Atmospheric Aerosol and weather vulnerability on Maize production in India

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Abstract

The gradual increment of anthropogenic aerosol pollutants, changes the properties of atmosphere and causes a significantly negative impacts on agriculture. The present study evaluated the long term aerosols and weather impact on the maize yield during the time period from the years 1998 to 2019 in India. The multiple linear regression analysis is carried out between the dependent variable (maize yield) and independent variables (AOD and weather). The performance of multiple linear regression analysis is found excellent between the dependent and independent variables in terms of the coefficient of determination (R^2 = 0.945), root mean squared error (RMSE = 0.515 tons/hectare) and bias (0.0 tons/hectare). The atmospheric aerosols impact on the weather parameters is also evaluated because the changes in weather parameters due to aerosol is also affected the crop yield. The linear regression analysis is carried out to evaluate the aerosols impact on weather parameters and it is observed that the yearly increases in AOD impacts more on temperature variations than the fraction of absorbed photosynthetically active radiation (FAPAR) variation. The overall loss in maize yield is found approximately 8.8% per year due to variations in the weather variables with the increment of anthropogenic aerosol pollutants during 1998-2019 over India. In future, the climate warming and increment of aerosols may have differing impacts on crop yield and should be jointly considered in any assessment of Indian food security.

1. Introduction

The Green Revolution is adopted in India around 1960s, has play critical roles in the world food economy as well as food security[1]. Now a day, India has produced the food within the country to feed around 1.2 billion peoples of its population. Other Asian and African nations are also depending on the Indian agriculture production and they import the Indian rice and wheat grains to ensure their food security [2]. The Maize crop production is contributing about 36 % of global grain production, which is cultivated over around 150 m ha in about 160 countries with various soil diversity, climate, biodiversity and management practices [3]. The maize crop is the third most important crop in India after rice and wheat [4] with average productivity is about 2.43 t ha^{-1} and it contributing nearly 9 % in the national food basket. In addition, the maize is used as basic raw material for ingredients in various industrial products namely starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package etc. [5].

It is essential to have a complete understanding of the processes involved in crop growth and its development for the getting the appropriate agriculture production to ensure the proper food supply with population rises. The plant growth is influenced by various factors like climate variables, agricultural practices/management, availability of nutrients, and water in the soil etc. The most important climate variables like solar radiation, temperature and precipitation is affected by the by atmospheric aerosols [6]. Aerosols are mixtures of solid and liquid particles suspended in the atmosphere that come in a variety of sizes, forms, and compositions. The understanding about the interaction of aerosol particles with the radiation, temperature, and precipitation is very necessary to analyse the effects of aerosols on plant growth. The atmosphere aerosols also significantly affect the water cycle, climate, and public health [7]. The temperature of the Earth has been directly impacted by aerosol, which scatters and absorbs incident solar energy [8]. The understanding of specific role of aerosol in crop productivity will be critical from the assessment of overall impact of climate change and air quality on agricultural food security in particularly for high-pollution regions like India [9].

First time this study is carried out to examine the impacts of climate (temperature and precipitation), fraction of photosynthetically absorbed active radiation (FAPAR) and the aerosols on historical maize yields in India. The statistical model is used to estimate the temperature, FAPAR and aerosol impacts on historical maize yields. The long-term (1998-2019) spatial and temporal variation of maximum and minimum temperature, rainfall (RF), relative humidity (RH), soil moisture (SM), FAPAR and aerosol optical depth (AOD) have been used to develop the statistical model and analyzing their impacts with historical maize yield.

2. Data and Methodology

2.1 Data collection

In this study the entire crop land over India is taken as the region of interest /study area. The classified crop land region has been taken from the MODIS land use and land cover (LULC) classification based on International Geosphere-Biosphere Program (IGBP) over India, which is classified into total 17 broad categories. The daily gridded $(1°\times1°)$ data of maximum temperature $(T_{\max})$, minimum temperature $(T_{\min})$ and daily gridded $(0.25°\times0.25°)$ data of rainfall of over India for the years 1998 to 2019 have been downloaded from the official website of Indian Meteorological Department (IMD). The daily FAPAR data captured by the AVHRR radiometer onboard NOAA 19 Satellite is downloaded from the official website of NCEI-NOAA gridded at the spatial resolution of $(0.5°\times0.5°)$. The daily relative humidity data is taken from the Physical Sciences Laboratory, NASA USA. The daily soil moisture data with the spatial resolution $(0.25°\times0.25°)$ is taken from the Climate Change Initiative (CCI) and monthly gridded $(1°\times1°)$ aerosol optical depth data at 550 nm is taken from the NASA GIOVANNI. The historical maize yield data is collected from the Ministry of Agriculture's Directorate of Economics and Statistics (https://aps.dac.gov.in/APY/Index.htm).

2.2 Methodology

The Pearson correlation test is carried out for each variable to examine the collinearity between two separate parameters on year basis [10]. The yearly average has been carried for the computation of yearly dataset of $T_{\max}$, $T_{\min}$, FAPAR, RH, SM, AOD. However, the summation of entire year of rainfall data is taken to compute the annual values of the rainfall.

A statistical model is carried out between yearly historical datasets of independent variables (weather parameters including aerosol) and dependent variable (maize yield), using multiple linear regression [11] as given in Equation 1,

$$Yield_{Yt} = \beta_o + (\beta_1.Y) + (\beta_2.T_{\max,ga}) + (\beta_3.T_{\min,ga}) + (\beta_4.RF_{gs}) + (\beta_5.RH_{ga}) + (\beta_6.SM_{ga}) + (\beta_7.FAPAR_{ga}) + (\beta_8.AOD_{ga}) + \varepsilon \tag{1}$$

Here, $Yield_{Yt}$ refers the total yearly yield of the crop. β_o is the time specific controlling parameter and ε is the residual error term. Other $\beta^{'s}$ are the corresponding regression coefficients. Here $'Yt'$ refers to the annual total, $'ga'$ refers to the growing seasonal average. The kharif season in India is the main growing season for maize crop includes months from July to October in every year.

The possible estimation of aerosols impact on maize crop yield is not straightforward [12] because aerosols is impacting the weather variables like $T_{\max}$, $T_{\min}$, and FAPAR. Therefore, it is not possible to estimate the yield loss using single regression equation. The effect of aerosols on maize yield and climate variables are integrating together to estimate the proper impact of aerosols on maize yield. For this purpose, the estimation of the aerosols impacts on weather variables and the impact of weather variables on maize yield [13] are carried out, separately. Finally, Equation 2 is used for the computation of net maize yield loss due to the aerosols impact [14].

$$\frac{dYield}{dAOD} = \left(\frac{\partial Yield}{\partial T_{\max}} \times \frac{\partial T_{\max}}{\partial AOD}\right) + \left(\frac{\partial Yield}{\partial T_{\min}} \times \frac{\partial T_{\min}}{\partial AOD}\right) + \left(\frac{\partial Yield}{\partial FAPAR} \times \frac{\partial FAPAR}{\partial AOD}\right) \tag{2}$$

3. Results and discussions

Figure 1 shows the observed and estimated values of maize yield by statistical model (Equation 1) using the historical datasets. The performance of the model is found excellent in terms of coefficient of determination (R^2), root mean squared error (RMSE) and bias. The value of R^2 (0.945), RMSE (0.515 tons/hectare) and bias (0.0 tons/hectare) are found between the observed and estimated values of maize yield. It is simply concluded that the results can safely predict maize crop yields using the above linear multiple regression model with near about 94.5% accuracy. Figure 2 (a-c) show the scatter plots between the weather variables ($T_{\max}$, $T_{\min}$, and FAPAR) and AOD to estimate the AOD impact on the weather variables using the linear regression analysis. The value of correlation coefficients are found 0.406 (between AOD and $T_{\max}$), -0.209 (between AOD and $T_{\min}$) and -0.045 (between AOD and $FAPAR$). On the basis of the values of correlation coefficients, it is observed that the yearly increases in AOD impacts more on temperature (minimum and maximum) variations than FAPAR variation.

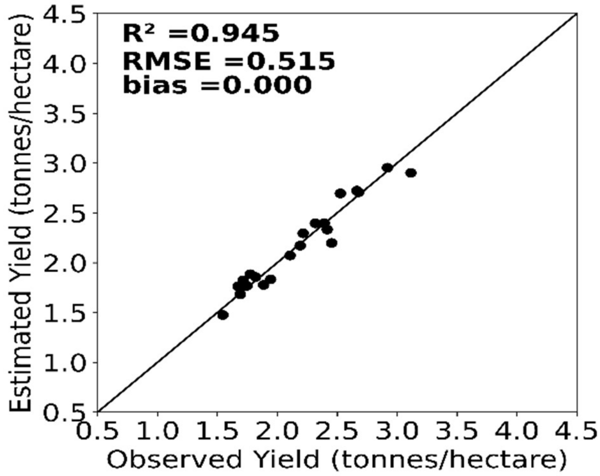

Figure 1. Scatter plot between observed and estimated values of maize yield by statistical model using historical datasets

Figure 3 (a-c) show the scatter plots between the weather variables ($T_{\max}$, $T_{\min}$, and FAPAR) and maize yield to estimate the weather impact on the maize yield using the linear regression analysis.

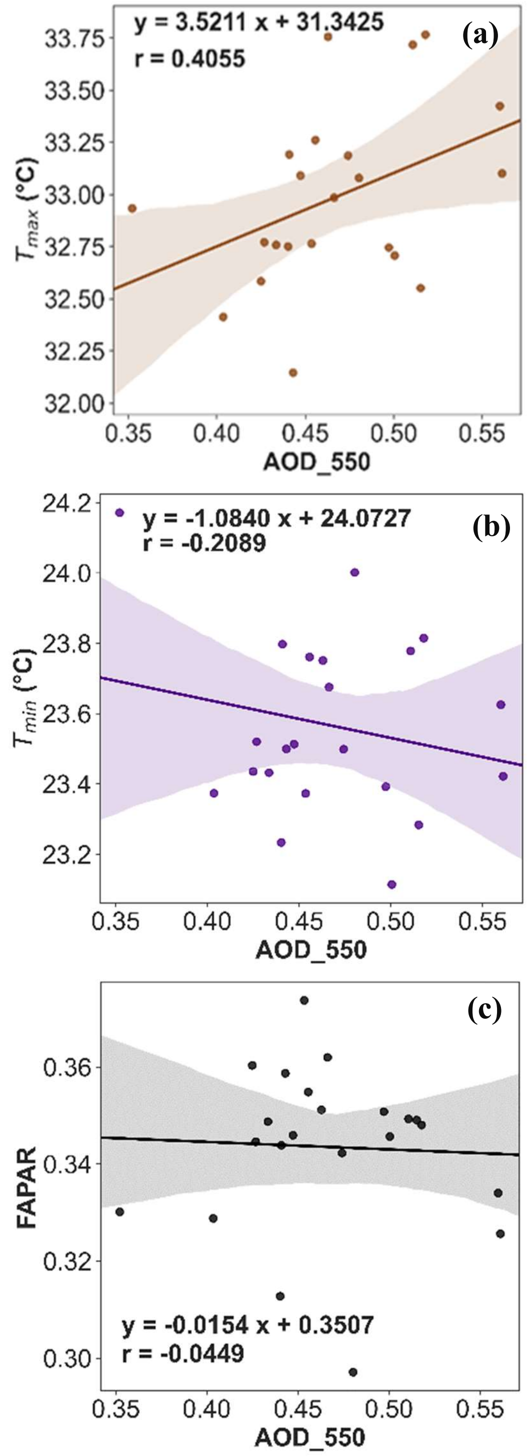

Figure 2 (a-c). Scatter plots between AOD and weather variables ($T_{\max}, T_{\min}$, and $FAPAR$) (maintaining 95% confidence interval).

The value of correlation coefficients are found 0.133 (between maize yield and $T_{\max}$), 0.315 (between maize yield and $T_{\min}$) and -0.046 (between maize yield and FAPAR). On the basis of the values of correlation coefficients, it is observed that the yearly temperature variation supports the maize yield, while the variation in FAPAR reduces the maize yield.

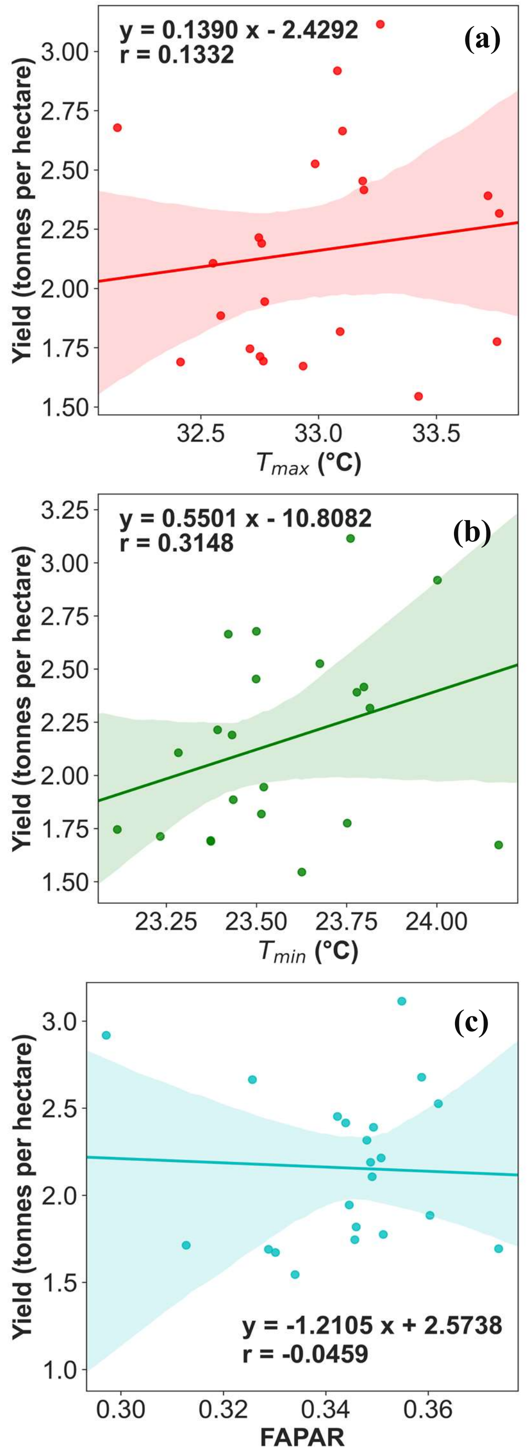

Figure 3 (a-c). Scatter plots between maize yield and weather variables ($T_{\max}, T_{\min}$, and $FAPAR$) (maintaining 95% confidence interval).

The values of the changes in the weather variables due to the increment in AOD are found $\frac{\partial T_{\max}}{\partial AOD} = 3.521$, $\frac{\partial T_{\min}}{\partial AOD} = -1.084$, and $\frac{\partial FAPAR}{\partial AOD} = -0.015$ from the slope of the linear regression equations provided in Figure 2. The values of the changes in the maize yield due to the variation in weather variables are found $\frac{\partial Yield}{\partial T_{\max}} = 0.139$, $\frac{\partial Yield}{\partial T_{\min}} = 0.550$, and $\frac{\partial Yield}{\partial FAPAR} = -1.210$ from the slope of the linear regression equations provided in Figure 3. Here, it is observed that the impact of FAPAR variation is more than temperature variation. Finally, the overall impact of the AOD on maize yield is computed using Equation (2) by substituting the above determined partial differentiating terms. Therefore, the reduction in maize yield by approximately 8.8% per year is found due to the increment in anthropogenic aerosol pollutants during the year 1998 to 2019 over India.

4. Conclusions

The increment of anthropogenic aerosol pollutants is caused due to growth of industries, urbanization etc. and it is responsible for the reduction in solar radiation, as well as increment in the annual average temperature, which causes Earth warming. The high aerosol loading in the atmosphere is gives negative impact on the agriculture production. The AOD and weather variables ($T_{\max}$, $T_{\min}$, FAPAR, RH, SM) can predict the maize yield with higher accuracy about 95% using multiple linear regression analysis. The aerosols impact on temperature variations is observed higher than FAPAR variation using the linear regression analysis. It is also observed that the yearly increment in the temperature is supports the maize yield, while the maize yield decreases with the decrement in FAPAR. The overall loss in maize yield is found approximately 8.8% per year due to variations in the weather variables with the increment of anthropogenic aerosol pollutants during 1998-2019 over India. In future, the climate warming and increment of aerosols may have differing impacts on crop yield and should be jointly considered in any assessment of Indian food security.

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