with soybean yield and are presented in Figs 1 to 4. It is seen from Fig. 1 that the rainfall during the 50% flowering to maturity phase displayed a positive linear relationship with grain yield, with a coefficient of determination (R^2) of 0.449, which signifies that about 45% in soybean yield can be explained by the rainfall only. One mm of additional rainfall during 50% flowering to maturity phase may increase the yield by 5 kg ha^{-1}. The number of rainy days has better explanation of the soybean yield (R^2 = 0.55) than the rainfall (R^2 = 0.45) (Fig. 2). One additional

Table 2: Correlation coefficients between grain yield and weather parameters during different phenophases of soybean

Stages	Rainfall	Rainy days	Maximum temperature (T_{max})	Minimum temperature (T_{min})	Morning relative humidity (RH-I)	Evening relative humidity (RH-II)	Sunshine hours (BSS)	Soil moisture percent (SM)
Sowing to flower initiation	0.57**	0.20	-0.54*	-0.33*	0.40*	0.50*	-0.52**	0.42*
Flower initiation to pod formation	-0.38*	-0.41*	-0.01	-0.05	-0.09	-0.25	0.03	-0.41*
Pod formation to grain formation	-0.17	-0.15	-0.01	-0.43*	-0.22	-0.19	0.21	0.21
Grain formation to physiological maturity	0.81**	0.83**	-0.81**	0.16	0.58**	0.61**	-0.67**	0.63**

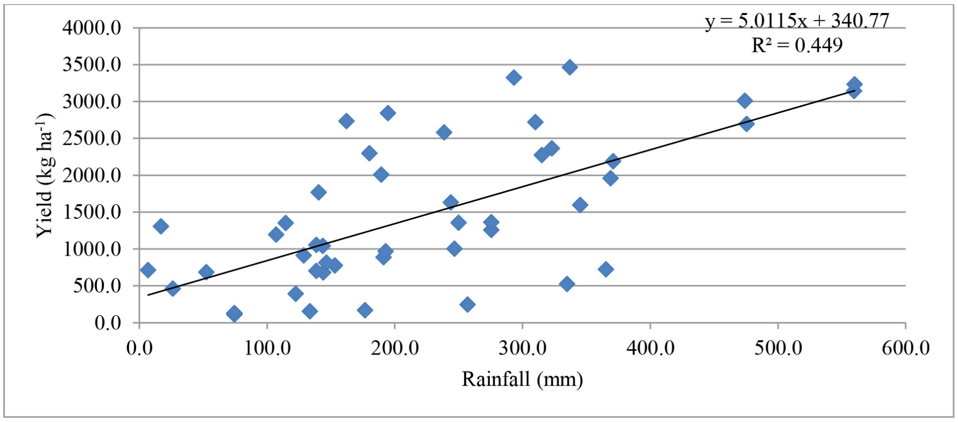

Fig. 1: Relationship between grain yield and rainfall (mm) during 50 % flowering to maturity stage of soybean

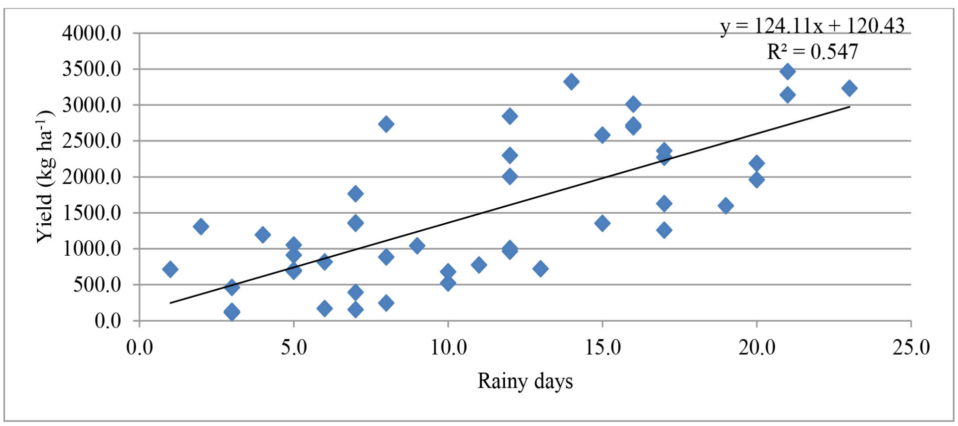

Fig. 2: Relationship between grain yield and rainy days during 50 % flowering to maturity stage of soybean

rainy day may increase the yield by 124 kg ha^{-1}. The maximum temperature during 50% flowering to maturity phase exhibited overall a negative relationship with grain yield with R^2 of 0.40 (Fig. 3). The relationship signifies hat with an increase in maximum temperature by 1°C, the yield may decrease to the extent of 640 kg ha^{-1}. Furthermore, soil moisture during the 50% flowering to maturity stage showed a positive linear relationship with grain yield, with an R^2 of 0.51, significant at the 1% level. Soil moisture explained 51.1% of the total variation in grain yield (Fig. 4).

These findings corroborate previous studies, such as those reported by Hays *et al.,* (2007), which observed that increased temperature can restrict growth and productivity, particularly during reproductive crop stages. Soybean yield is particularly sensitive to water deficits during the pod-filling stage of development (Westgate *et al*., 1993).

Development of prediction equation

Multiple linear regression models were developed to predict the grain yield of soybean at different stages of crop growth, with grain yield as the dependent variable and weather parameters occurring at various growth phases as independent variables (Table 3). The models were able to explain 69%, 50%, 41%, and 82% of the total variations in grain yield by linear functions during sowing to flower initiation, flower initiation to pod formation, pod formation to grain formation, and grain formation to maturity stages, respectively. Among these, the model based on weather data during the grain formation to maturity stage exhibited the highest R^2 value of 0.82**, indicating that rainfall, rainy days, maximum and minimum temperatures, and soil moisture during this stage played the most vital roles in influencing soybean grain yield. The results suggest that the grain formation to maturity stage is

Table 3: Regression equations for grain yield prediction using weather parameters during different phenophases of soybean

Growth phases	Regression equations	R^2
Sowing to flower initiation	$Y=-9930.78+2.8947X_1-98.818X_2+100.85X_3+286.36X_4-283.07X_5+143.12X_6$	0.69
Flower initiation to pod formation	$Y=-1580.88-5.558X_1-63.47X_2-11.64X_3+223.25X_4-180.45X_5-8.19X_6$	0.50
Pod formation to grain formation	$Y=-3219.36-9.05X_1+161.03X_2-48.41X_3+174.55X_4-79.56X_5+91.37X_6$	0.41
Grain formation to physiological maturity	$Y=-3096.04+0.04X_1+61.76X_2-27.05X_3-81.67X_4-256.57X5+64.54X_6$	0.82

Y= Grain yield of soybean (kg ha^{-1}), X_1 = Rainfall (mm), X_2= Rainy days, X_3=Maximum temperature (°C), X_4 = Minimum temperature (°C), X_5=BSS (hours), X_6= Soil moisture (%)

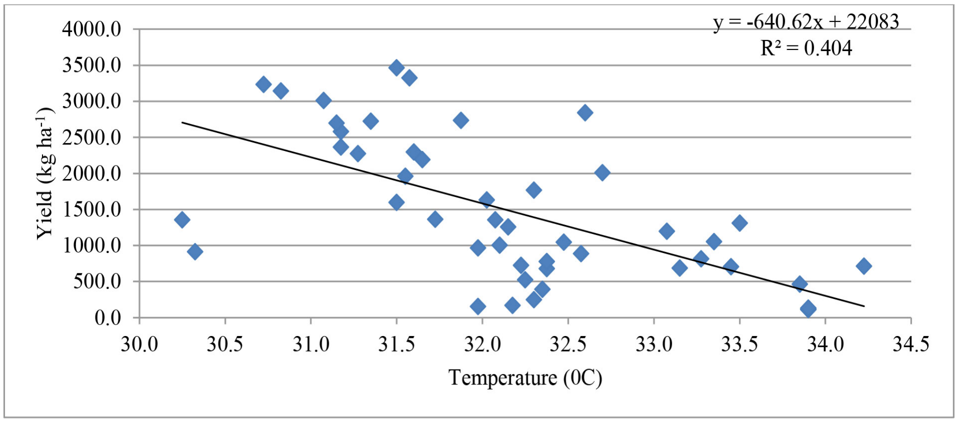

Fig. 3: Relationship between grain yield and temperature (°C) during 50 % flowering to maturity stage of soybean

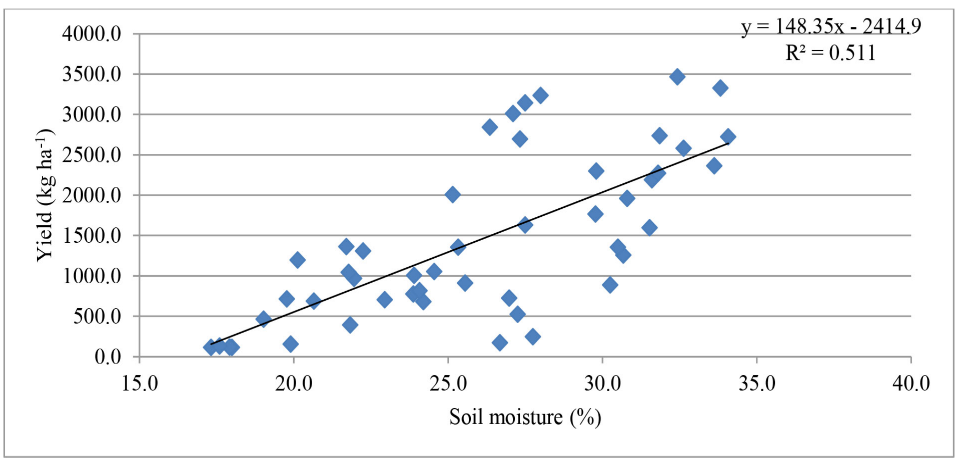

Fig. 4: Relationship between grain yield and soil moisture (%) during 50 % flowering to maturity stage of soybean

the most sensitive phase of growth, followed by sowing to flower initiation and flower initiation to pod formation stages, in terms of their susceptibility to discrepancies in rainfall, soil moisture, and temperature variations associated with late sowing environments. Elevated temperatures above a threshold value during the flowering to pod formation period can significantly reduce yield by adversely affecting subsequent reproductive processes (Wheeler *et al*., 1996).

CONCLUSION

Weather was found to play a significant role in soybean yield during different phenophases. It was found that, early sown crop enjoys all the favorable moisture regimes resulting in maximum yield. Rainfall, rainy days, humidity and soil moisture had significant favorable effect during the vegetative period (sowing to flower initiation) and a highly significant positive effect influence during grain formation to the physiological maturity period. Temperature and bright sunshine hours were found to have significant negative correlations during these periods. Soil moisture during the 50% flowering to maturity stage alone could explain about 51 % variation in the soybean yield. The multiple regression equation developed incorporating all the weather parameters during grain formation to the physiological maturity stage altogether could explain 82% variation in the soybean yield. This predictive equation can be used for predicting soybean yield in the region.

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Data availability: Data can be made available on request

Author's contributions; **K K Dakhore**: Conceptualization, Investigation, Methodology, editing, Writing-original draft; **Y. E. Kadam**: Data curation, Formal analysis, Writing-review and editing; **D. R. Kadam**: Supervision; **P. R. Kapse**: Writing-review and editing; **R. B. Mane:** Writing-review and editing; **S. K. Bal:** Methodology, Visualization.

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