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Research Paper

Developing weather-based biomass prediction equation to assess the field pea yield under future climatic scenario

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ABSTRACT

The present research focuses on the variation of field pea production under different prevailing weather parameters, aiming to develop a reliable forecasting model. For that a field experiment was conducted in New Alluvial Zone of West Bengal during 2018-19 and 2019-20 with three different varieties (VL42, Indira Matar, Rachana) of this region. Biomass predicting equation based on maximum temperature, minimum temperature and solar radiation was developed to estimate field pea yield for 2040-2099 period under SSP 2-4.5 and SSP 5-8.5 scenarios. It reveals that solar radiation positively influences crop biomass, while high maximum and minimum temperatures have adverse effects on yield. The developed forecasting equation demonstrated its accuracy (nRMSE=17.37%) by aligning closely with historical data, showcasing its potential for reliable predictions. Furthermore, the study delves into future climate scenarios, showing that increasing temperatures are likely to impact field pea yield negatively. Both biomass and yield showed decreasing trend for the years from 2040 to 2099. SSP 5-8.5 scenario, which is more pessimistic one, foresees a substantial reduction in crop productivity. This weather parameter-based biomass prediction equation can be effectively utilized as a method to assess the impact of climate change on agriculture.

Keywords: Field pea, weather parameters, crop yield prediction, New Alluvial Zone, nRMSE

Pea is the third most important pulse crop at global level, after dry bean and chickpea. It's also the third most popular vegetable and *rabi* pulse of India after chickpea and lentil. Field pea is known for its nutritional components and can be fractionized into various ingredients and food products enriched in protein (20–25%), starch (40–50%), fibre (10–20%) etc. (Rubio *et al*., 2014). In India, field pea is cultivated in 6.06 lakh ha and occupies fourth position in production with 8.76 lakh tonnes (FAOSTAT, 2021). West Bengal also put a significant contribution in this scenario with production of 147.26 thousand tonnes with a productivity of 11.89 q ha^{-1} (National Horticultural Board, 2021-22). Now a days in India farmers are keener to cultivate field pea rather than chick pea and other beans due to adjustable sowing and harvesting windows (Saha *et al*., 2020). Accurate yield predictions of these important crops hold considerable value for both trade and industry sectors. Precise and dependable yield predictions have a crucial role in shaping food policies, economic strategies, and food security initiatives within the nation (Ray *et al*., 2014). These projections empower the policymakers to anticipate and strategize the required import or export quantities, contingent on instances of shortages or excess production. Many researchers have done yield forecasting using weather parameters through different complex methods for various crops (Kumar *et al*., 2019). Though many of these techniques require vigorous amount of information and computer programming skill which make the work very tiresome, the need of the hour demands it. Consequently, very less amount of work has been done on yield assessment of field pea in Lower Gangetic Plains. So, a field experiment has been carried for two consecutive years (2018-19 and 2019-20) to establish relationship among the weather parameters and the crop yield as well as to develop a weather-based yield predicting equation. Another objective was to forecast yield of field pea using the yield predicting equation for the future climatic condition.

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MATERIALS AND METHODS

Study location

The field experiment was conducted in C-Block Farm of Bidhan Chandra Krishi Viswavidyalaya (Lat 22^0 58' N and Long 88^0 32' E), Kalyani, West Bengal during *rabi* seasons of 2018-19 and 2019-20. The experimental area is located within the New Alluvial Zone of West Bengal, possessing physiographic and climatic characteristics that mirror those of the lower Indo-Gangetic plains. The soil in the experimental field is alluvial soil with silty clay texture. The average annual rainfall of this area is 1467.5 mm, ranging from 1195.5 to 1691.9 mm and 80% of this rainfall is from South-West monsoon. The warmest month is May with temperature ranging from 27.3 ℃ to 33.5 ℃. January is the coldest month and temperature varies from 14.7℃ to 20.5℃.

Field experiment details

The experiment was laid out in a randomized block design with split plot arrangement; sowing dates in main plots and varieties in sub plots. Three local varieties of field pea i.e., VL42, *Indira Matar* and *Rachana* were sown in three sowing dates at an interval of 10 days, namely 15^{th} November (D_1), 25^{th} November (D_2) and 5^{th} December (D_3) of both 2018-19 (Y_1) and 2019-20 (Y_2) periods. A plant spacing of 30 cm x 10 cm was maintained and 12 square meter plot was allotted for each of the replications. Standard package of practices as recommended for New Alluvial Zone of West Bengal were followed for raising the field pea crop. Overall, maximum temperature ranges from 18.6℃ to 34 ℃, minimum temperature ranges from 7.5 ˚C to 21.5 ˚C and 0.6 to 51 mm rainfall received during the growth stage of the crop for the two experimental years. Stage wise dry matter accumulation of the crop determined using the oven dry weight of the plant sample. The final yield was derived from the harvested pods of the field pea crop. In this study three phenological stages were taken into consideration i.e., vegetative (30 DAS), reproductive (90 DAS) and maturity (125 DAS).

Weather data collection

Daily data on maximum and minimum temperatures, and rainfall during the crop growing season were collected from the nearby Kalyani meteorological observatory. Solar radiation data were generated by utilizing the DSSAT 4.7 model's weatherman tool, which employs daily weather data for the specified years, including maximum temperature (Tmax), minimum temperature (Tmin) and rainfall, to calculate the total solar radiation.

Statistical analysis

A thorough statistical analysis was undertaken, wherein weather data, including maximum and minimum temperatures, total solar radiation, and rainfall, served as independent variables, while crop biomass acted as the dependent variable. These parameters were utilized in various combinations to determine the suitable model. Furthermore, the analysis took into account three diverse sowing dates and three distinct varieties for the year 2018-19 and 2019-20. The primary objective of this analysis was to pinpoint the most accurate model for forecasting the crop yield. The analysis was carried out in excel with the help of 'data analysis' package.

Assessing future yield based on weather parameters

The study period for estimating future yield was ranged from 2040 to 2099. The above-mentioned weather parameter-based yield predicting equation was developed irrespective of varieties to predict the future yield under two climatic scenarios i.e., SSP 2-4.5 and SSP 5-8.5. The SSP 2-4.5 scenario is generally considered a more optimistic path for countries aiming to achieve sustainable development, while the SSP 5-8.5 scenario represents a more pessimistic outlook, characterized by a fossil-based, energy-intensive economy, reflecting the consequences of unconventional development. As a result, we chose to focus on SSP 2-4.5 and SSP 5-8.5 in CMIP6 for our future projections (Arunrat *et al.*, 2022). Global near-surface maximum air temperature, minimum air temperature and precipitation data, simulated by 15 CMIP6 models (ACCESS, CMCC, CNRM-CM6, EC-EARTH3-VEG etc) from 2000 to 2014, were retrieved from the Copernicus climate data store website (https://cds.climate.copernicus.eu/cdsapp#!/home). Then it is compared with observed data set collected from meteorological observatory and the best model was selected for that location. The future data were retrieved then simulated by that selected model for SSP 2-4.5 and SSP 5-8.5 scenario from 2040 to 2099 (https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip6?tab=form).

Predicting yield under climate change scenario

To project the future yield of field peas, we applied a conversion factor with a fixed value of 0.28, which was established based on the observed relationship between biomass (accumulating dry weight of leaf, stem, pod, root biomass) and yield (oven dried grain weight) in the context of this biennial experiment. Field pea yield tends to be affected by pest and diseases (especially pea rust) (Singh *et al.*, 2014) at the time of harvesting. So, the biomass was considered for the analysis. So, to avoid the pest and disease effect, the biomass was predicted first, then yield can be calculated easily with the help of the conversion factor. For our baseline, we considered the average values of the accumulated biomass (8.75 t ha^{-1}) and yield (2.35 t ha^{-1}) data of ten years (2010-11 to 2019-20). These averages were used to represent the current parameters for field pea production. To assess how the projected yield differs from the current production level, we expressed this difference as a percentage.

RESULTS AND DISCUSSION

Predicting biomass using meteorological parameters

In the context of simple linear regression, various combinations of meteorological parameters were employed to create a model for predicting field pea yield. The regression analysis used data on biomass (Table 1) along with weather variables, considering three sowing dates and three distinct varieties across the three aforementioned growth stages in two separate experimental years.

Initially, our focus was on establishing a linear relationship between biomass and meteorological factors, specifically maximum temperature, minimum temperature and rainfall. However, the resulting coefficient of determination (R^2) exhibited notably low values (0.42), indicating that this particular equation was not deemed suitable for our purposes (Table 2). This prompted us to explore alternative modelling approaches to better capture the dynamics of field pea yield in response to meteorological conditions. During the field pea growing season one pre-sowing irrigation and one light irrigation were given at pod development stage. This might be the reason behind the rainfall value in the equation did not give the satisfactory output.

After that the solar radiation value was included and rainfall value has been discarded. In case of this process best result found including biomass of three stages of the crop as dependent variable and SRAD (MJm^2d^{-1}), Tmax (^0C) and Tmin (^0C) as independent variables. The suitable equation with R^2 value of 0.63 (Table 3) or model for predicting field pea yield is as follows:

Y=369.447*SRAD-158.675*Tmax-4.13*Tmin-741.246

This field pea yield forecasting equation is feasible for Tmax in the range of 23.28 ˚C – 32 ˚C, Tmin in the range of 10.6 ˚C – 20.9 ˚C and SRAD in the range of 12.96 $MJm^{-2}d^{-1}$ – 18.41 $MJm^{-2}d^{-1}$. The research outcomes illuminate a fascinating interplay between environmental factors and crop performance. Total solar radiation emerges as a catalyst, exerting a positive influence on crop biomass. Conversely, maximum temperatures showed a detrimental impact, exhibiting a significant negative correlation with total biomass. Higher maximum temperature disrupts net photosynthesis during crucial growth periods, culminating in a slowdown of the plant's growth rate (Basu *et al*., 2016). Furthermore, minimum temperatures also exhibit a negative impact on biomass production and yield. This phenomenon may be attributed to elevated nighttime temperatures, which escalate respiration rates. As a consequence, this process diminishes the translocation of photosynthates from the leaves to the grains, ultimately resulting in reduced yields—a phenomenon supported by earlier studies (Marcellos and Single, 1972; Asana and Williams, 1965). In alignment with these findings, Dubey *et al.* (2011) conducted research that underscores the real-world implications of temperature fluctuations. Their work revealed that with each increment 0.1 ˚C in Tmax, crop yields experienced reductions of 0.038 tha^{-1}, 0.04 tha^{-1} and 0.026 tha^{-1} for chickpea, lentil and pigeon pea, respectively. Moreover, even a modest 0.1 ˚C increase in Tmin had adverse effects on the yield of these three vital crops.

Before applying the yield prediction equation, the equation was verified for its accuracy by using eight years of historical yield and weather data (from 2010-11 to 2017-18) for Nadia district. Predicted yields generated by the weather-based yield predicting equation compared with the actual yields for this time period. When we plotted the predicted yield data against the observed yield data, we found that the points aligned closely along a 1:1 line (Fig. 1). Furthermore, the model's performance was assessed using the Root Mean Square Error (RMSE) and the normalized RMSE (nRMSE) values. The RMSE value was remarkably low at 0.38 tha^{-1}, indicating high accuracy, and the nRMSE value of 17.37 per cent fell within the range of 10 - 20 per cent, suggesting good model performance (Loague and Green, 1991).

Table 1: Yield and plant biomass at maturity achieved by VL 42, *Indira Matar* and *Rachana* varieties

Varieties	2018-19		2019-20	
	Yield (tha^{-1})	Biomass (tha^{-1})	Yield (tha^{-1})	Biomass (tha^{-1})
VL42	2.23	9.30	2.85	9.90
Indira Matar	4.26	12.79	2.72	10.17
Rachana	1.81	7.37	1.47	6.18

Table 2: Statistical analysis of yield as dependent variable and Tmax, Tmin and RF as independent variable

Regression Statistics	
Multiple R	0.64
R Square	0.42
Adjusted R Square	0.38
Standard Error	415.31
Observations	54

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	6131272	2043757	11.8	5.59E-06
Residual	50	8623921	172478.4		
Total	53	14755193			

Table 3: Statistical analysis of yield as dependent variable and Tmax, Tmin and SRAD as independent variable

Regression Statistics	
Multiple R	0.80
R Square	0.63
Adjusted R Square	0.61
Standard Error	329.11
Observations	54

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	9339579	3113193	28.7	6.04E-11
Residual	50	5415615	108312.3		
Total	53	14755193			

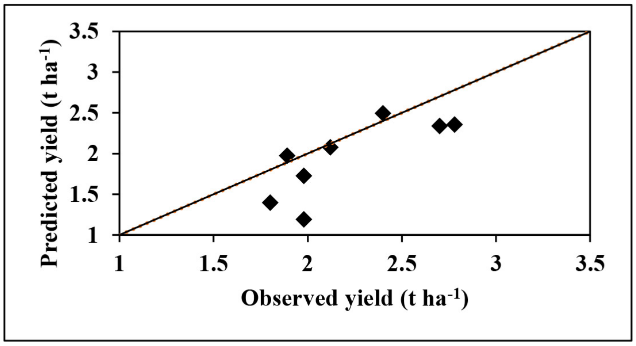

Fig. 1: Comparison of observed and predicted yield of field pea for the period of 2010-11 to 2017-18 through 1:1 line

Assessing future climatic scenario during field-pea growth period

Within the provided figure (Fig. 2), a visual representation showcases the deviation in Tmax when compared to the baseline data from 1991 to 2022. This analysis was performed for two distinct scenarios: SSP 2-4.5 and SSP 5-8.5, with a specific focus on field pea growing season spanning from November 15th to March 16th using the future data, retrieved and simulated by the best suited model (EC-EARTH3-VEG) for this location. The baseline Tmax during this period is recorded at 27.9 ˚C. What emerges as a significant observation is that in both SSP scenarios, temperatures exhibit a consistent upward trend from 2040 to 2099. On average, the deviation from the baseline data is measured at 0.27 ˚C for SSP 2-4.5 and 0.40 ˚C for SSP 5-8.5 up to 2070. Especially after mid-

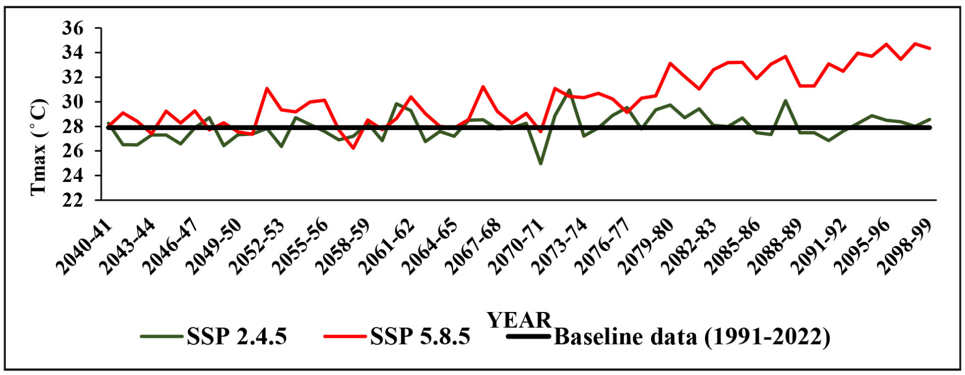

Fig. 2: Future climatic scenario for maximum temperature (Tmax)

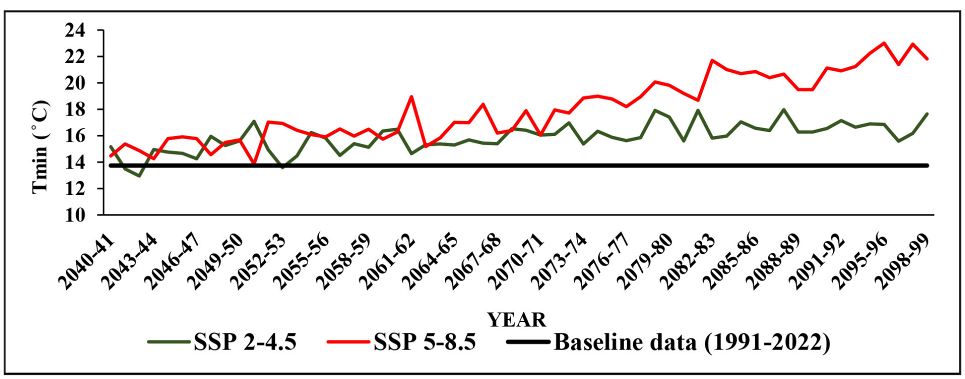

Fig. 3: Future climatic scenario for minimum temperature (Tmin)

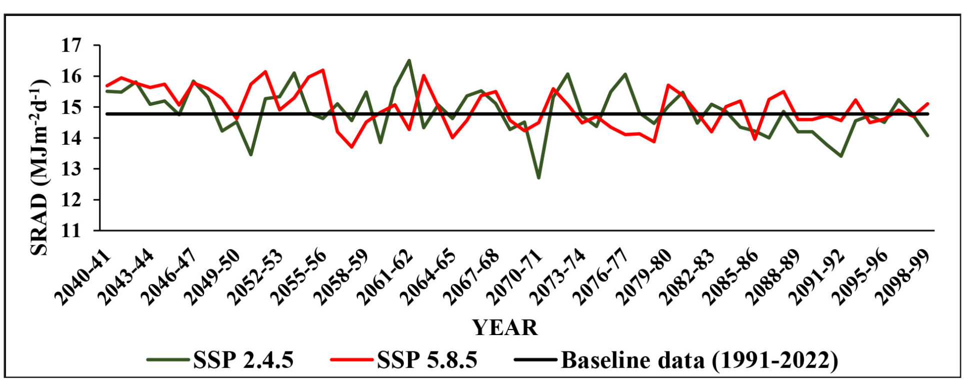

Fig. 4: Future climatic scenario for solar radiation (SRAD)

Table 4: Situation of yield and biomass of field pea in future under SSP 2-4.5 and SSP 5-8.5 scenarios

Year	Biomass derived from weather data (t ha^{-1})		Yield (t ha^{-1})		Variation in biomass relative to the current average biomass (%)		Variation in yield relative to the current average yield (%)	
	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5
2049-50	4.76	4.31	1.33	1.21	-48.75	-55.14	-51.08	-55.61
2059-60	3.17	2.30	0.88	0.64	-65.80	-76.28	-67.35	-76.28
2069-70	3.01	0.74	0.84	0.21	-67.53	-92.35	-69.04	-92.35
2079-80	1.72	-	0.48	-	-81.47	-	-82.31	-
2089-90	0.87	-	0.24	-	-90.61	-	-91.04	-
2098-99	0.39	-	0.11	-	-95.73	-	-95.92	-

century the maximum temperature increased at higher rate and goes up to a maximum value of 34.71 ˚C for this cropping season.

Intriguingly, when examining SSP 2-4.5 and SSP 5-8.5, we observe that the average increase in Tmin, in comparison to the baseline, stands at 2.12 ˚ Cand 4.16 ˚ C, respectively (Fig. 3). This phenomenon is notable, given that the baseline Tmin for this period is 13.74 ˚C. In both the scenarios the most of the values were above the baseline data. Importantly, the increment in Tmin surpasses that of the maximum temperature, signalling potential challenges for crop growth and ecosystem dynamics.

In case of solar radiation, a significant observation emerges that there is overall rise in solar radiation levels for both SSP scenarios but the increment was not consistent over the decades. To be specific, solar radiation exceeds the baseline level by 0.07 MJm^{-2}d^{-1} in SSP 2-4.5 and by 0.2 MJm^{-2}d^{-1} in SSP 5-8.5. The baseline data for solar radiation was 14.77 MJm^{-2}d^{-1} (Fig. 4). In case of SSP 5-8.5 scenario at the end of the century the solar radiation data was 2.25 % more than the baseline.

Evaluating field-pea yield under projected climatic scenario

In this study, variations in biomass production and the yield of field peas under projected future climatic conditions were observed (Table 4). The developed model was feasible upto mid-century (2040-2069) for SSP 5-8.5. Beyond this, the values of the considered weather parameters were exceeding values which considered for the model development. Both biomass and yield showed decreasing trend with the passing year from 2040 to 2099. For SSP 5-8.5 where the world characterized by high challenges to sustainability faces more yield loss than SSP 2-4.5. At 2049-50 the yield has been reduced to almost half (1.33 t ha^{-1}) from the present average yield for SSP 2-4.5 and in 2098-99 it has been reduced to 0.11 t ha^{-1}. Biomass also reduced 48.75 % and 55.14 % from present average biomass for SSP 2-4.5 and SSP 5-8.5, respectively in 2049-50. Between 2080 and 2100, it is foreseen that India may experience a 10-40 % decline in crop productivity. This is chiefly attributed to escalating temperatures, unpredictable rainfall patterns, and alterations in their timing. Kadiyala *et al.* (2016) found in their study that the expected climate change by 2069 (in the mid-century period) will lead to a reduction in chickpea yield, ranging from 4.3 % to 18.6 % across different tested locations of Andhra Pradesh, in comparison to the baseline climate. Beside this among the crops studied, field pea demonstrates the highest sensitivity to the anticipated climate changes in the future. It has been found through APSIM 7.5 model that the projected changes in field pea yield, as indicated by the ensemble median, vary from a decrease of 12 % to a decrease of 45 %, contingent upon the specific location (Anwar *et al.*, 2014).

CONCLUSION

It can be concluded that there was a strong relationship between weather parameters (maximum temperature, minimum temperature, solar radiation and rainfall) and the crop yield as well as biomass of field pea, although rainfall should not be included in the development of linear regression model to predict field pea yield. To develop predictive equation, solar radiation can be considered as a significant and valuable determinant instead of rainfall for our study area. Solar radiation had positive correlation with crop yield while maximum and minimum temperature had a negative impact. As both maximum and minimum temperatures showed an increasing trend for the future, there was a corresponding decrease in crop yield. The developed equation worked well which was validated with historical data-set and observed as effective one in assessing crop biomass and yield, which demands minimal input data. In the both future climatic conditions (SSP 2-4.5 and SSP 5-8.5), the crop yield has been declined mainly due to increase of maximum and minimum temperature. Considering the climate change issues, this paper forms a base to address adaptation strategies and related policies.

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Conflict of interest: The authors declare that there is no conflict of interest.

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