J. Ind. Geophys. Union (April 2008)
Vol.12, No.2, pp.89-96

Development of an agroclimatic model for the estimation of rice yield

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ABSTRACT
It deserves an utmost importance to look out for an agroclimatic model for the expected quantum of the rice production especially in Andhra Pradesh in advance in the present era of increasing food demand. Growing degree day or heat unit theories of the crops and Integrated Normalized Difference Vegetation Index along with the rainfall are made use of in obtaining in relation with the crop yield of rice. The atmospheric and oceanic indices such as Southern Oscillation Index and Sea Surface Temperature of Nino 3 region are also incorporated in developing the multi-regression model for the estimation of rice yield.

INTRODUCTION

Rice production is influenced by a set of meteorological variables such as rainfall, temperature etc (Ji et al., 2007). The climate extremities, particularly high temperatures affect the plant growth and reduce the rice yield significantly (Satake & Yoshida 1978). So the study of the aberrations of the climate on the crop yields to plan for the better yields that are sufficient to people has got prominence. The inter-annual variation in the rice yields is linked to inter-annual climate variability and based on this; Yao et al., (2007) studied the B2 climate change scenario on rice yield over China. Terjung et al., (1985) studied the potential paddy rice yields for rain-fed and irrigated agriculture in China and Korea by reporting the interactions of crop performance and climate. Bishnoi, Bhan & Niwas (1991) studied the relationship between seasonal rainfall and pearl millet and reported the dependence of yield on rainfall. It is reported that the rising temperatures (warming) are harmful and the increase in rainfall might be beneficial to agriculture (Seo et al., 2005). Lareef Zubair (2002) examined the impact of El Nino Southern Oscillation (ENSO) and found that ENSO conditions lead to a decline in the rice yield for the Yala season and an increase in the Maha season in Srilanka. Sarma & Lakshmi Kumar (2006a) highlighted the effects of warm phase of ENSO on the agro-climatic elements such as rainfall, potential evapotranspiration and soil wetness etc which play the basic role in the crop productivity. Das, Rase & Shewale (2006) elucidated the dependence of rice yield on rainfall and sea surface temperature anomalies of equatorial Pacific as a case study from Orissa in observing the sensitivity relation between rainfall and rice yield. Chakraborty, Panigrahy & Parihar et al (1993) made use of the satellite derived product of Normalized Difference Vegetation Index (NDVI), in estimating the rice yield production. Sarma & Lakshmi Kumar (2006) studied the relation between integrated NDVI and soil moisture adequacy which strongly influences the crop yields over Andhra Pradesh and reported the dependence of vegetation in relation to the meeting of water need. Sarma & Lakshmi Kumar (2007) elucidated the decreased trend of vegetation with the warm phase of ENSO and an increased trend with LNSO events. The present attempt is an extension in exploring the relation of INDVI with rice yield as a case study for Andhra Pradesh. Amien et al., (1999) reported that higher air temperatures will increase the rice plant respiration rate and reduce the net photosynthesis, hence ultimately reducing plant yield. Idso et al., (1979) and Bollero, Bullock & Hollinger (1996) studied the impact of effective air temperature through growing degree day for crop yield estimation by using correlation analysis. Dubey, Bhan & Attri (2006) proposed a statistical model for the prediction of groundnut yield over Saurashtra using rainfall and mean temperature. The present paper involves not only rainfall and equatorial SST anomalies but also the Southern Oscillation Index (SOI), Growing Degree Day and Integrated NDVI (INDVI) in developing the statistical mode of agroclimatic model in predicting the rice yield for Andhra Pradesh.

Data and Methodology

Yield data of rice for all Andhra Pradesh from 1950 to 2002 was collected from the Agro-Economic centre, Andhra University, Visakhapatnam. Rainfall, maximum and minimum temperatures are procured from the India Meteorological Department, Pune. The data of SOI, SST of Nino 3 region and NDVI are downloaded from the website www.cdc.noaa.gov and www.jisao.washington.edu.

The Growing Degree Day (GDD) of All Andhra Pradesh is calculated using the following expression

$$GDD = (T_{max}+T_{min})/2 - T_b$$

Where T_{max} and T_{min} are the daily maximum and minimum temperatures and T_b is the threshold temperature for the crop, below which physical activity is inhibited and equal to 10°C.

The correlation analysis has been carried out using Pearson correlation technique and the statistical model is developed using multi- regression method.

RESULTS AND DISCUSSION

Fig.1. depicts the percentage departures of All Andhra Pradesh rice yields from the median for the period 1950 to 2002. The departures showed an over all increased trend with some dips and ups that was started from -42% in the year 1950 to a high value of

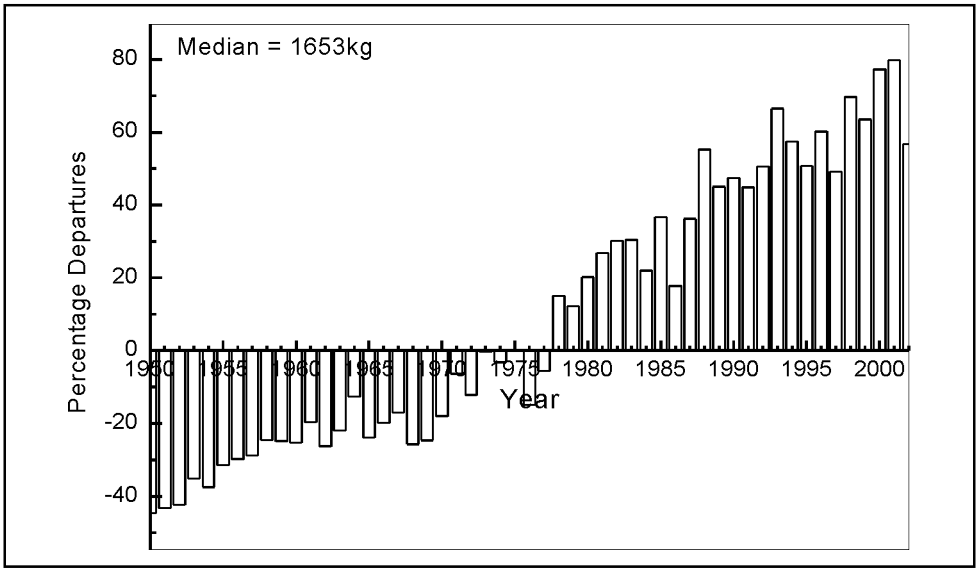

Figure 1a. Annual percentage departures of AP rice yield.

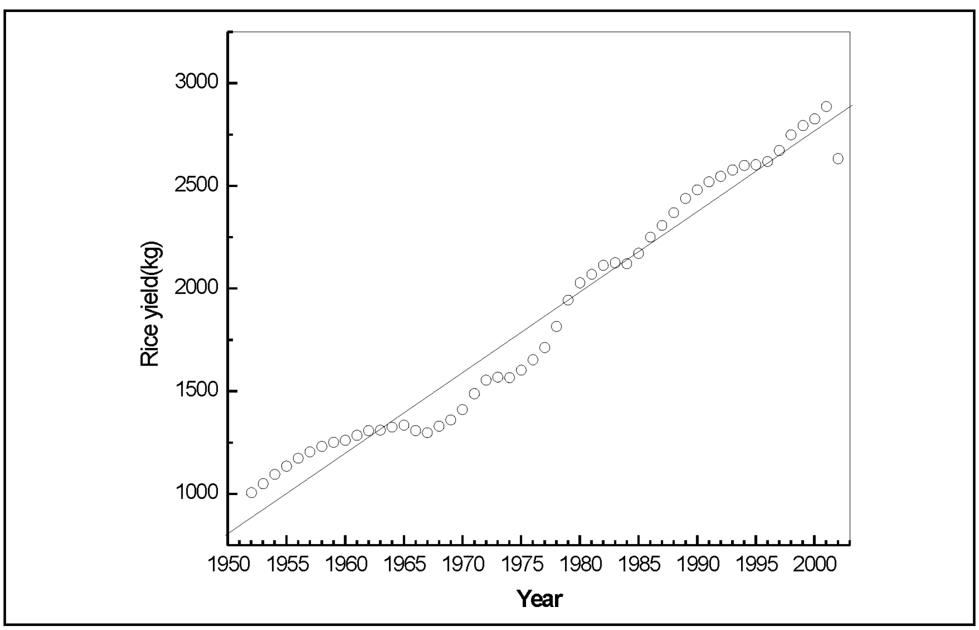

Figure 1b. 5 – year moving average and trend of AP rice yield.

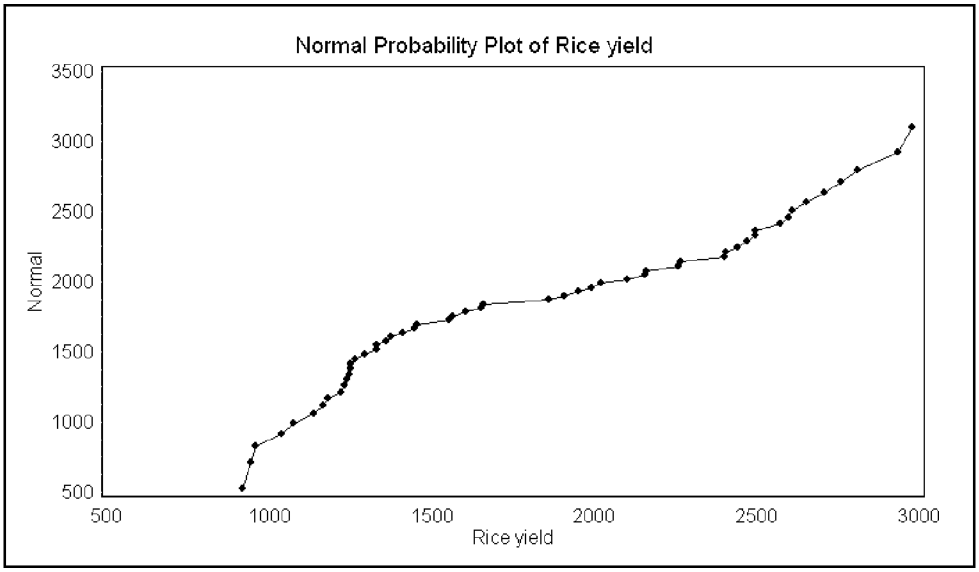

Figure 1c. Normal probability plot of rice yield.

80% in the year 2001. The yields are below the median till the year 1977 and there after a steady rise above the median. The variability in rice yield is high during the period 1979 to 2002 than 1950 to 1978. It is also observed from the study that the median of the rice yield during the El Nino years (1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1987, 1997, 2002) was 1410 while in La Nina years (1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1975, 1988, 1998) it was 1447, from which it can be inferred that the effect of warm phase of ENSO was clear on AP rice yields. It is worth mention to note that the rice yield was less in El Nino years compared to that in the case of La Nina events when the consecutive El Nino and La Nina events were considered (1969, 1970; 1987, 1988 and 1997, 1998).

Fig.1b and 1c infers the 5-year moving average, trend and the normal probability plot of AP rice yield for the period 1950 to 2002. The 5-year moving averages showed an increased trend and a linear fit is approximated. The normal probability plot of rice yield concludes that 1237kg of yield occurs with 20% probability and consequently 1653kg and 2494kg of yield can be produced for the probabilities of 50% and 80% respectively.

Variability of rice yield with respect to the meteorological parameters

The annual figures of rice yields and rainfall for the period 1982 to 2000 is depicted in the Fig.2a. It is observed that the rice yield is increasing linearly and the trend was significant where as the rainfall trend was insignificant and was not at all showing any trend. The highest rice yield is recorded in the year 2000 for a rainfall amount of 916mm and lowest in the year 1986 with a rainfall of 840mm. The correlation between rainfall and rice yield was 0.14 which is very less and is an indicator of direct dependence of rice yield on rainfall. It is very important to note the point that the irrigation which acts as a surrogate for the rainfall is increased prominently from 1950 to 2000 and 37, 23, 560 hectares of the cropped areas has been utilized under major, medium and minor irrigation projects and it is reported that 40% of the state cropped area is irrigated and 60% of the state agricultural yield is from the irrigation (www.aponline.gov.in). This might be the one of the causal factors that was unable to explain the pertinent relation between rainfall and rice yield even though the state agriculture is mainly rainfall dependant.

The march of rice yield with the Southern Oscillation Index is presented in the Fig.2b. The interannual variability in SO Index is high and is varied from -2.18 in the year 1987 for an yield 2258kg to a maximum value of 1.21 for an yield of 2710kg in the year 1999. The Pearson correlation value of +0.39 explains the positive dependence of rice yield on SOI.

Fig.2c. illustrates the variability of rice yield with the sea surface temperature anomalies of Nino 3 region. It is clear that the SST followed a decreased trend where as the rice yield behaviour is in quiet opposite direction. The correlation analysis witnessed the inverse relation and the highest SST anomaly recorded in the ENSO year 1997 for an yield of 2471kg. The LNSO year of 1988 displayed a very low value of SST for an yield of 2572kg. The Pearson correlation is -0.48 and is significant at 0.05 levels and can be used as an indicator that influence the tropical climate and thus modulates the yield considerably compared to SO index (Sarma & Lakshmi Kumar 2007).

Fig.2d depicts the integrated response of rice yield from the *Khariff* and *Rabi* seasons in relation to the growing degree day units. It is obvious from the Fig.2d, that the rice yield reacted greatly to the GDD units by showing the positive correlation of +0.71 with 99% confidence interval. The range of GDD is 519 units with the highest and lowest values 3365 and 3885 units that are recorded during the years 1984 which is preceded by the ENSO year 1983 and 1998, an LNSO year respectively.

Fig.2e. shows the march of rice yield with the integrated NDVI (INDVI) of *Khariff* and *Rabi* seasons for All Andhra Pradesh. It is inferred from the fig.2e that the rice yield increased as INDVI increases and the Pearson correlation for the variables is +0.73 which reflects the proportionate rice production with the vegetation index. Maximum INDVI of 3.25 is recorded for an yield of 2812kg in the LNSO year 1998 where as the lowest INDVI of 2.27 was for an yield of 2156kg in the year 1982.

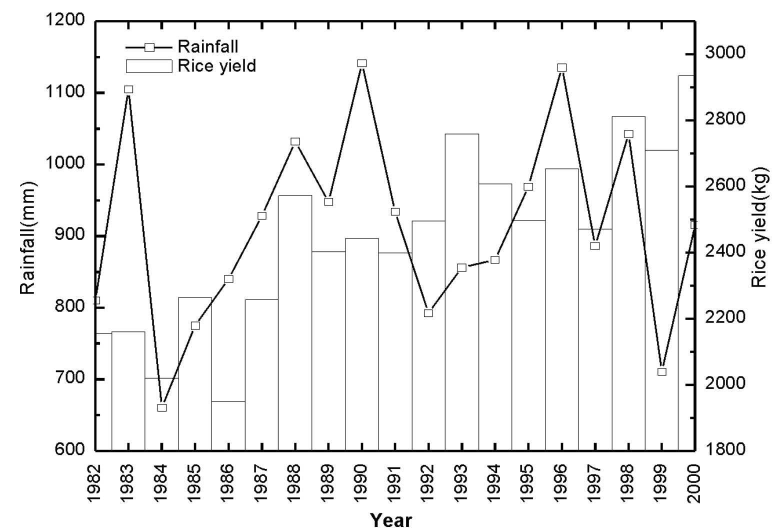

Figure 2a. Variability of All AP rice yield and annual rainfall.

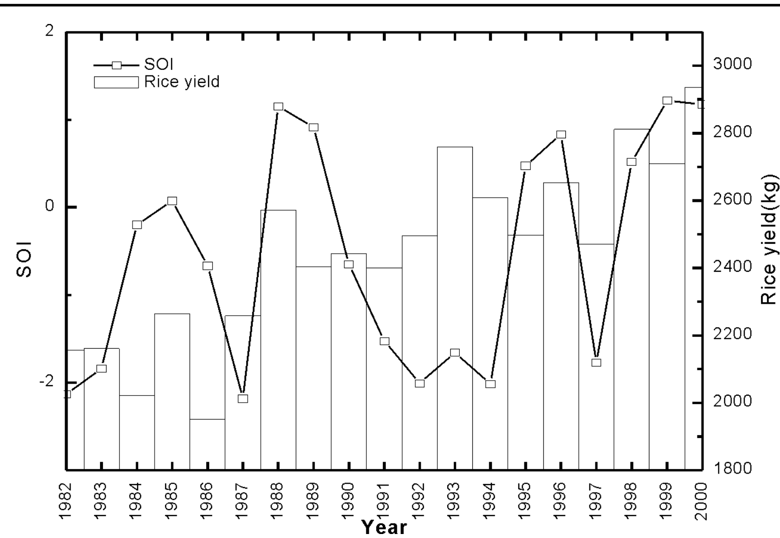

Figure 2b. Variability of All AP rice yield and SO Index.

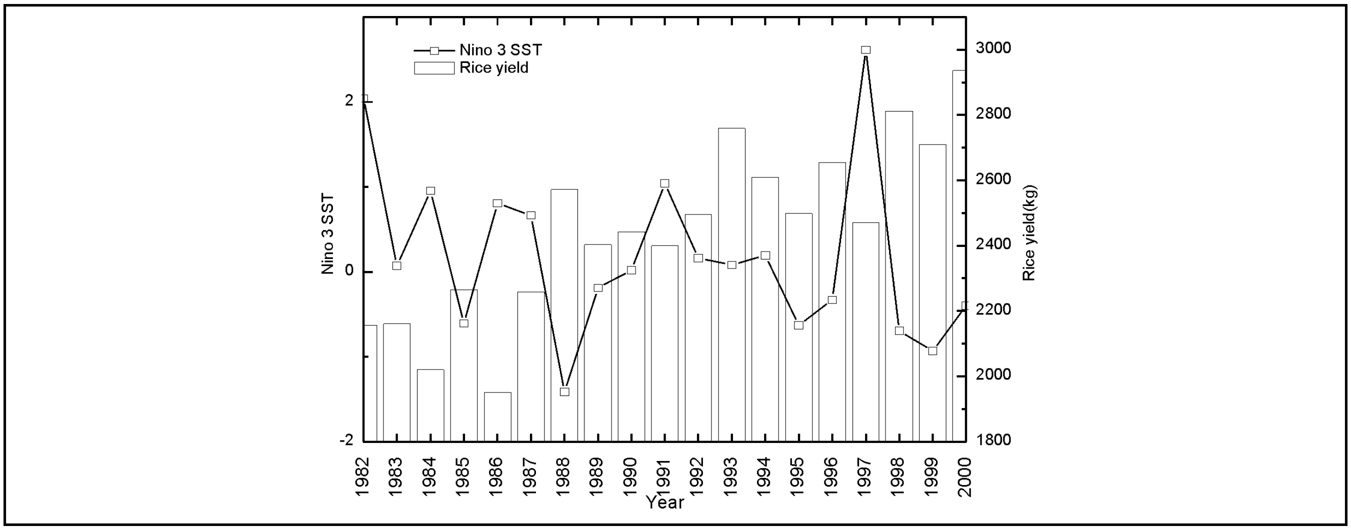

Figure 2c. Variability of All AP rice yield and SST of Nino 3 region.

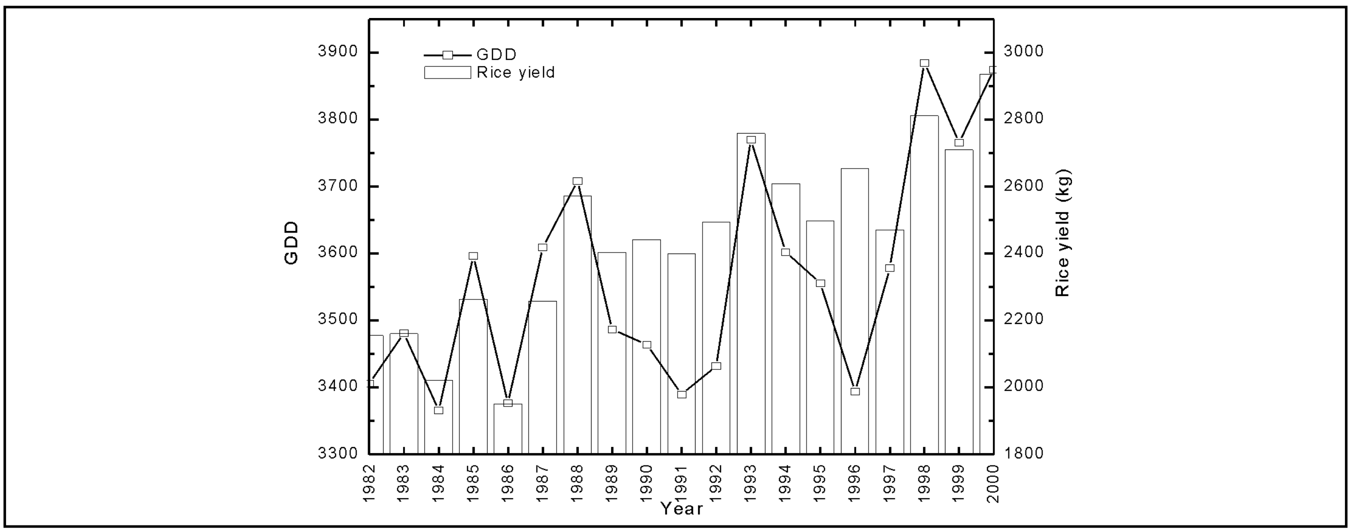

Figure 2d. Variability of All AP rice yield and GDD units of khariff and rabi seasons.

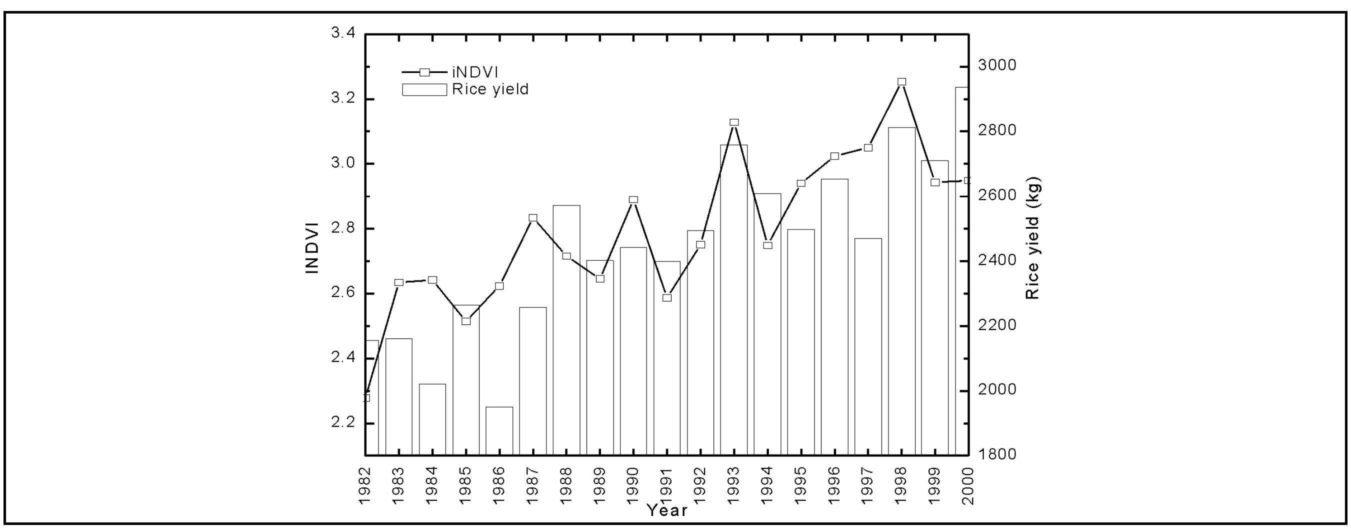

Figure 2e. Variability of All AP rice yield and INDVI for kahariff and rabi seasons.

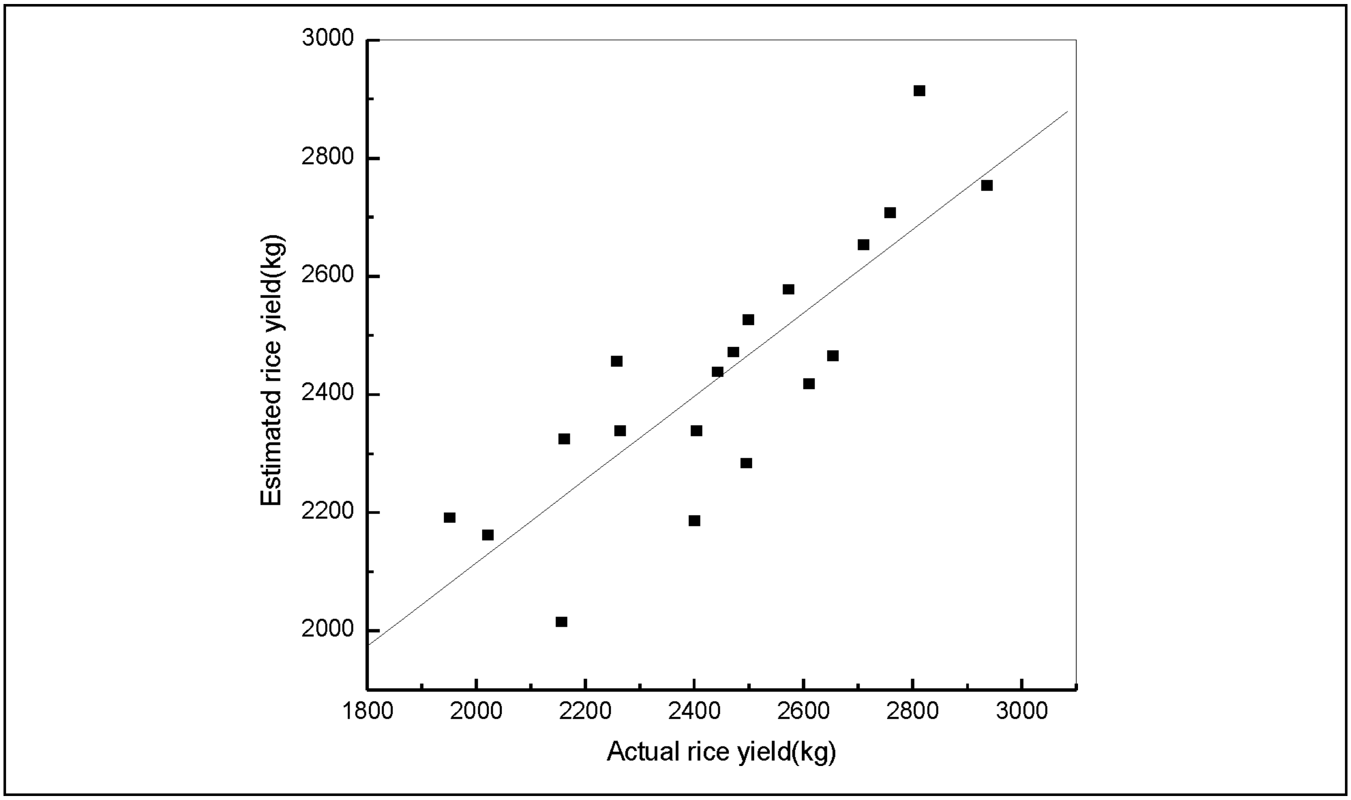

Figure 3a. Linear fit of actual and estimated rice yields.

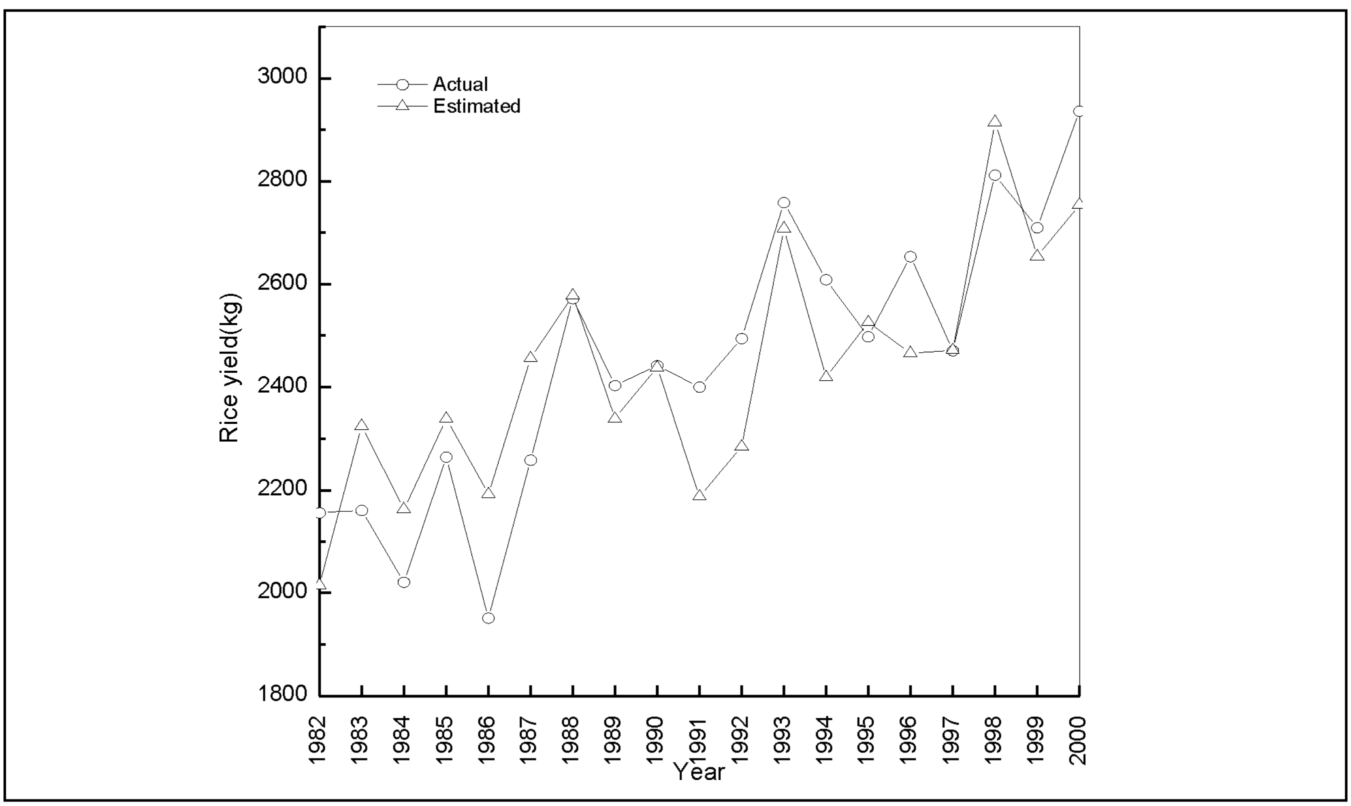

Figure 3b. Actual and estimated annual rice yield - Andhra Pradesh.

Statistical model

The meteorological variables in the present investigation, for All AP are rainfall, SOI, SST of Nino 3 region, All AP growing degree day units and All AP integrated NDVI for *Khariff* and *Rabi* seasons are involved and the multi-regression analysis has been employed for the estimation of rice yield. The study elements are all well responded by giving the variance of 0.71 with 170 of root mean square error. The regression expression is as follows

$$Y = 0.16(X_1) + 8.8(X_2) - 26.1(X_3) + 0.73(X_4) + 427.78(X_5) - 1502.95$$

Where Y = Rice yield in kg
X_1 = Annual rainfall in mm
X_2 = SOI
X_3 = Nino 3 SST
X_4 = GDD Units
X_5 = INDVI

Fig.3a infers the correlation of +0.84 and a linear fit approximation of slope of 0.71 for the actual yields and estimated rice yields that are obtained from the suggested equation. The correlation in this case is significant at 0.01 levels. Fig.3b shows the march of actual and estimated rice yields where the maximum difference was in the year 1986 and it was about 241kg/ha, which was more than actual yield.

CONCLUSIONS

The study portrays the significance of not only the regional meteorological variables but also the indices of atmospheric tele-connections on rice yield. The rice yield is not varied linearly with the rainfall of AP but maintained good relations with the growing degree day units and the satellite derived vegetation index, INDVI. The impact of sea surface temperature of Nino 3 region is more on rice yield compared to that of SOI. The suggested statistical agrometeorological model imbibed the five (5) variables that have significant impact on yield.

ACKNOWLEDGEMENTS

The authors acknowledge Additional Director General of Meteorology (Research), Pune for supplying the meteorological data. Dr.C.Rtanam, In-charge, Agro economic centre, Andhra University is acknowledged for having supplied the rice yield data for AP.

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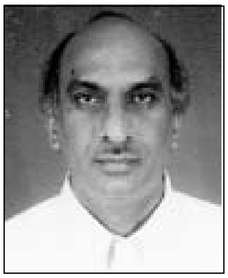
(Accepted 2008 April 30. Received in original form 2007 August 30)



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ii) Vegetation Phenology from satellite measurements.
iii) Physioclimate spectrum of India, induced bioclimate changes and the effects of psycho-physiological sensations and
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