Study of Potential Productivity of Rice Crop using DSSAT Model over Varanasi Region of Eastern Uttar Pradesh (India)

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ABSTRACT

Rice, one of the most important staple food, grows in varying agroclimatic conditions and its growth and yield is severely affected by changes in rainfall, temperature and solar radiation. In this study, DSSAT v.4.5 is used to simulate crop growth for three different cultivars namely NDR-359, NDR-97 and Sarjoo-52, to know the impact of radiation and temperature on productivity of rice over Varanasi. The study shows that fluctuations in mean radiation and mean diurnal temperature impact the potential yield. It is also found that the Sarjoo-52 is the highest yield producing variety in the agroclimatic conditions of Varanasi.

Keywords: *Agroclimatic conditions, radiation, diurnal temperature, yield prediction.*

1. Introduction

Rice is grown under the diverse environmental conditions of a wide range of latitudes and altitudes. The major climatic factors affecting growth and yield include solar radiation, temperature and rainfall (Choudhury et al, 2008). The rice yield simulated by Mathauda and Mavi (1994) for Punjab indicated that under the warm climate scenarios there was decline in the grain yield and under the cool climatic scenario, there was increase in the grain yield. Sinha et al. (1991) analysed the decline in the grain yield under the warm climatic conditions and indicated the need for selection of the suitable genotypes which will have the potentials to produce as good as, under the normal climatic conditions.

Crop growth simulation models pave the way to choose the best crop variety which is tolerant to drought, disease, pests and to adopt adequate soil and management practices to achieve best productivity and sustainability of agricultural production. Pathak et al. (2005) used DNDC model and found it useful for optimizing agronomic management, changing land use, water and fertilizer management in rice fields.

CERES-Rice models have been calibrated, evaluated and used for predictions of phenological development and grain yield of the crop in different agroclimatic conditions of Kerala and Andhra Pradesh states of India (Saseendran et al., 1998, 2001). It achieved reasonable accuracy hence, recommended its use for making various strategic and tactical decisions related to agricultural planning. CERES-Rice model was used by Kumar et al. (2007) for solar radiation stress management on the rice production in Orissa. They found that the model predicted phenological developments accurately.

Application of model for solar radiation stress assessment due to atmospheric brown clouds at Cuttak, Orissa during dry season (January-May) revealed a reduction in rice grain yield by 4% with reduction of incident solar radiation by 30% under non-fertilized condition (Swain et al, 2007). Pathak et al. (2003) concluded that the negative trends in solar radiation and an increase in minimum temperature, results in decreasing trends of potential yields of rice and wheat in the Indo-Gangetic plains of India.

In Kerala the sensitivity experiments of the CERES-rice model to CO2 concentration changes were carried out by Saseendran et al (2000) indicated that over the Kerala state, an increase in CO2 concentration level enhanced yield due to its fertilization effect and also increased the water use efficiency. The experiments have also shown that for a positive change in temperature upto 50C, there was a continuous decline in the yield. Lobell (2007) using a combination of historical datasets and climate model projections and national crop yields for 1961-2002 tried to evaluate the empirical relationships between average temperature, diurnal temperature range (DTR) and crop yields and established that the historical reduction of DTR in many locations in the latter half of the 20th century may have aided yield progress of rice and maize. Bera et al (2013) used WOFOST model over New Alluvial Zone of West Bengal for two commonly grown rice cultivars IR-36 and Khitish to determine the year-wise variation of simulated yield and change of it due to change in sowing dates and observed that July-end transplanted crop performed better than mid-July transplanted crop, also, mid-July transplanted crop performed better than 1st July transplanted crop.

Mall and Singh (2000) analyzed the wheat yield progress in the Punjab State from trends in the actual average yields, followed by adjustments of these yields for weather fluctuations using weather based yield prediction models CERES-wheat and WTGROWS and compared them. Annual weather variations remain major hindrance in identifying the contribution of the different factors to yield across the years. However, trends might be analysed better through modelling, which allows prediction of yield potential as a function of weather alone across years. Contribution of factors other than weather to the yield trends could be evaluated (Bell and Fischer, 1994) by comparison of actual yields with those obtained from weather-driven models.

In the present study, an attempt is made to see the effect of climatic variability through associated maximum and minimum temperature and solar radiation, on the potential productivity of three different cultivars of rice namely NDR-97, Sarjoo-52 and NDR-359 over Varanasi region in the Eastern Uttar Pradesh using DSSAT-v 4.5 model. Such regional impact studies are very critical and important for India which has about 65% of its population relying on agriculture directly or indirectly. This will help in developing crop varieties, which can withstand to weather conditions of a particular region, so as to maintain food and nutritional security.

2. Materials and Methods

2.1 Data used

Average yearly rice yield (Table 1) for the Varanasi District is obtained from Ministry of Agriculture, Lucknow for a period 1973-2009. Further, any variation in the productivity of rice in Varanasi District due to separation of Bhadohi (Name changed as Sant Ravidas Nagar for few years) in 1995 and Chandauli in 1997 is removed while calculating productivity of unbifurcated district of Varanasi for these years; incorporating area and production data of newly created districts of Bhadohi and Chandauli. Daily weather data including sun shine hour, maximum temperature and minimum temperature from 1973 to 2009 were collected from India Meteorological Department.

2.2 Model

In the present study the CERES-Rice model a part of DSSAT-v 4.5 is used to assess the potential yields of rice during a period of 37 years (1973-2009) over unbifurcated district of Varanasi using maximum temperature, minimum temperature and solar radiation under unlimited water and nutrient supply conditions. It is attempted to study the effect of these weather parameters on potential yields of rice for three different cultivars, under varying growing conditions. Since experimental yield data for these crops are not available in sufficient, therefore, the genetic coefficient for these rice cultivars (Table 2) are taken from crop data base available at IMD, New Delhi (Singh et al. 2009).

2.3 Yield prediction

The potential yields of the Varanasi District for the period 1973 to 2009 (year of sowing) as influenced by weather were predicted using the CERES rice model. CERES rice simulation model was run, assuming no limitations due to nitrogen and water for three cultivars of rice with different date of sowing i.e. NDR-97 (6 July), Sarjoo-52 (11 July) and NDR-359 (26 July).

2.4. Statistical significance test

The non-parametric Mann-Kendall (M-K) statistical rank test (WMO, 1966) which is widely used in climate research, is employed in this study to find out significance of trends present in time series data of actual and simulated productivity of rice as well as various weather parameter used in the study. The statistical significance is tested at 95% confidence level.

3. Results and Discussion

3.1. Actual yield trends

Linear regression analysis of actual yield suggests that the average yield in Varanasi unbifurcated District has significantly increased (r=0.5976) from 1973 to 2009 at a rate of 46.2 Kg ha-1y-1 (R^2=0.58) (Fig.1 and Table-1). Considerable variation in annual yield was obvious and a sharp decline was observed in yield (1383 Kg ha-1) in the year 2004 which followed by low yield years 2005, 2006 and 2007. A remarkable variation is seen in rate of change of average yield between two periods (1) earlier period of 1973-1997 showing a rate of increase of 79.6 Kg ha-1 y-1 in average yield (R^2=0.83) and (2) later period of 1997-2009 recording a decrease in yield at rate of 61.4 Kg ha-1 y-1 (R^2=0.30).

TABLE 1

Actual and Predicted Yields, monthly and crop duration Mean Temperature and Mean Radiation.

Year	Actual avg. Yield	Mean Temp. for crop duration	Monthly Mean Temp					Mean Radiation for Cropduration	Monthly Mean Radiation					Simulated Potential Yield	ActualYield as a % age of Potential Yield
			July	Aug.	Sept.	Oct.	Nov.		July	Aug.	Sept.	Oct.	Nov.		
1973	969	28.2	29.3	29.7	27.4	28.5	24.7	18.9	19.6	20.7	16.7	19.7	16.8	5261	18.42
1974	698	28.5	29.1	30.4	28.9	27.5	23.9	17.9	18.5	18.7	18.3	17.3	16.6	4648	15.02
1975	878	27.9	32.1	29.4	28.3	25.9	20.8	19	19.4	20.7	18.2	18.9	16.5	5073	17.31
1976	846	27.8	29.7	29.7	28.7	26.4	21.2	18.1	20.9	18.6	17.5	17	17	4774	17.72
1977	1329	27.7	30.4	29.5	29.8	26.2	21.0	19.3	19.7	19.8	19.9	18.9	16.5	5130	25.91
1978	1412	28.3	29.4	33.1	28.3	26.1	21.0	19.6	19.4	23.8	17.9	18.9	16.5	3658	38.60
1979	351	27.4	28.8	29.1	28.7	26.5	21.0	20.1	18.5	21.4	20.4	19.8	16	5405	6.49
1980	1416	26.5	28.5	28.0	27.8	25.5	21.1	17.6	17	16.7	18.1	18.3	17.3	5152	27.48
1981	1239	27.5	29.5	29.4	28.8	26.1	20.8	18.2	17	19.4	17.7	19.2	16.9	5152	24.05
1982	1371	28.1	32.2	29.5	28.6	27.1	21.9	18	19.5	19.5	17.9	18.3	14.6	4681	29.29
1983	1417	27.9	30.3	30.4	29.5	26.0	20.5	18.8	18.3	21.6	17	18.4	17.2	4730	29.96
1984	1325	27.4	29.6	29.2	28.0	26.9	20.7	17.8	18.2	18	17.8	17.9	17	4966	26.68
1985	1646	27.5	29.4	29.7	28.9	25.8	21.5	17.6	15.9	18.3	18.2	17.2	17	4862	33.85
1986	1434	27.4	29.0	29.2	28.5	25.6	22.4	18.5	16.7	19.7	18.6	18.6	16.5	5108	28.07
1987	1504	27.8	30.6	29.5	28.2	26.5	22.1	16	16	16.6	13.7	17.2	16.5	4180	35.98
1988	2013	28.3	29.7	29.9	30.3	26.4	21.8	18.5	17.2	16.9	20.9	18.8	16.8	4639	43.39
1989	1961	27.0	29.1	29.1	28.2	25.6	20.8	18.2	17.2	20.3	17.5	18.6	16.8	5131	38.22
1990	2128	27.4	27.8	29.2	28.9	26.3	22.2	17.7	13.9	19.8	17.6	18.9	16.4	5050	42.14
1991	2129	27.7	31.8	28.9	29.1	26.2	20.9	17.9	18.7	14.8	18.9	19.5	16.2	4773	44.61
1992	2017	27.8	31.2	29.4	28.8	26.6	22.1	18	19.6	18.6	18.3	18.5	15.2	5079	39.71
1993	2270	28.3	31.2	29.5	28.6	27.8	22.5	17.6	19.8	16.7	15.5	19.1	16.7	4530	50.11
1994	2604	27.6	30.0	28.7	28.6	26.4	22.3	16.5	18.3	14.6	15.3	18.7	16.4	4667	55.80
1995	2000	28.1	31.2	29.5	28.5	27.7	21.7	17.7	19.8	16.7	16.7	19.5	15.7	4680	42.75
1996	2764	27.5	30.1	28.7	29.4	26.1	21.1	16.8	18.4	14.6	17.9	17	17.3	4611	59.95
1997	2856	27.4	29.9	29.0	28.4	25.8	22.5	16.8	17.4	16.1	16.1	17.8	15.2	4597	62.12
1998	2552	28.8	30.2	30.0	29.6	28.3	23.0	15.9	16.9	15.3	15.6	16	16.8	4175	61.12
1999	2779	29.1	30.7	29.8	29.7	28.7	24.6	17.1	18.5	17.2	15.8	16.9	17.6	4520	61.49
2000	2221	28.2	29.3	29.7	27.3	28.4	24.7	17.9	17.1	19	15.4	19.5	17.3	5042	44.06
2001	2648	28.1	29.2	30.5	28.8	26.8	22.6	17	16.1	17.1	17.7	17.5	16.7	4643	57.04
2002	2307	27.9	32.1	29.4	28.3	25.9	20.8	18.2	17.3	19.2	17.3	18.9	17	4869	47.39
2003	2859	27.8	29.8	29.6	28.8	26.5	21.4	17.1	18.5	17.2	16.1	16.9	17.6	4755	60.13
2004	1383	27.7	30.2	29.5	29.8	26.0	21.0	18.5	17.4	18.2	18.9	18.8	16.9	4988	27.73
2005	1912	28.3	29.4	33.1	28.3	26.1	21.0	18.8	17.2	22.6	17	18.9	17	3642	52.49
2006	2192	27.4	28.8	29.1	28.7	26.5	21.0	19.4	19.1	19.9	19.6	20	16.4	5366	40.85
2007	2247	27.4	29.8	29.2	28.6	25.8	21.6	17.3	17.3	16.4	18.1	19	16.3	5024	44.73
2008	2436	28.1	28.6	29.6	29.4	27.4	22.1	17.8	13.9	17.2	20.9	18.9	15.7	4973	48.98
2009	1860	28.3	30.7	30.3	29.5	26.0	21.8	18.2	18	17.4	18.8	19.5	15.5	4742	39.22

TABLE 2

Actual and Predicted Yields, monthly and crop duration Mean Temperature and Mean Radiation.

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4
Sarjoo52	450.0	170.0	365.0	12.2	47.0	.0238	1.00	0.80
NDR-97	385.0	85.0	448.0	11.9	52.0	.0220	1.00	1.00
NDR-359	600.0	150.0	410.0	12.0	42.0	.0200	1.00	0.80

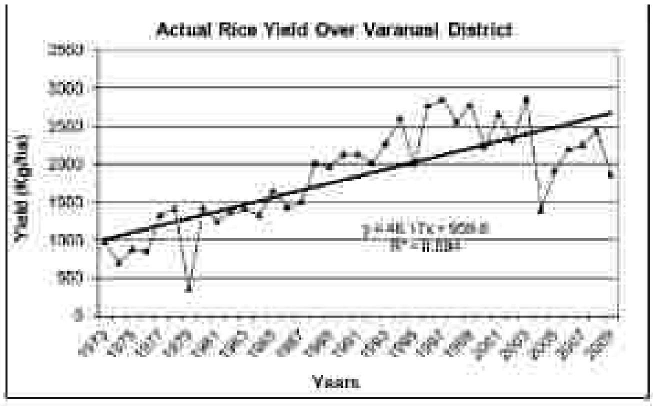

Fig.1 Progress of Actual rice yield fom 1973 to 2009.

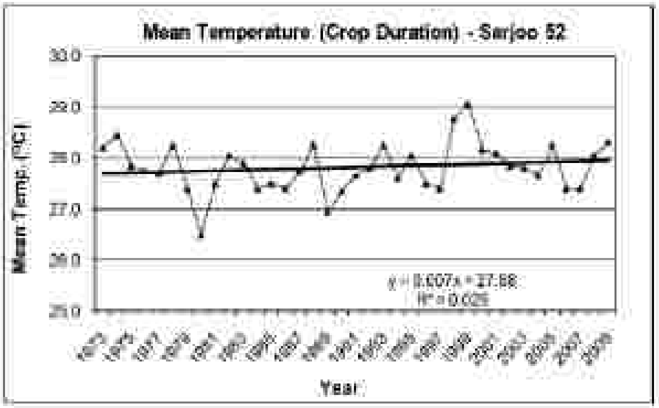

Fig.2 Mean temperature for crop duration (Sarjoo52) versus year of sowing.

The year to year variation in actual yield exhibited by the graph is expected firstly due to variations in weather parameters and secondly due to changes in the farming strategies applied each year viz. the changes in inputs e.g. fertilizers, selection of different cultivars, time of sowing, amount and time of irrigation etc.

3.2 Weather trends

To study the weather trends, sarjoo52 (crop duration 11 July to 18 November) is considered as representative of whole rice crop, as 65% crop area is covered by this cultivar (as per local observations), whereas 15% of the land are planted by NDR-97 and 20% are covered by NDR-359. If average potential yield of Sarjoo-52 (4791 Kg.ha-1) is compared with the average of area weighted mean of the potential yields of the three varieties (4616 Kg.ha-1) taken over the period of 37 years 1973-2009, it seems justifiable.

The average growing season (11 July- 18 November) mean temperature versus year of sowing is presented in Fig.2 and Table-1. The Linear regression analysis of mean temperature shows that the mean temperature at Varanasi has increased, but insignificantly at a rate of 0.010C y^{-1} (R^2=0.03). It indicates that there is large year to year variation present without a definite trend. The R squared value is very small, which shows that this trend line is unable to predict the future values. The highest mean temperature of 29.10C is observed during the cropping year 1999, whereas lowest mean temperature was 26.50C during the crop growing year 1980.

The crop season (11 July-18 November) mean radiation versus year of sowing is shown in Fig.3 and Table-1. The Linear regression analysis shows that the mean radiation has decreased significantly at a rate of 0.03 $MJm^{-2}day^{-1}y^{-1}$ (R^2=0.12). The highest mean radiation received is 20.1 $MJm^{-2}day^{-1}$ (1979) and minimum mean radiation received is 15.9 $MJm^{-2}day^{-1}$ (1998).

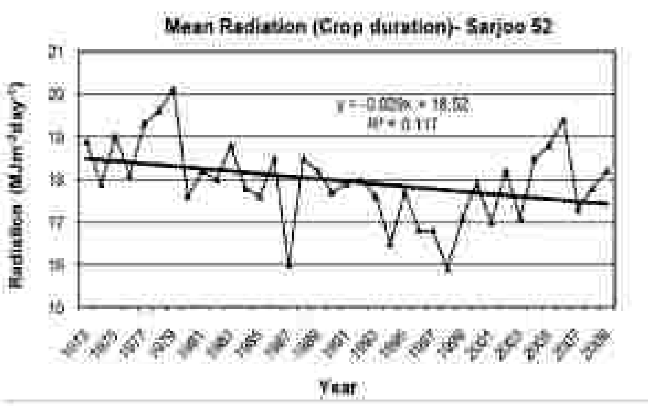

Fig.3 Mean Radiation for crop duration (Sarjoo-52) versus year of sowing.

3.3 Simulated yield trends

Fig.(4) shows the progress in potential yield for three rice cultivars chosen for the present study. The variation in their potential yields is similar but they differ in their magnitude. All the three cultivars show insignificant (r values for NDR97= -0.2102, Sarjoo-52= -0.1742, NDR-359= -0.0901) decreasing trend in their potential yields. Quantitatively Sarjoo-52 is showing highest yield as compared to the other two, most probably due to NDR-97 being early sown and NDR-359 being late sown. The average potential yield for the period 1973-2009 (37 year average) for three varieties clearly shows that Sarjoo-52 is highest yield producing variety. (Fig.5)

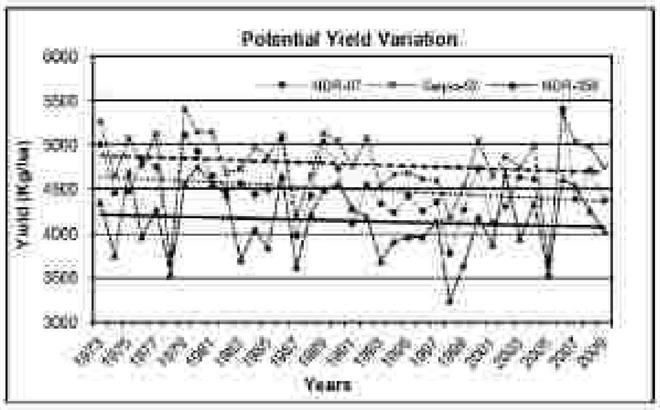

Fig.4 Comparison of potential yield among three crop varieties.

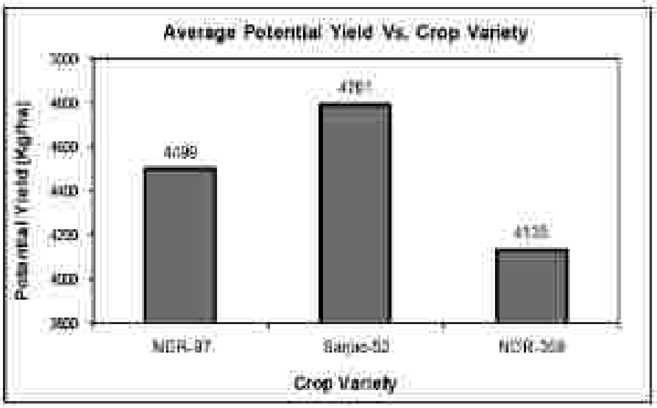

Fig.5 Average potential yield for three crop varieties during the period (1973-2009).

Further, the actual yield is compared with the potential yield for each variety, but presented for only Sarjoo-52 (Fig. 6). While the actual average annual yield in Varanasi show an increasing trend over time, potential yields predicted by the CERES rice model (for the case of Sarjoo-52) shows decreasing tendency of 5.3 Kg ha-1y-1 (R2=0.02) as shown in Fig. 6. It is also observed, that there is a yield gap, showing that actual yield may be increased by minimising this gap, provided the optimum crop management practices are adopted.

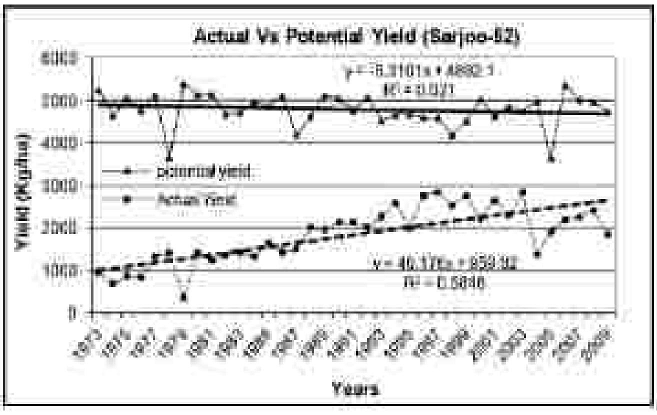

Fig.6 Progress of Actual Yield Versus Potential yield for Sarjoo-52.

3.4 Yield and weather variation

As rice crop mainly depend on three weather parameters namely temperature, rainfall and radiation, therefore, temperature and radiation are plotted to study their variation and relation with productivity, however, rainfall is not discussed as model assumes availability of adequate rainfall. The analysis of these graphs reveals the complicating effect of year to year variations of mean temperature and mean radiation on the predicted potential yields. Fig.7 shows the variation of potential yield and crop duration mean temperature versus year of sowing for Sarjoo-52. It is seen that with increasing trend of mean temperature there is decline in the grain yield. Similar results were obtained by Mathauda and Mavi (1994).

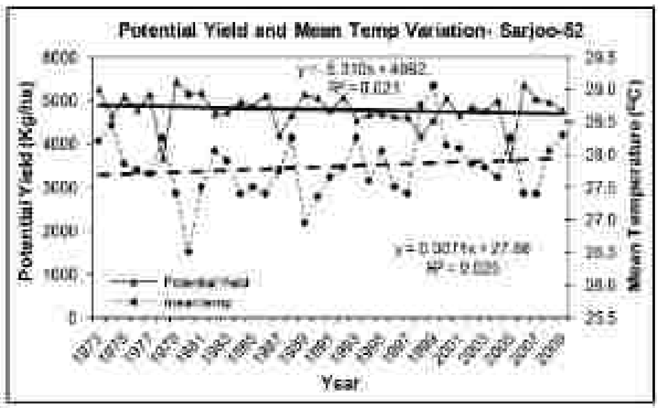

Fig.7 Potential yield and Mean Temperature variations for Sarjoo-52.

Year to year variations in potential yield together with mean radiation (crop duration) is presented in Fig. 8 for Sarjoo-52. A small but statistically significant decreasing trend in mean radiation is the common feature in all the three varieties. A decreasing trend in the potential yields of each crop variety is associated with the decreasing trend of corresponding mean radiations. The same is analysed by calculating the correlation coefficient between potential yield and mean radiation for each crop variety and it is found to be 0.4, 0.3 and 0.4 for NDR-97, Sarjoo-52 and NDR-359 respectively. Analysis of variations of mean diurnal range of temperature (Fig. 9) is considered for Sarjoo-52 where it seems to be one of the important factors controlling the increase or decrease of potential productivity of rice. However, the trend of mean DTR is decreasing but insignificantly at a rate of -0.00130Cy-1.

To study all the three cultivars and associated temperature and radiation collectively, area weighted mean has been taken, such that the variety which covers larger area has more representation (weight) in the area weighted mean. In Fig.10, 11 and 12 the area weighted mean of simulated yield is compared with area weighted mean radiation, area weighted mean temperature and area weighted mean diurnal temperature range respectively. Fig.10 shows the variations of area weighted simulated yield and area weighted mean radiation, where, area weighted mean radiation shows a significant decreasing trend at rate of 0.03 MJm-2day-1y-1. The two curves are in phase except at few years, and hence deviations in radiation may be important influencing parameter for potential productivity of the rice crop. The similar characteristic is seen in Fig. 12, showing importance of diurnal range of temperature, with a decreasing trend but not significant, in deciding the potential yield.

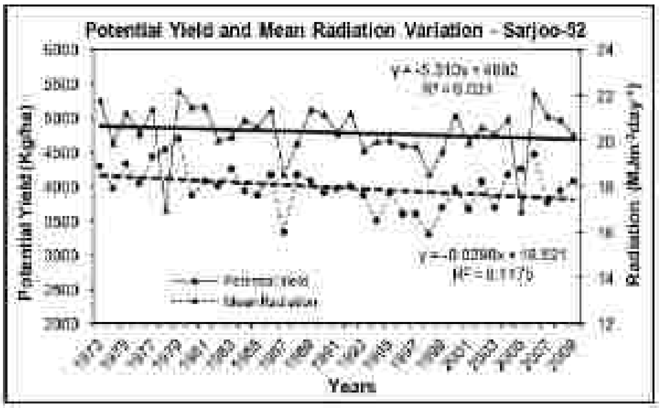

Fig.8 Potential yield and Mean Radiation variations for Sarjoo-52.

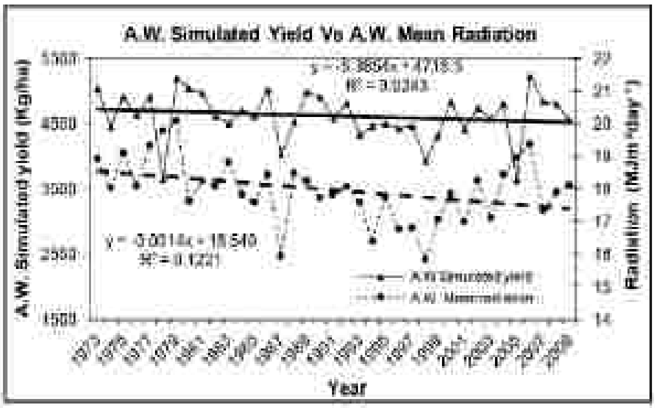

Fig.10 Comparison of Area weighted Simulated Yield and Area weighted Mean Radiation.

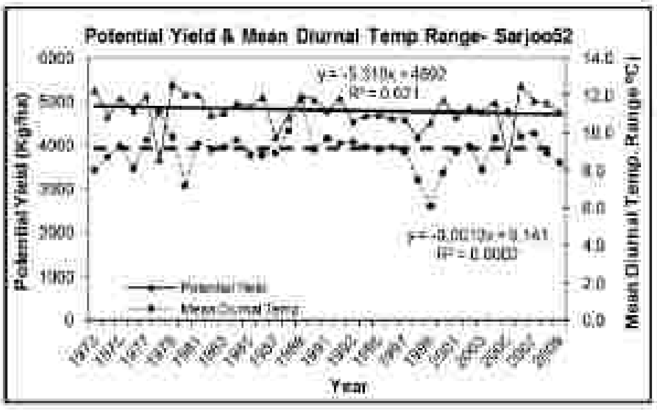

Fig.9 Comparison of Simulated Yield and mean diurnal range of temperature.

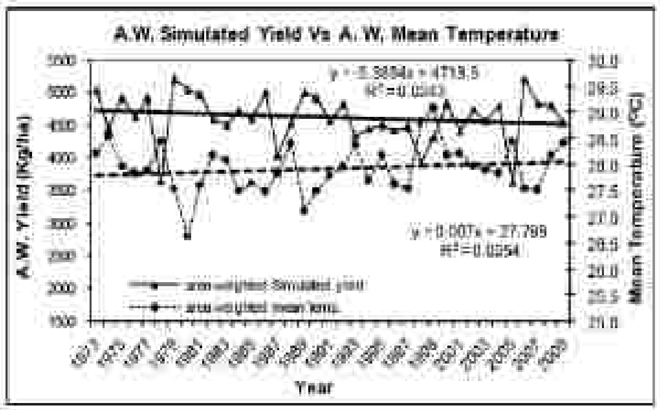

Fig.11 Comparison of Area weighted Simulated Yield and Area weighted mean temperature.

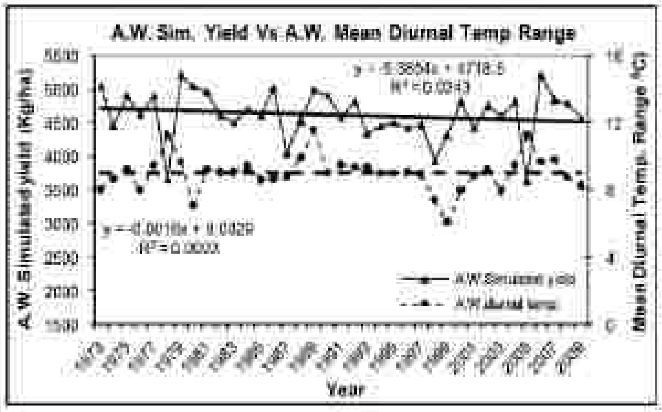

Fig.12 Comparison of Area weighted Simulated Yield and Area weighted mean diurnal range of temperature.

3.5 Removal of weather variation

Weather effects were removed from yield trend, by subtracting the actual average yields from the weather-based potential yields, to give a more appropriate account of the rate at which the yield gap decreases. Fig.13 depicts that when weather effects on yield are removed, yield gap decreased at a linear rate of 51.5 kg ha-1 y-1 (R2=0.13) with significant trend.

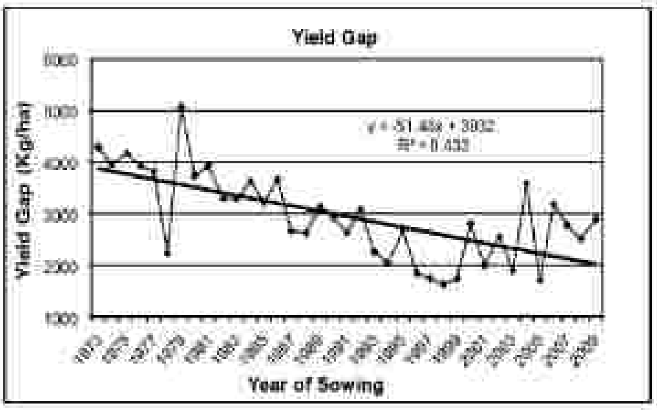

Fig.13 Yield gap between predicted potential yield using CERES model and oberved actual yield as functions of year of sowing.

Although, taking yield difference, considerable variation due to weather is removed, there are still, however, large annual deviations present. The remaining annual fluctuation in yield is reflecting model error, annual management deviations from the long term average and pest/disease. The actual yields are always below predicted potential yields indicate suboptimal management and marginalization of the rice crop in the region.

4. Conclusions

In the present study different weather parameters were analysed and it is found that small changes in the growing season mean radiation and mean diurnal range of temperature over the years appeared to be the key aspect of weather, affecting yearly yield. Among the three rice cultivars considered for the current study, Sarjoo-52 is found to be highest yield producing variety. This type of study could help to find out crop varieties, which can withstand to the varied climatic conditions in different regions.

Variation in yield due to weather could be removed by taking yield difference; however, remaining fluctuations may be due to imperfect model, variations in crop management strategies, nature and intensity of pest and disease over the years. The variations in rainfall may be other factor, although it is assumed to be adequate in the model. The actual yields are always below predicted potential yields indicate suboptimal management. Rice productivity may be enhanced by minimizing yield gap through improving efficiency of present agricultural system and appropriate management practices.

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