Characterization of climate and crop productivity using DSSAT for SW Uttarakhand, India

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Abstract

Haridwar district in south west Uttarakhand India is agriculturally very sensitive as this contributes about 35% food grain and 80% sugar to the total production of the state. Weather conditions affected production both directly and indirectly. DSSAT is a very useful tool presently available for yield forecasting taking into account the weather condition, soil condition, crop management condition and genetic coefficients. Weather data (1979–2011) was collected from the Indian Institute of Technology, Roorkee whereas the data of soil, crop management and genetic coefficients were collected conducting survey from different parts of the district. Acreage and yield data of rice, wheat and sugarcane of the district was obtained from the office of the Director Agriculture Uttarakhand for the period 2000–2011. Weather data analyzed using DSSAT recorded 1026 mm/year average annual rain with 68 rainy days/year and 65% probability of wetness/year in Haridwar. Actual average yield of rice, wheat and sugarcane was reported as 22.4 q/ha, 25.0 q/ha and 609 q/ha respectively. The DSSAT however forecasted the average yield of rice and wheat as 26.3 q/ha and 28.2 q/ha respectively. Marginally higher forecast of yield in rice and wheat over the actual through DSSAT needs further scrutiny. Regression model however responded at par with the actual forecasting the average yield in rice as 22.9 q/ha, wheat as 25.2 q/ha and sugarcane as 610 q/h. These observations confirm the scope of using DSSAT in characterising weather condition and crop yield forecasting in Uttarakhand.
Keywords: bhabhar, khadar, DSSAT, rabi, kharif.

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1 Introduction

Haridwar located in the south western part of Uttarakhand India is agriculturally a very sensitive district contributing about 35% food grain and 80% sugar production to the total production of the state. Geographical area of Haridwar is 2360 km^2 and falls in the sub humid agro climate zone. Ganges is a perennial stream originating in Himalaya flows through Haridwar. A large number of seasonal streams originate from *shiwalik* ranges present in the northern part of the district and flow over land to join Ganges. The district is rich in surface (5.6 km^3) and ground water (0.9 km^3) resources both [1]. There are three land zones present in the district called *bhabhar* in north, *khaddar* in south and normal in centre. Artesian wells use to be active during rainy season in the past in *khaddar* zone. A very good canal network exists in this district. Their irrigated cropping intensity is > 200% and the cropping pattern is primarily consists of rice, wheat and sugarcane [1]. The yearly variation in the climatic condition unlike in any other part of the country is natural and affected cropping pattern and crop productivity [2–4]. The average weather condition viz., temperature, humidity and sunshine etc influenced rainfall and vice versa [2].

DSSAT is a very good tool for decision making in crop management and yield forecasting and characterising the weather and soil conditions [5]. There is selective statistical software available to analyze weather data particularly the rainfall but they are limited to general characterization. The DSSAT specifically focussed on the statistical analysis weather data from crop planning and management point of view. However no report on rainfall characterization using DSSAT is available for region.

Keeping these points in view the study was undertaken with the objectives to use DSSAT as a tool to characterise weather and crop productivity of Haridwar district in Uttarakhand India.

2 Study area

Haridwar is an important district of South West Uttarakahnd extending from 77° 20’ E – 79° 20’ E Long. and 29° 30’N – 31° 0’ N Lat. **(Fig. 1)** with the geographical area of about 2360 km^2. From the agriculture point of view this is an important district of Uttarakhand. This consists of three sub divisions viz. Roorkee, Bhagwanpur, Laksar and six development blocks viz. Roorkee, Bhagwanpur, Laksar, Khanpur, Bahdarabad and Narsan. There are 622 villages.

Haridwar experiences humid and sub humid agro climate with three distinct crop seasons. The summer season is called *zaid* (April-May), rainy season is called *kharif* (June–September) and winter season is called *rabi* (October-March). The average annual rainfall of the district is 1074 mm and distribution is variable recording high in northern part and low in southern part. Annual rainfall received is 84% during *kharif* and 16% during rabi and *zaid* seasons. Topography in the district is also variable. Shiwalik range (869 m) is present in the north and plain (232 m) land in south. Ganges is the main, and perennial

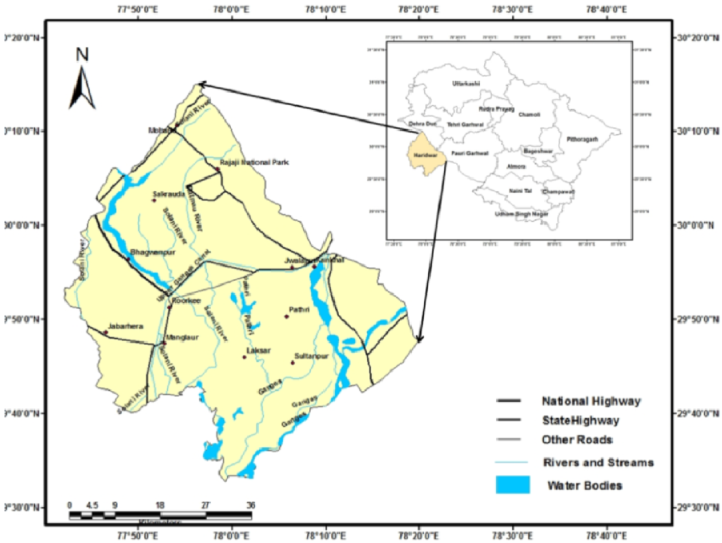

Figure 1: Map of Haridwar (Uttarakhand).

stream flowing through the district. Seasonal streams called *Solani*, *Ratmau*, *Ranipur*, *and Pathari* originating from Shivalik ranges join holy river Ganges.

Livelihood of the majority of rural population is agriculture. Farmers are very progressive. Major crops occupying the net sown area of the district are rice (15%), wheat (36%) and sugarcane (58%). Crops are irrigated with average productivity of 2.2 t/ha, 2.5 t/ha and 61 t/ha in rice, wheat and sugarcane respectively [1]. About 98% of the cultivated area is irrigated through a network of canals of Uppar Ganga Canal System whereas about 2% is irrigated by tube well. The surface and ground water utilized in the district is 2.3 km^3 and 0.8 km^3 respectively [1].

There are three distinct soil zones called *bhabhar*, *khaddar* and normal lands [6–8] in the district.

In the vicinity of Shivalik Hills, the gradient is steep and soils present there are called *bhabhar* or *Entisols* occupy about 5% of the geographical area of the district. They are shallow to deep sandy soils underlain with boulders. They are poor in water holding capacity and fertility.

The flood plain zone of the district is called the *khaddar/Tarai or Mollisols.* This occupies about 15% of the geographical area in the district. *S*oil is fertile and rich in clay and organic matter. These are one of the most productive soils in the country.

The plain areas bearing all the good conditions for cultivation of crops with well developed soil profile are normal lands and also called *Ultisols.* This is distributed throughout the district and occupies about 80% of the geographical area. Soils are brown in colour. The soil horizon is fully developed.

There are three sugar mills located at village Ikbalpur, Laksar and Libberhedy with annual sugarcane crushing capacity of about 7.0 million tonnes per year are present in the district.

3 Methodology

Daily weather data (rainfall, maximum temperature, minimum temperature and sunshine hours) for the period 1979-2011 recorded at the agro meteorological observatory of the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India was collected. Annual variability of rainfall was statistically analyzed using Fourier method on Microsoft excels.

Acreage and production of rice, wheat and sugarcane was collected from the office of the Director Agriculture Uttarakhand and District Agriculture Officer Haridwar [7, 8] and is presented in **Table 2.**

The DSSAT v 4.5 is a collection of number of crop models that operate together to give a functional output. This is supported by data base files created for soil (S built), weather (weatherman), crop management/experimental data (X built) and genotype (genotype coefficient). Soil samples were collected from all over the district. Climate file was created running weatherman to obtain the average values of solar radiation (MJ/m^2/day), maximum temperature (°C), minimum temperature (°C), rainfall (mm) and rainy days (days), mean maximum temperature of dry days TxMND), standard deviation of maximum temperature of dry days (TxSDD), mean maximum temperature of wet days (TxMNW), standard deviation of maximum temperature of wet days (TxSDW), mean minimum temperature of dry days TxMND), standard deviation of minimum temperature of dry days (TxSDD), mean minimum temperature of wet days (TxMNW), standard deviation of minimum temperature of wet days (TxSDW), Kurtosis (Ku), mean maximum solar radiation of dry days (XMND), standard deviation of solar radiation of dry days (XSDD), mean minimum solar radiation of wet days (XMNW), standard deviation of solar radiation of wet days (XSDW), probability of dry dry wet sequence (PDDW), probability of wet dry wet sequence (PWDW), probability of wet wet sequence (PWW) and probability of wet day (PW). DSSAT was run to simulate productivity of rice and wheat in Haridwar district for the period 2000–2011[9, 10].

The *regression model* was another statistical tool applied to simulate productivity scenario of Haridwar district from 2000-2011 [11, 12]. Average annual yield along with the weekly average temperature, humidity and rainfall was taken for the crop growing period to run the model. Regression model is explained using following equation:

$$Y = a_0 + \sum_{i=1}^{p} \mathrm{ai} \,.\, \mathrm{Zi} + \sum_{\mathrm{i} \neq \mathrm{j}}^{\mathrm{p}} \mathrm{aij} \,.\, \mathrm{Zij} + \mathrm{e} \tag{1}$$

where,

$$\mathrm{Zi} = \mathrm{a}_0 + \sum_{\mathrm{w}=1}^{\mathrm{m}} \mathrm{riw.\,Xiw} \tag{2}$$

$$\mathrm{Zij} = \sum_{\mathrm{w}=1}^{\mathrm{m}} \mathrm{rijw.\,Xiw.\,Xjw} \tag{3}$$

where,

- Y = crop yield and
- e = random error
- r_{iw}/r_{ijw} = correlation coefficient of Y with i^{th} weather variable/ product of i^{th} and j^{th} weather variables in w^{th} week
- m = week of forecast
- p = number of weather variables
- Zi and Zij = independent variables which are functions of the basic weather variables like maximum and minimum temperature, rainfall, relative humidity etc.

Yields of rice, wheat and sugarcane for the period 2000–11 were simulated using regression models.

4 Results and discussion

Observations recorded on climate variability and crop productivity using DSSAT is presented and discussed in the forthcoming paragraphs.

4.1 Climate

A climate file with monthly average generated using DSSAT v 4.5 models with daily weather data of solar radiation, maximum temperature, minimum temperature, rainfall and rainy days from Jan. 01, 1979 to Dec. 31, 2011 is presented in Table 1. The average annual mean probability of dry/dry/wet sequence was recorded as 0.12; this is highest during August (0.33) and lowest during November (0.02). The average annual mean probability of wet/dry/wet sequence was recorded as 0.22; this is highest during August (0.4) and lowest during March (0.09). The average annual mean probability of wet/wet sequence was recorded as 0.47; this was highest during August (0.62) and lowest during November (0.35). The average annual mean probability of only wet sequence was recorded as 0.18; this was highest during August (0.49) and lowest during November (0.04). The month of August in Haridwar is critical for *Kharif* season crops as they are at grand growth and flowering stage. Observations recorded confirm that the probability of wet days during August is very high therefore rain fed *kharif* season crops are safe. The crop productivity is stable during k*harif season* but unstable during *rabi season* has also already been reported for Haridwar [6–8].

Maximum and minimum temperature as well as the solar radiation for dry days and wet days in the month, a valuable information to assess crop health when this is not constrained by water and nutrient, has been generated through DSSAT. This information is extremely important from point of view of forecasting insect pest and disease. Since no record of yield loss caused to different crops in the wake of insect pest and disease incidence no relationship could be analyzed in this study.

The actual and fourier analyzed (at 50% probability) values of annual rainfall are presented in **Fig. 2.** Actual extreme events of rainfall occurring at the interval of 8±2 years recorded increase at about 20 mm/year in the Haridwar district.

Similar pattern of event was also expressed in fourier analysis. In 1980, 1988, 2000 and 2010 Extreme rainfall events recorded were 1100 mm, 1400 mm, 1500 mm and 1600 mm during 1980, 1988, 2000 and 2010 respectively. This observation shows that the next extreme rainfall event that is likely to occur by 2018 in Haridwar district will be still fierce.

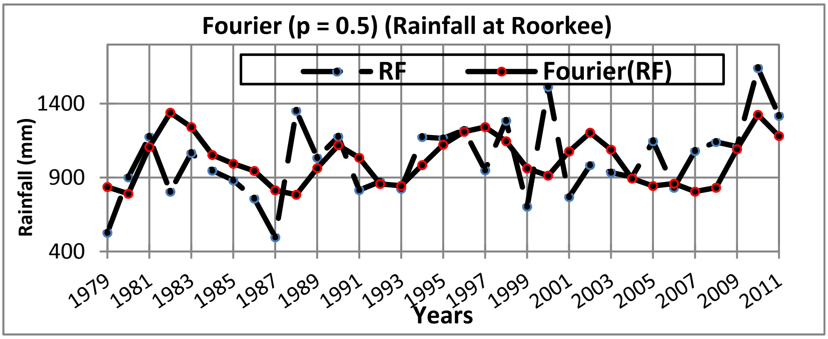

Figure 2: Annual rainfall pattern.

4.2 Crop productivity

Rice, wheat and sugarcane are the predominating crops occupying about 95% of net sown area in the district of Haridwar. Area and productivity of these crops given in Table 2 revealed that area under rice is drastically decreasing at about 800 ha/year whereas the area under sugarcane is increasing at about 500 ha/year. Surprisingly the wheat area remains unchanged. Decrease in the area of rice could be ascribed to the shortage of agricultural labour needed to work in the rice field during transplanting, weeding and harvesting. Increase in the sugarcane area could be attributed to the decrease rice acreage. The presence of three sugar mills in the district also act as a driving force for increasing sugarcane acreage [5, 6]. Wheat is a staple food crop but rice and sugarcane are treated as the cash crops in the area. Farmers also evaluate the relative benefit between rice and sugarcane and then decide their cropping pattern. Wheat is also grown as an intercrop of sugarcane therefore there is no loss of its acreage. The year to year productivity variation in rice and wheat is not remarkable that may be attributed to its richness in surface and ground water [7].

It is surprising to note that productivity of sugarcane in the area is gradually increasing probably due to the increased technical and infrastructural support from sugar mills. Cultivation of sugarcane is although distributed throughout the district but is more concentrated in *khadar* zone due to the soil fertility and easy water availability. It is common observation of farmers that the productivity of sugarcane, rice and wheat is increased when rainfall is less than average. Heavy rainfall adversely affected their crop for want of surface drainage facility in the area.

Table 1: Weatherman generated climate of Roorkee (CLIMATE: IITR - GENERAL).

@ Latitude Longitude Elev Zone TAV TAMP REFHT WNDHT SITE
29.850 77.883 252 Af -99.0 -99.0 1.3 2.0 IITR; @WYR WFIRST WLAST: 0 1979001 2011365

*AVERAGES													
@ Mean	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG/TOT
SRad	12.62	15.62	19.07	22.01	23.26	21.79	17.93	16.93	16.91	18.08	15.24	12.89	17.70
TMax	19.75	23.34	28.68	35.04	37.41	36.41	33.59	32.70	32.65	31.49	27.39	22.48	30.08
TMin	6.84	9.67	13.73	18.34	22.81	25.04	25.62	25.34	23.58	18.19	12.46	8.02	17.47
Rain	26.91	35.74	23.90	17.15	35.96	103.62	292.18	279.39	155.94	36.01	5.44	13.68	1025.92
RNum	3.03	3.85	3.53	2.56	4.88	7.50	13.59	15.06	8.09	2.26	1.24	2.00	67.59
*HIGH-FREQUENCY PARAMETERS													
@Param	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
TxMND	19.93	23.66	28.99	35.30	37.90	37.20	34.52	33.51	33.32	31.58	27.46	22.62	30.50
TxSDD	3.09	2.54	2.78	2.72	2.63	3.30	2.35	1.97	1.71	1.93	2.20	2.61	2.48
TxMNW	18.17	21.28	26.26	32.20	34.76	34.05	32.40	31.85	30.83	30.35	25.70	20.55	28.20
TxSDW	2.96	3.21	3.51	3.63	2.86	3.16	2.54	2.40	2.60	2.87	3.45	3.34	3.04
TnMND	6.64	9.49	13.68	18.40	23.07	25.46	26.22	25.83	23.68	18.10	12.45	7.91	17.58
TnSDD	2.10	2.26	2.45	2.91	2.42	2.24	1.82	1.44	1.85	2.72	2.20	1.89	2.19
TnMNW	8.66	10.79	14.17	17.68	21.39	23.79	24.84	24.83	23.28	19.33	12.75	9.60	17.59
TnSDW	1.98	2.01	2.20	2.30	2.11	1.79	1.60	1.47	1.57	2.13	3.46	1.99	2.05
Ku	0.91	0.89	0.85	0.84	0.82	0.83	0.87	0.90	0.90	0.88	0.94	0.95	0.88
XMND	12.78	16.15	19.50	22.18	23.59	23.02	19.59	18.46	17.83	18.00	15.17	12.71	18.25
XSDD	0.61	0.57	0.53	0.44	0.44	0.57	0.54	0.50	0.51	0.44	0.39	0.44	0.50
XMNW	9.65	11.67	15.67	19.76	21.37	18.09	15.79	15.31	14.44	16.19	13.00	10.91	15.15
XSDW	0.71	0.67	0.74	1.03	0.64	0.67	0.61	0.62	0.88	0.97	3.61	0.88	1.00
PDDW	0.06	0.08	0.07	0.05	0.11	0.16	0.31	0.33	0.13	0.03	0.02	0.03	0.12
PWDW	0.15	0.11	0.09	0.15	0.18	0.24	0.38	0.40	0.32	0.19	0.25	0.17	0.22
PWW	0.41	0.47	0.45	0.40	0.39	0.50	0.57	0.62	0.56	0.51	0.35	0.47	0.47
PW	0.10	0.14	0.11	0.09	0.16	0.25	0.44	0.49	0.27	0.07	0.04	0.06	0.18

Table 2: Area and productivity (actual and forecasted) of rice, wheat and sugarcane along with weather condition of Haridwar District.

Year	Rice				Wheat				Sugarcane			Average Annual Weather					
	A	P	DSS	Regr	A	P	DSS	Regr	A	P	Regr	Tmax	Tmin	Rhmax	Rhmin	RF	SRAD
2000	23.0	23.7	31.6	23.8	45.7	24.8	26.8	24.5	64.5	583	605	28.8	17.2	76	57	1514	19
2001	21.6	23.7	32.7	23.2	43.0	25.3	27.8	24.7	67.6	583	606	29.8	17.4	72	56	769	19
2002	16.2	22.5	30.1	23.3	41.3	23.5	28.0	24.8	72.5	619	607	29.8	17.5	72	50	984	19
2003	18.8	23.3	27.7	22.2	44.2	22.8	33.3	25.0	69.9	619	608	29.2	17.3	74	55	934	21
2004	19.9	20.6	29.3	24.1	45.3	21.4	30.1	25.2	67.7	621	609	30.6	18.0	73	52	904	18
2005	17.1	22.3	26.2	23.5	42.1	24.1	25.9	25.3	70.6	622	610	29.8	17.3	78	49	1146	20
2006	12.6	22.9	31.9	22.8	42.0	27.5	26.5	25.5	74.9	614	611	30.1	18.3	76	37	831	15
2007	11.0	22.6	20.6	21.6	42.6	26.0	30.5	25.6	74.8	619	612	30.8	17.3	80	33	1080	18
2008	17.1	22.6	25.6	21.4	48.3	27.7	27.4	25.8	69.0	622	613	30.9	18.1	75	44	1141	18
2009	19.2	22.3	24.1	21.5	48.3	27.3	28.0	25.9	66.5	603	613	29.9	19.3	73	46	1109	19
2010	16.5	22.8	26.9	21.9	45.8	25.1	24.5	26.1	69.9	603	614	31.1	18.8	74	53	1641	20
2011	15.3	19.9	28.6	22.2	-	-	29.5	23.7	70.8	605	615	31.4	19.5	76	64	1317	22
Mean	**17.4**	**22.4**	**26.3**	**22.6**	**44.4**	**25.0**	**28.2**	**25.2**	**69.9**	**609**	**610**	**30**	**18**	**75**	**50**	**1114**	**19**

A= Area (tha); P= Productivity (q/ha); DSS= Productivity forecasted by DSSAT; Regr.= Productivity forecasted by Regression model; Tmax.= Max Temperature (°C); Tmin.=Min. Temperature (°C); Rhmax.= Max. Relative Humidity (%); Rh min= Min. Relative Humidity (%); RF= Rainfall (mm); SRAD= Solar Radiation (MJ/m^2/day).

Source: Annual Progress Report 2011, Directorate of Agriculture Uttarakhand; Annual Progress Report of FASAL project, IMD, Govt. of India.

4.3 Model analysis

Yield recorded (actual) and simulated by DSSAT and regression models from 2000–2011 is presented in Table 2. The DSSAT forecasted productivity was high (26.3 q/ha in rice and 28.2 q/ha in wheat) over that of the actual (22.4 q/ha in rice and 25.0 q/ha in wheat). The actual average yield of sugarcane was 609 q/ha. This could not be simulated using DSSAT. Gap between actual and DSSAT model predicted could be minimized by improving the collection of crop management data.

The regression model forecasted yield (22.6 q/ha in rice and 25.2 q/ha in wheat and 610 q/ha in sugarcane) very close to the actual (22.4 q/ha in rice and 25.0 q/ha in wheat and 609 q/ha). The regression model has taken only weather condition into account ignoring the crop management practice, genetic character and soil conditions. The regression model has been reported to be very helpful to find out the relationship between different weather elements and crop productivity [9, 11, 12]. Weather elements that significantly affected the crop productivity was rainfall and humidity in rice; minimum temperature in wheat whereas maximum temperature and solar radiation in sugarcane in the district of Haridwar.

5 Conclusion

The study undertaken could be concluded with the facts that DSSAT is a useful tool for weather data analysis and yield forecasting of rice, wheat and sugarcane. The information on different probabilities of wet days calculated by DSSAT could be used for crop planning and management. Marginally higher forecast of yield by DSSAT could be acceptable at this stage and further improvements on soil water balance model could be incorporated and or field data collection could be further refined. The potential factors that affected yield were: humidity and rainfall in rice; minimum temperature in wheat whereas the maximum temperature and solar radiation in sugarcane were analysed through regression model.

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