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Short Communication

Use of Time-Series Data of Temperature and Yield to Assess the Impact of Climate Change on Crop Yield Using Mustard in Haryana as an Example

Shabnam[1], Bansal S.K.[2] and Dabas D.S.[3]
[1]Lecturer in Geography, S.C.D.S. Government Girls Senior Secondary School, Rohtak, Haryana, INDIA
[2]Department of Geography, Maharishi Dayanand University, Rohtak, Haryana, INDIA
[3]Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana, INDIA

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Abstract

This paper describes how the regression analysis of temporal variability of crop yield and temperature can be used as a tool to easily assess the quantitative impact of increased temperature, due to climate change, on crop yield. The time series crop yield and weather data are readily available for different districts. The last 30 years yield data of the seven mustard growing districts and the weather data of Hisar were used to model the yield of mustard crop to assess the impact of temperature on the yield of mustard in Haryana. It was estimated that an increase of one degree centigrade in the temperature during the crop growth period will increased the mustard yield in the state by around 140 Kg ha^{-1}.

Keywords: Mustard, temperature, yield, climate change, regression models.

Introduction

Climate change is a challenge of 21st century for all of us for several reasons. Agricultural vulnerability is a major contributor in the overall vulnerability of a region to climate change[1]. It is likely to impact the yield of various crops threatening food security[2]. One important challenge is to reliably assess its quantitative impact on the yield of different crops. The controlled conditions greenhouse experiments are very cumbersome and time consuming and besides that it is difficult to create real natural conditions artificially. The use the simulation models for this purpose has its own limitations of logic and validity[3,4,5]. In the light of the above limitations efforts were made to use the regression analysis of historical data as a tool for the purpose. Regression analysis can discover quantitative relationships between the related variables[6]. The regression analysis of temporal variability of the yield and the temperature of the mustard growing districts of Haryana was used to illustrate how this can be an easy way out for assessing the impact of the future projected temperature regime of an area. Since this is based on the real measured data of the past, the results have an empirical basis and are expected to be more reliable.

Methodology

Methods and Data: The historical yield of mustard from 1979-80 to 2008-09 of all the seven mustard growing districts (as in 1979-80) of the Haryana state was used for this study. The daily weather data of the period 1979 to 2009 from agro-meteorological station, Hisar, Haryana was used for the purpose of this analysis. The daily data was aggregated by fortnightly periods, the first to fifteenth date of a month formed the first fortnight and the rest of the dates of a month formed the second fortnight of a month. Since the crop remains in the field from October to February the data of this period was used for the purpose. A more complete description of the data and the methods can be found elsewhere[7].

A linear trend equation was fitted to the yield data for each district individually using 'Regression Analysis' in the 'Tools' menu of the 'MS-Excel' program. The trend yield equations with their R^2 values for each of the district are presented in the table below. The coefficients of determination (R^2) for various districts varied from 0.41 to 0.59. This indicates high intra year variability in the yield due to susceptibility of the mustard crop to the weather3. A much better linear trend relationship was obtained in case of wheat in Haryana which is relatively less susceptible to the effect of weather[8]. The slope of the linear fit varied from 24.3 to 30.2 kgha^{-1}year^{-1} in different districts.

Table-1
The district wise mustard trend yield equations and their R^2 values

District	Trend Yield Equation	R^2 value
Rohtak	Y = 25.57x+708.15	0.419
Mahendragarh	Y = 27.92x+779.31	0.480
Hisar	Y = 24.98x+751.77	0.432
Bhiwani	Y = 25.67x+688.26	0.471
Sirsa	Y = 30.20x+624.63	0.575
Faridabad	Y = 24.28x+890.09	0.434
Gurgaon	Y = 26.09x+726.18	0.587

The trend yield indicated a secular increase in the mustard yield with time. These steadily increasing linear trends were assumed to be the result of aggregate improvement in the technology of the mustard cultivation in their districts. The year wise deviation of the actual yield from this linear trend yield was assumed to be the impact of the weather on mustard yield of that year. Regression equations were fitted to the yield values (dependant variable) and various fortnightly weather parameters (independent variables) using SPSS, a statistical software package. The more complete details of the data and methods used can be found elsewhere.

Results and Discussion

Results: The three of the regression relationships obtained, explaining over 80% variation in the yield, are as follows.

The regression models of mustard yield: i. Mustard Yield ($kgha^{-1}$) = - 782.5 TRYIELD + 1.090 RHOCT2 - 25.15 ARFSEPT2 + 2.705 TMNJAN1 72.075 ARFFEB2 + 4.861 RHN=OV2 + 11.03 TMNOCT1 + 25.88 TMNDEC2 + 38.25 TMNDEC2 + 45.67 SSHFEB1; R = 0.904, R^2 = 0.818, Adj- R^2 = 0.807, SEOE = 121.168, ii. Mustard Yield ($kgha^{-1}$) = -1263.7 + 1.175 TRYIELD -23.20 RHOCT2 + 2.85 ARFSEPT2 + 72.86 TMNJAN1 + 4.459 ARFFEB2 + 11.96 RHNOV2 23.20 TMNOCT1 + 42.09 TMNDEC2 + 44.32 SSHFEB1 + 32.68 SSHNOV1; R = 0.910, R^2 = 0.829, Adj- R^2 = 0.818, SEOE = 117.722, iii. Mustard Yield ($kgha^{-1}$) = - 1166.5 + 1.163 TRYIELD - 21.38 RHOCT2 + 3.011 ARFSEPT2 +73.0 TMNJAN1 + 4.397 ARFFEB2 + 9.063 RHNOV2 +19.27 TMNOCT1 + 41.46 TMNDEC2 + 53.18 SSHFEB1 + 30.36 SSHNOV1 + 2.066 ARFFEB1; R = 0.913, R^2 = 0.834, Adj- R^2 = 0.822, SEOE = 116.324

Whereas: TRYIELD = Linear trend yield ($kgha^{-1}$) of the district. RHOCT2 = Mean relative humidity (%) of the 2nd fortnight of the month of October. ARFSEPT2 = Accumulated rainfall (mm) of 2nd fortnight of the month of September. TMNJAN1 = Mean minimum temperature (°C) of the 1st fortnight of the month of January. SSHFEB1 = Bright sunshine hours of the 1st fortnight of the month of February.

The coefficient of correlation (R), coefficient of determination (R^2), Adjusted R^2 and the standard error of the estimate (SEOE) values for each of the relationship show that all the relationships are robust enough to be useful models of mustard yield. These relationships offer very useful quantitative understanding into the role of the weather (independent variables) in the yield (dependant variable) of the mustard crop in the state. It can be inferred from these relationships that the minimum temperature had significant impact on the yield of mustard in all these relationships while the average or the maximum temperature of any period has no similar role.

The increase in minimum temperature of the first fortnight of October (TMNOCT1) increased the yield from 19.3 to 29.8 $kgha^{-1}$ $°C^{-1}$. Similarly the increase in the minimum temperature during the second fortnight of December (TMNDEC2) and the first fortnight of January (TMNJAN1) increased the yield of mustard by 32 to 42.1 and 51 to 73 $kgha^{-1}$ $°C^{-1}$ respectively. The very low minimum temperature during January slows down the growth process especially if it goes very low (<5ºC). This may be the reason that minimum temperature of January first fortnight being most effective predictor of the crop yield.

The three regression models obtained show that an increase of one degree centigrade in the minimum temperature during the growth period of mustard will increase the yield of the crop by 134 to 144 Kg ha^{-1}. Surprisingly, the same authors have estimated the impact of temperature on the mustard yield to be very similar in another study using a different approach[10].

Conclusion

The study illustrates that the regression analysis of time-series data of temperature and crop yield can be used to quantitatively estimate the impact of temperature due to climate change on the crop yield. The approach should be useful irrespective of the crop, region and even the parameter and has a sound empirical basis. On the basis of this study it can be concluded that in Haryana the mustard yield will increase significantly with the increase in temperature due to climate change.

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