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Impact of aerosol on climate and productivity of rice and wheat crop in Bihar

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ABSTRACT

Interactions among aerosol optical depth (AOD), maximum temperature, minimum temperature, rainfall and solar radiation for different agro-ecological zones of Bihar in different seasons were examined during 2001-2012. There was significant negative correlation between aerosol and maximum temperature, in post monsoon season in zone I and II and in winter season in zone III B. There was significant negative correlation between aerosol and minimum temperature in pre monsoon and winter season in zone II and III A respectively. In monsoon season, there was negative correlation between rainfall and aerosol for all the zones but statistically not significant. There was significant positive correlation between aerosol and rainfall in pre monsoon season. There was significant negative correlation between aerosol and solar radiation in post monsoon season in zone II. There was significant negative correlation between aerosol and rice yield in zone III A and III B and significant positive correlation between aerosol and wheat crop in zone III A. The effect of aerosol on rice yield was predicted to be in the range of -28 to +44 per cent decrease or increase in yield depending on sky condition. Similarly, the wheat yield also depends on the sky condition during the growing season and ranges from -29.4 to +40.9 per cent decrease or increase due to aerosol.

Key words: Aerosol, trend, temperature, rainfall, solar radiation, rice and wheat yield

The importance of dust solar absorption has been recognized as a potential forcing in altering rainfall distribution globally (Miller *et al.*,2004) and more specifically over south Asia (Lau *et al.*, 2006 a). The small droplets limit collision and coalescence, prolonging the lifetime of clouds and inhibiting the growth of cloud drops to raindrops (Rosenfeld *et al.*, 2001). In increasing moisture and buoyancy, hygroscopic aerosol may activate more CCN and increase rainfall. With the growing attention on the potential effects of aerosol radiative forcing on the Indian monsoon rainfall and circulation in recent years (Menon *et al.,* 2002; Ramanathan *et al.*, 2005; Meehl *et al.*, 2008). Rice yield in India and other parts of Asia are positively correlated late in the season, with solar radiation (Stanhill *et al.,* 2001). On the other hand they are negatively correlated with minimum (night time) temperature (Peng *et al.*, 2004). In general, a large sustained increasing aerosol loading trend has been found over Northern India in Indo Gangetic plain area with the analysis of NASA TOMS data in the past two decades (Massie *et al.*, 2004; Bollasina *et al.*, 2008). However in the IGP, especially in Bihar, the aerosol and their climatic effects have been little known despite the heavy pollution in the region. Burning of fossil fuels and biomass have increased aerosol in the Indo-Gangetic plain. Due to multiple effect of aerosol on climate, there is possibility that reduction or increase in aerosol could have positive impact on yield of crops like rice and wheat, which are major crops of the region. Only a few studies have examined the impacts of aerosol on yield aspects in agriculture (Karande *et al* 2012a & b). But no study has been done on seasonal interaction of aerosol and climatic parameters and yield of crops. Wheat yields are more often limited by moisture or temperature than by solar radiation. However, when these conditions are not limiting, yields can be affected by variations in solar radiation receipt (Lomas *et al.*, 1976). Aerosol can affect the flux of solar radiation directly or indirectly (Schwartz *et al.,* 1996).

MATERIAL AND METHODS

Study area

Bihar is located in the alluvial plains of India. The state is situated between 24^0 N and 27^0 N, 83^0 E and 88^0 E with a height of 52 m amsl, It is divided into three agro-ecological zones: zone I (North West alluvial plains), zone II (north east alluvial plains) and zone III (South Bihar alluvial plains). Zone III is further subdivided into categories A and

B. Four different stations were selected representing different zones (Pusa zone I; Purnea zone II; Sabour zone III A; Patna zone III B). Weather data for Pusa and Sabour were collected from 1955-2012 and for Purnea and Patna from 1969-2012. Satellite data of aerosol optical thickness was downloaded from the website of Goddard space, NASA between latitudes for Bihar region for 2001-2012. Productivity data for rice var. Swarna and wheat crop var. HD 2733 were collected from for duration 2001-2012. The interactions among aerosol optical thickness, rainfall variability, yield of rice and wheat crop in each season were determined. Trends of temperature and rainfall based on long term weather data were tested by Mann Kendall test at 5 % level of significance. Trends of aerosol optical thickness were also tested by the same method for 2001-2012. Correlations were examined between aerosol optical thickness and different weather parameters viz. solar radiation, maximum temperature, minimum temperature and rainfall for different seasons for different stations. Correlations were also examined among productivity of rice and wheat crop and aerosol optical thickness for different regions.

Crop model

The generic grain cereal simulation model CERES Version 4.5 (Ritchie *et al.,* 1998) was used to estimate the effect of aerosols on crop yield and has been integrated in the Decision Support System for Agro technology Transfer (DSSAT). For this study, the model was employed to estimate the radiative influence of atmospheric aerosols on crop growth and yield. The model was modified so that RUE was not a longer static variable but was dynamically calculated as a function of the diffuse fraction on each simulation day. The model computes daily CO_2 uptake based on PAR, RUE, LAI, and various water and nutrient stress levels. The standard CERES model assumes that RUE is a constant value for each species of crop and does not change with the diffuse fraction. In order to isolate the influence of aerosols, it was necessary to make sure that plant growth was not limited by water or nutrient availability. Therefore, the model was configured so that the crops never experienced water or nutrient stress. In order to examine the influence of aerosols on crop growth, cumulative daily radiation was estimated for each day of the year using a radiative transfer model that considers the influence of aerosols. The observed daily cumulative radiation in the meteorological files was replaced with the estimated PAR intensity calculated by the radiation model. In addition, the fraction of PAR which is diffuse was added to each day of the meteorological files. In order to estimate the influence of aerosol loadings on crop yields, the recorded cumulative daily radiation values reported in the observed meteorological data set were substituted with values calculated using the National Center for Atmospheric Research (NCAR) Tropospheric Ultraviolet Visible (TUV) radiation model (Madronich, 1993). This model estimates the intensity of solar radiation incident at the surface based on the amount of radiation at the top of the atmosphere taking into account the absorption and scattering of radiation by gases, particles and cloud droplets. The 2-stream mode of this model was used to compute diffuse fractions. The temperature and precipitation data in the measured meteorological data sets were not changed. Several response curves were used in order to estimate the sensitivity of crop growth to the increase in RUE associated with an increasing diffuse fraction. The response curves ranged from no change at all in the base RUE to a doubling of RUE at high diffuse fractions. For each day in the CERES model runs, RUE is calculated as the base RUE plus a percent increase. For each value of AOD, the CERES model was run for each year for which weather data were available. The yields from each of these years were summarized by calculating an average and a standard deviation. This process was repeated for each RUE response curve. The TUV model was used to estimate the change in PAR reaching the surface and the diffuse fraction as AOD increases. Under clear skies, PAR decreases by 30% as AOD is increased to 1.0 from the background level of 0.05. At the same time, the diffuse fraction was increased by over 200%.

RESULTS AND DISCUSSION

Trends in maximum temperature

Trend statistics (Table 2) of maximum temperature indicates that there is significant decreasing trend of annual maximum temperature (-0.008^0 Cy^{-1}) and (-0.012^0 Cy^{-1}) for stations Pusa and Sabour respectively. There is significant increasing trend (0.041^0 C y^{-1}) of maximum temperature in *kharif* season in Purnia whereas decreasing trend (-0.013^0 C y^{-1}) of maximum temperature in *rabi* season in Sabour.

Trends in minimum temperature

Minimum temperature of all the stations Pusa, Purnia, Sabour and Patna has significant increasing trend in *rabi* season (0.022 ^{0}C y^{-1}), (0.081 ^{0}C y^{-1}), (0.026 ^{0}C y^{-1}) and (0.038 ^{0}C y^{-1}) respectively (Table 3). Purnia shows significant increasing trend (0.037 ^{0}C y^{-1}) of minimum temperature in *kharif* season too. Purnia, Sabour and Patna show

Table 1: Selected meteorological stations representing different agro-ecological zones of Bihar

Station	Agro- ecological Zone	Latitude (^{0}N)	Longitude (^{0}E)	Elevation (m)	Weather data
Pusa	I	25.85	85.78	47	1955-2012
Purnea	II	25.98	87.80	53	1969-2012
Sabour	III A	26.10	87.70	37	1955-2012
Patna	III B	25.58	85.25	41	1969-2012

Table 2: Mann Kendall test (Kendall's tau) with trend for maximum temperature

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.031	0.002	-0.115	-0.008	-0.199	-0.008*
Purnea	0.472	0.041*	0.094	0.006	0.244	0.015*
Sabour	0.058	0.003	-0.23	-0.013*	-2.53	-0.012*
Patna	0.100	0.009	-0.169	-0.012	-0.058	-0.003

*Significant at 5%

Table 3: Mann Kendall test (Kendall's tau) with trend for minimum temperature

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.128	0.010	0.210	0.022*	0.174	0.017
Purnea	0.323	0.037*	0.503	0.081*	0.538	0.057*
Sabour	0.012	0	0.44	0.026*	0.345	0.014*
Patna	0.156	0.008	0.322	0.038*	0.36	0.025*

*Significant at 5%

Table 4: Mann Kendall test (Kendall's tau) with trend for rainfall

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.024	0.829	-0.196	-1.471*	-0.013	-0.342
Purnea	-0.047	-2.038	-0.118	-0.945	-0.099	-4.233
Sabour	0.08	1.647	-0.052	-0.316	0.14	3.513
Patna	-0.104	-3.015	-0.085	-0.627	-0.114	-4.506

*Significant at 5%

Table 5: Mann Kendall test (Kendall's tau) with trend for aerosol

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Zone I	-0.303	-0.01	0.273	0.004	-0.242	-0.002
Zone II	-0.485	-0.008*	0.303	0.009	-0.242	-0.001
Zone III A	-0.303	-0.006	0.394	0.009	0.091	0
Zone III B	-0.091	-0.005	0.152	0.002	-0.091	0.002

*Significant at 5%

Table 6: Correlation coefficient (r) of aerosol and weather parameters in different seasons

	Zone I				Zone II			
	Winter	Pre monsoon	Monsoon	Post monsoon	Winter	Pre monsoon	Monsoon	Post monsoon
Max temp	-0.104	-0.070	-0.427	-0.528*	0.179	-0.367	0.084	-0.442*
Min temp	-0.386	0.482*	0.291	0.010	0.351	-0.596*	-0.199	-0.152
Rainfall	-0.203	0.189	0.005	0.308	-0.414	0.460*	-0.207	0.168
Solar radiation	0.365	-0.227	0.097	-0.203	0.289	-0.476	0.219	-0.540*
	Zone III A				Zone III B			
	Winter	Pre monsoon	Monsoon	Post monsoon	Winter	Pre monsoon	Monsoon	Post monsoon
Max temp	0.030	0.118	0.356	-0.201	-0.440*	-0.162	0.333	-0.039
Min temp	-0.488*	0.326	0.295	-0.021	-0.270	0.148	0.007	-0.059
Rainfall	-0.280	-0.114	-0.023	-0.239	-0.035	0.246	-0.262	-0.477
Solar radiation	0.221	-0.388	0.011	-0.390	0.206	0.019	-0.034	-0.046

*Significant at 5%

Table 7: Correlation coefficient (r) of aerosol and yield of rice and wheat crop in different zones

Crops	Zone I	Zone II	Zone III A	Zone III B
Rice yield	-0.232	-0.188	-0.763**	-0.595*
Wheat yield	0.201	-0.197	0.596*	0.547

*Significant at 5% ** significant at 1 %

significantly increasing trend of annual minimum temperature (0.057 ^{0}C y^{-1}), (0.014 ^{0}C y^{-1}), (0.025 ^{0}C y^{-1}) respectively.

Trends in rainfall

In Pusa, rainfall is decreasing significantly (-1.471 mm y^{-1}) in *rabi* season (Table 4). In all the stations except Sabour, annual rainfall is decreasing but they are statistically non-significant. At Sabour station, there is increasing trend of *kharif* and annual rainfall but statistically non-significant.

Trends of aerosol

There is significant decreasing trend (-0.008) of aerosol in *kharif* season in zone II (Table 5). Though there is also decreasing trend in *kharif* season and in annual mean of aerosol in all the zones and increasing trend in rabi season but statistically not significant.

Interactions among aerosol and weather parameters

There was significant negative correlation between aerosol and maximum temperature, in post monsoon season in zone I and II and in winter season in zone III B (Table 6). There was significant negative correlation between aerosol and minimum temperature in pre monsoon and winter season in zone II and III A respectively. In monsoon season, there was negative correlation between rainfall and aerosol for all the zones but statistically not significant. There was significant positive correlation between aerosol and rainfall in Pre monsoon season and negative correlation in post monsoon season in all the zones but it was statistically significant in zone II only.

Interactions among aerosol and crop yield

There was significant negative correlation between aerosol and rice yield in zone III A and III B. In zone II, there is also negative correlation between aerosol and rice yield but statistically non-significant (Table 7). In case of wheat, there was significant positive correlation with aerosol in zone III A. In zone I and in zone III B also, there was positive correlation between aerosol and wheat crop yield but statistically non-significant.

Impact of aerosol on rice and wheat crop

Under clear sky condition, an increase in aerosol loading results in a substantial increase in the diffuse fraction. For model simulations in which RUE increases in response to the diffuse fraction, the enhanced efficiency associated with increasing aerosol optical depth (AOD) partially or completely offsets the decrease in total photosynthetically active radiation (PAR). For both rice and wheat crops, a greater increase in RUE results in a less negative influence on average yield. Yield for wheat and rice was predicted to decrease linearly if RUE does not change resulting in a maximum reduction of approximately 30 per cent at AOD =

Table 8: Percent change in crop yield as a function of aerosol optical depth and RUE

	Aerosol Optical Depth														
	0.2			0.4			0.6			0.8			1		
	RUE (%)			RUE (%)			RUE (%)			RUE (%)			RUE (%)		
Crops	0	50	100	0	50	100	0	50	100	0	50	100	0	50	100
Rice	-6.0	7.5	17.2	-10.0	13.0	37.3	-16.1	14.3	42.2	-24.0	13.2	44.0	-28	7.7	42
Wheat	-5.6	8.0	20.2	-13.2	13.4	33.4	-16.5	14.1	40.7	-23.4	10.8	40.9	-29.4	8	39.7

1.0 (Table 8). If RUE fluctuates as a function of the diffuse fraction, the predicted influence on wheat and rice yield was positive. If the maximum change in RUE was 50 per cent, the maximum increase in yield was approximately 15 per cent at AOD = 0.5. If DRUE = 100 per cent, the maximum increase was nearly 44 per cent at AOD = 0.8 in case of rice and 41 per cent in wheat crop yield. An increase in the diffuse fraction can increase the amount of photosynthesis occurring in shaded leaves. Aerosol light scattering decreases total PAR at the same time that it increases the diffuse fraction, aerosols are therefore expected to increase RUE in rice and wheat crops (Rochette *et al.* 1996). The increase in RUE is likely to be less at low LAI than in mid-growing season when a crop is fully developed and has multiple canopy layers and a high LAI. Aerosol radiative forcing usually (though not always) has a negative influence on temperature. This can have either a positive or negative influence on plant growth and development depending on the stage of development and if the temperature is above or below the optimum. The decrease in radiation associated with increasing aerosol concentrations also results in less water loss due to soil evaporation and leaf transpiration. The change in mean yield as a function of aerosol optical depth is highly dependent on the radiation use efficiency of the crop. RUE itself is dependent on the fraction of radiation that is diffuse. The amount of increase in RUE seems to be the most important factor in determining the magnitude and in a few cases even the sign of the change in yield. If RUE increases more than 50 per cent over the base value at high diffuse fractions, this increased efficiency frequently offsets the reduction in PAR due to the influence of aerosols, and consequently, yields are predicted to either increase or decrease by less than if the RUE does not change.

CONCLUSION

There was good correlations with weather parameters like maximum temperature, minimum temperature, rainfall and solar radiation. The presence of aerosols in the atmosphere simultaneously decreased PAR and increased the fraction of PAR which is diffuse. Increasing the diffuse fraction tends to increase the radiation use efficiency of a plant. Aerosols both decrease the amount of PAR reaching the surface and increase the diffuse fraction. Using the most likely set of assumptions concerning AOD and DRUE, the influence on rice yields was predicted to be in the range of -28 to +44 per cent decrease or increase depending on sky condition. Similarly, the wheat yield depends on the conditions during the growing season and ranges from -29.4 to +40.9 per cent decrease or increase due to aerosol. The results strongly suggest the need for a more comprehensive study that will examine the indirect influence of aerosols on temperature, evapotranspiration, clouds and precipitation and consequently on water and nutrient stress. It would also be of benefit for future studies to incorporate a canopy model in order to more accurately estimate RUE throughout the simulated growing season and to consider the influence of changes in the solar spectrum induced by aerosol light extinction.

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