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Research Article

Agroclimatic Modelling for Estimation of Wheat Production in the Punjab Province, Pakistan

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Abstract: Pakistan's economy hinges on agriculture and the most important agricultural commodity of the country is wheat. The province of Punjab has the predominant share in wheat production of the country. As agriculture sector is highly vulnerable to the climate change phenomena, the current global climatic change can have significant impact on sustainable wheat production and, hence, on food security. Thus, it was thought imperative to investigate the influence of current climate change on wheat production. This article reports on an attempted agroclimatic model for the estimation of wheat production in Punjab using meteorological parameters.

Keywords: Agroclimatic model, prediction of wheat yield, agrometeorological variables

1. INTRODUCTION

Agriculture is the linchpin of our national economy. According to economic survey of Pakistan 2011–2012 it has a share of 21% in the national GDP and employs 45% of the national labour force. The agricultural production system of Pakistan is based on irrigation. In Pakistan 84% of the total cultivated area (22.05 million ha) is under irrigation and the remaining is entirely rainfed or *barani* [1]. More than 90% of the available fresh-water resources in the country are utilized for irrigated agriculture [2]. Punjab is Pakistan's second largest province with 205,344 km^2 (79,284 mi^2), after Balochistan, and is located at the northwestern edge of the geologic Indian plate in South Asia. The Fig. 1 depicts the distribution of average yield of wheat in various districts across the country. According to McCarty's measure, 28 out of 35 districts of Punjab have higher yield than the country's average yield, i.e., 2.05 ton per hectare. The northern districts of the Punjab have lower productivity per unit land area, primarily due to the topographical features and more relative humidity [3]. Several studies have highlighted agro-ecological zones for the growth and development of crops across the country [3, 4]. The cultivate areas of the entire country are divided into 10 agro-ecological zones (Fig. 2). Out of which four agro-ecological zones, i.e., irrigated plains, *Barani* (rain fed) region, *Thal* region and Marginal Lands occur in the Punjab province.

The agricultural sector of Pakistan is confronted with many problems. The provision of livelihood and food security for the fast growing population, without affecting the fragile ecosystem, are the main challenges to the agriculture sector. Being open to vagaries of nature, agriculture sector is highly susceptible to climate change phenomena. The scholars opine that human activities have reached a level where these are adversely affecting global environment. Anthropogenic perturbations are causing the global climate change at a much faster rate compared to natural pace. The current global climatic change can have significant impact on sustainable agriculture production and food security as described by Adams et al. [5]. Increasing change in ambient temperature and rainfall and the resultant increased frequency and intensity of droughts and floods have long term influence on

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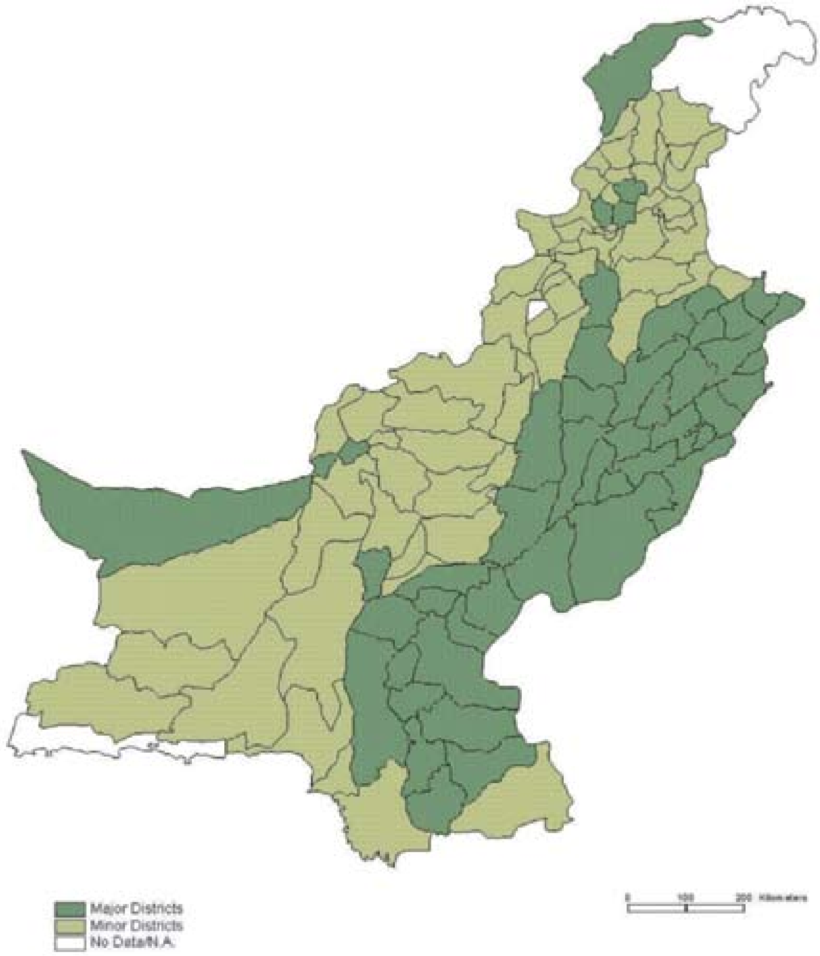

Fig. 1. Wheat growing areas in Pakistan, 2004-05 (courtesy: Dr. S.S. Ali).

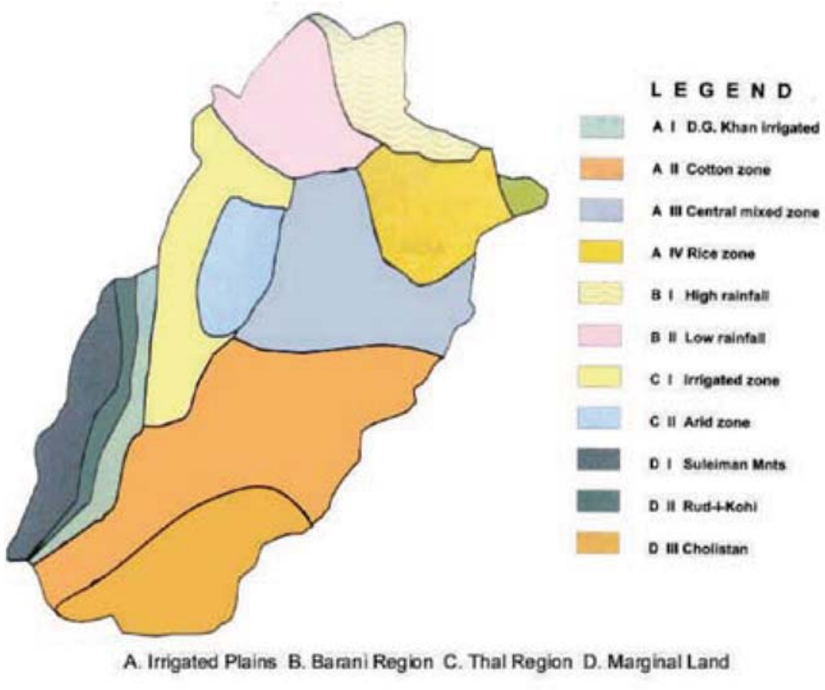

Fig. 2. Agro-ecological zones of Punjab (courtesy: Dr. S.S. Ali).

the crop-lands, pastures and forests. Thus, it was thought important to investigate the impact of current climate change on agriculture of the country. Estimates of evapotranspiration offer an outlook of soil-water balance in association with the amount of precipitation. Such estimates are of significance for computation of water demand of the field crops and irrigation scheduling [6]. Also, these estimates can help determine the nature of agro-climate, agro-climatic potential of the region and suitability of various crops or varieties which can be grown for obtaining the best economic returns [7].

A recent study employed Growing Degree Days (GDD) for expressing the relationship between period of every plant growth phonological stage and the temperature degree [8]. Growing Degree Days of all Andhra Pradesh were correlated with variability of rice yield of this Indian state [9]. Satellite-derived product of normalized difference vegetation index (NDVI) were used by Chakraborty et al. [10] for the estimation of rice yield. In this study as well, we employed NDVI for estimating the wheat yield of Punjab province by examining the relationship between wheat productivity per unit area and integrated NDVI. Finally, we constructed a multiple regression model of wheat in the Punjab using agro-meteorological variables derived from nearest stations, i.e., the remotely sensed satellite data (e.g. NDVI, GDD, and SOI).

2. DATA AND METHODOLOGY

2.1. Data

Yield of wheat crop has been collected from website of Agriculture Marketing Information Service Directorate of Agriculture (Economics & Marketing) Punjab, Lahore. The Pakistan Meteorological Department provided data of daily maximum and minimum temperature of Lahore, Jhelum, Khanpur, Multan, Faisalabad, Islamabad, Bahawalpur, and annual data of rainfall of Islamabad, Jhelum, Lahore, Sargodha, Faisalabad, Multan, Bahawalpur.

The following formula was used to compute the Growing Degree Days (GDD):

$$GDD = \frac{T_{Max} - T_{Min}}{2} - T_b$$

where T_{max} and T_{min} are daily maximum and minimum temperature, T_b is the threshold temperature below which growth of wheat crop is not possible, and T_b is to equal to 5°C [11 & 12]. We first calculate of monthly GDD temperature for each mentioned stations using T_{max} and T_{min}. Next, the monthly data of GDD temperature of Punjab was computed by taking average of monthly GDD temperature for each mentioned stations.

Normalized Difference Vegetation Index (NDVI) is the satellite-derived product which represents the green vegetation in area. It works on the phenomena that growing green plants absorb radiations in visible region and emit infra red radiation. Data of NDVI can be downloaded from the website www.jisao.washington.edu. NVDI was computed using the formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where NIR = Near Infrared Reflectance band

R = Red Reflectance band

This spectral pattern is described by a value ranging from -1 (usually water) to +1 (strongly vegetative growth). We computed spatial average of monthly NVDI over the region of Punjab province.

Other parameters which were used in this study is South Oscillation Index (SOI). SOI and Nino 3 were obtained from the website www.cdc.noaa.gov. SOI was used to indicate El Nino and La Nina events. It is calculated by using the Mean Sea Level Pressure (MSLP) difference between Tahiti and Darwin. It can be calculated as:

$$SOI = \left[\frac{(P_{diff} - P_{diffav})}{SD(P_{diff})} \right]$$

where P_{diff} = (Average Tahiti MSLP for the month) - (Average Darwin MSLP for the month)

P_{diffav} = Long term average of P_{diff} for the month

$SD\ (P_{diff})$ = Long term standard deviation of P_{diff} for the month

2.2. Methodology

To examine the impact of agro-climatic parameters on wheat yields of Punjab, we first calculated the season mean of crops from November to April. It is important to understand the role of agro-climatic parameters in modelling for wheat crop. Albeit techniques for identifying parameters range from simple correlation analysis to advanced procedures such as canonical correlation and neural network [13, 14], we used the Pearson correlation analysis because it is the simplest. At first, correlations were calculated between crop yields and agro-climatic parameters (e.g. rainfall, GDD, NVDI, SOI, etc.).

Secondly, multiple linear regression equation was constructed between wheat yields of Punjab and the previously identified independent and significant agro-climatic parameters only. The variance associated with each parameter designates the relative importance of the index in modulating the crop variability. Moreover, the total variance gives confidence in relating and explaining these inter-annual variations. The linear regression model is defined as:

$Y = b^0 + b^i X_i$, $(i \in \{0, 1, 2, 3, \ldots ,p\})$,

where Y is the estimated wheat yield in standardised unit, b^0 is the intercept, X_i is a value of the i th predictor (agro-climatic parameter) in the model, b^i is the model parameters representing the linear relationship between the predictor and predicted, p the number of the predictors variable in the model.

3. RESULTS AND DISCUSSION

Percentage departure of wheat yield in Punjab province from median 599.2 is plotted in Fig. 3. Percentage departure started from –65.5% and there is a fall initially up to minimum value of –132.2% (in 1952). After that it rose linearly with some ups and downs. It had the maximum value of 46.6% in the year 2006. Wheat yield was below the median till year 1977. Since 1978 the yield was above the median, except in 1983. In our study we also observed that during La Nina years (i.e., 1947, 1948, 1949, 1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1975, 1988, 1998, 2000, and 2007) the average yield of wheat was 558.32 kg/acre. During El-Nino Years (i.e., 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997, 2002 and 2009) the average yield was 621.68 kg/acre, which clearly indicated that warm phase of ENSO had positive effect on wheat yield. . Sarma et al [9] have also obtained similar results for rice production in Andhra Paradesh, a province of India.

3.1 Variation in Wheat Yield with Meteorological Parameters

The five-year moving average exhibited a linearly increasing trend (Fig. 4). The annual rainfall and wheat crop yields are plotted in Fig. 5. It shows that the wheat yield increased linearly and its trend is significant, whereas the rainfall trend was partial linear from 1987 to 1998. But overall its trend did not described the variation in wheat yield. The highest wheat yield was recorded in the year 1999 when the rainfall was observed 453 mm and the minimum wheat yield was recorded in the year 1983 when the rainfall was 766 mm. Pearson correlation coefficient of rainfall with wheat yield was –0.16, which was not significant. In the Punjab, as a large wheat area is irrigated by tube wells, this might be the reason of this insignificancy. The insignificant relationship of crop yield with the rainfall was also observed by Sarma et al [9].

Fig. 6 depicts the plot of wheat yield with Nino

Table 1. Correlation coefficient (r) of wheat yield with meteorological parameters.

Parameters/Months	Nov	Dec	Jan	Feb	Mar	Apr	Nov-Apr	Selected Months	
SOI	0.38*	0.36*	0.12	0.30	0.25	0.14	0.28	0.38*	Nov-Dec
GDD	0.45**	0.42*	-0.12	0.24	0.09	0.37*	0.41*	0.50**	Nov-Dec
NDVI	-0.08	-0.29	0.40*	0.58***	0.46**	0.03	0.22	0.52**	Jan-Mar

*significant at 0.1; **significant at 0.05; ***significant at 0.01

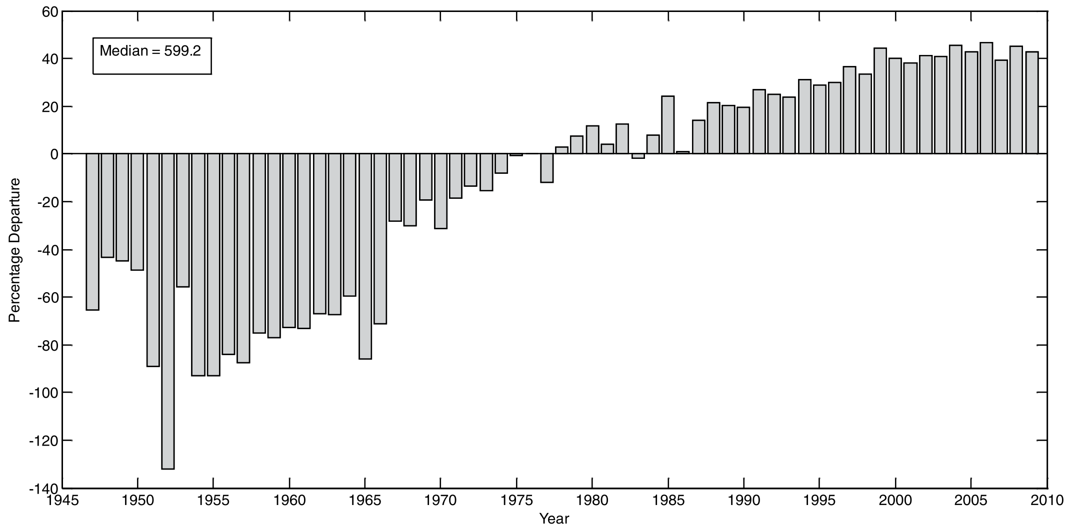

Fig. 3. Percentage departure of wheat yield in the Punjab.

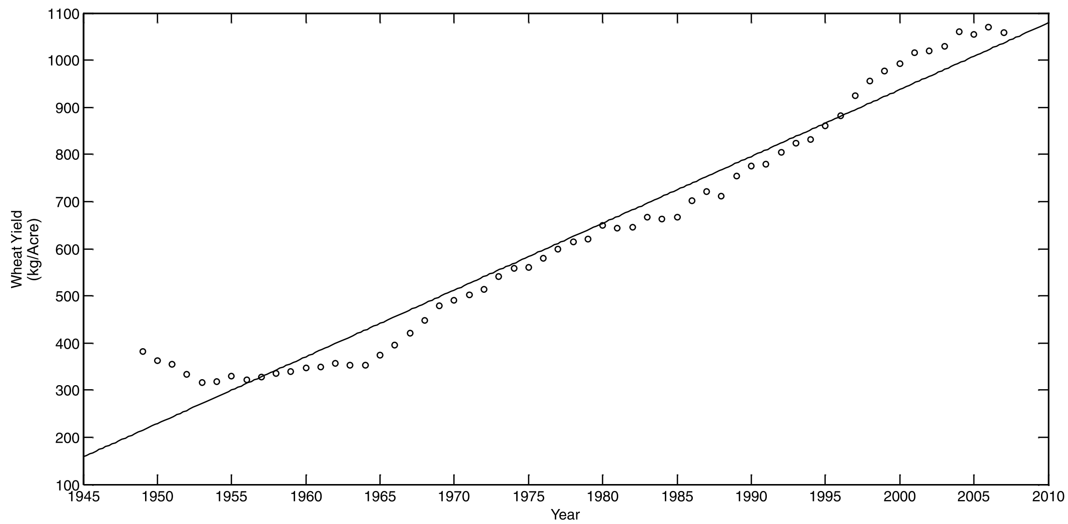

Fig. 4. Five-year moving average of wheat yield in the Punjab.

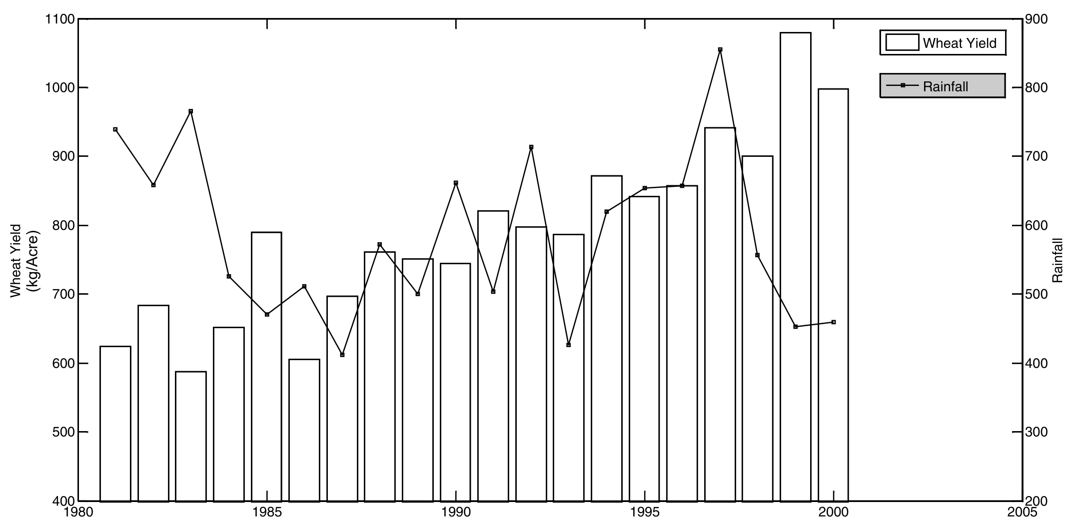

Fig. 5. Variability of wheat yield with rainfall in the Punjab.

3 SST. It was observed that there was no correlation between these variables; the Pearson correlation coefficient between them was –0.1, which was non significant at 0.1 level. Krishna Kumar et al [15] had similar finding for Indian agriculture and exported that Nino 3 SST anomaly hasdsignificant relation with Kharif crops whereas for Rabi crops it was not meaningful. There are different stages in growth of wheat plant. SOI has been tested month wise and its correlation with wheat yield which is tabulated in Table 1. As SOI had significant correlation (with p-value less than 0.1) during the months of November and December, we took the average of SOI for these two months for further analysis. This showed that the average SOI of the mentioned months significantly explained initial phonological stages of wheat plant growth. Fig. 7 illustrates the variability of wheat yield with the Southern Oscillation index (during Nov-Dec). Southern Oscillation index varied from –2.69 in the ENSO year 1982 for wheat yield of 684 kg to 1.59 in the ENSO year 1988 for wheat yield of 761.6 kg.

Growing degree day (GDD) had significant relationship with wheat yield in the months of November and December. So we understand that GDD explain the initial development of wheat plant

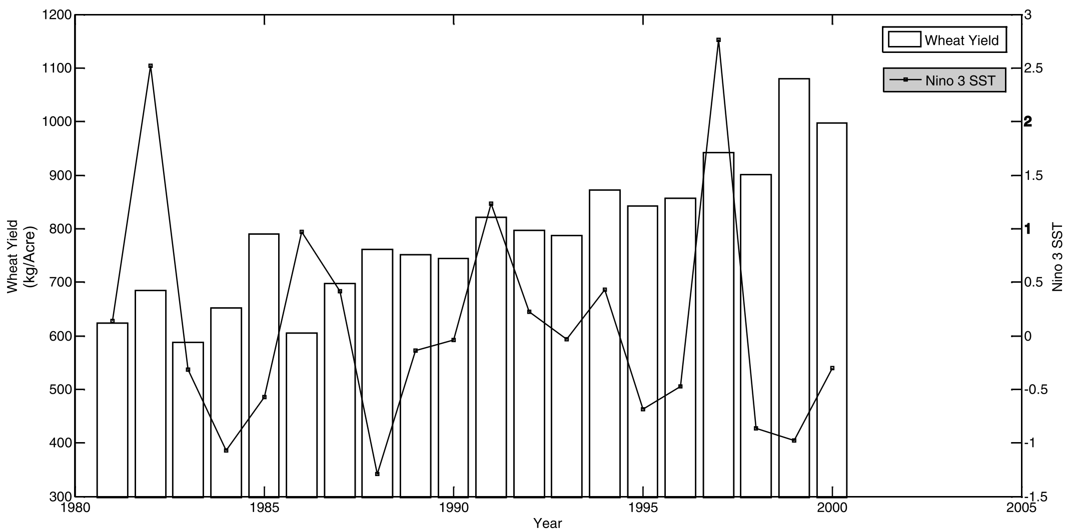

Fig. 6. Variability of wheat yield with Nino 3 SST in the Punjab.

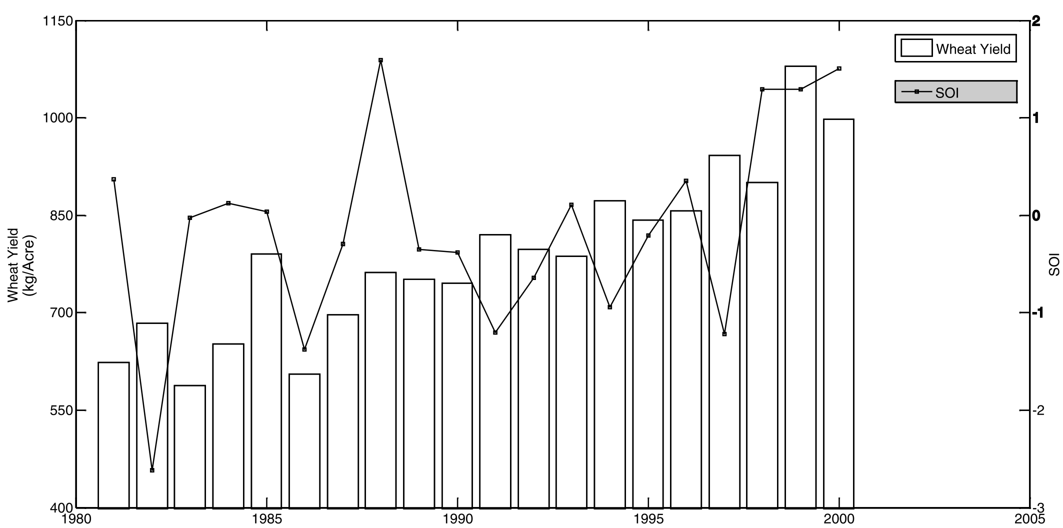

Fig. 7. Variability of wheat yield with SOI in the Punjab.

growth. Wheat yield had linear dependency on GDD (Fig. 8). GDD had the range of 135 units with the lowest value of 646 units in the ENSO year 1997 and highest value of 781 units in the year 1999 for the maximum yield of 1079 kg. It exhibited positive correlation of +0.50 with 97.4% confidence interval. As shown in Table 1, NDVI was significant during the period of January to March. Fig. 9 represents the proportionality of NDVI (for the months January to March) with wheat yield. Pearson correlation coefficient for NDVI with wheat yield was highest among all the other parameters. Its value was 0.52 with the 98.3% confidence interval. Minimum value of NDVI was 0.79 in the ENSO year 1982 for wheat yield of 684 kg and the maximum value of NDVI was recorded in the year 1993, which was declared as neutral according to JMA index classification. In this year the wheat yield was 786.6 kg. It is relevant to note that NDVI was also highly significant in the model developed by Bazgeer et al [16] for the prediction of wheat yield of Hoshiarpur district of Punjab, India.

3.2 Statistical Model for Prediction of Wheat Yield

We computed correlations among the significant meteorological parameters SOI (Nov-Dec), NDVI (Jan-Mar) and Growing Degree Day Temperature (Jan-Mar) for the Punjab province which (Table 2). It shows that NDVI and GDD were mutually

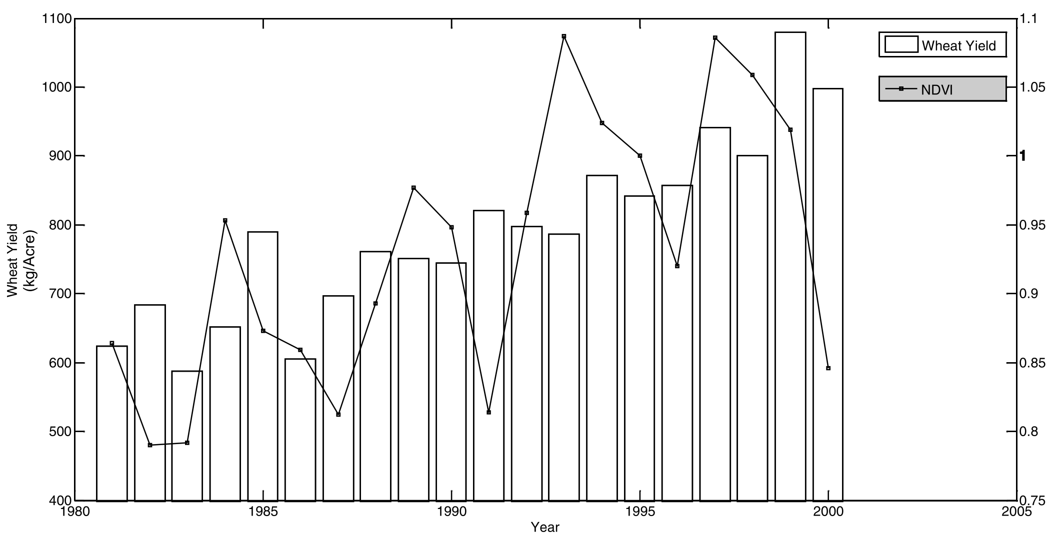

Fig. 9. Variability of wheat yield with NDVI in the Punjab.

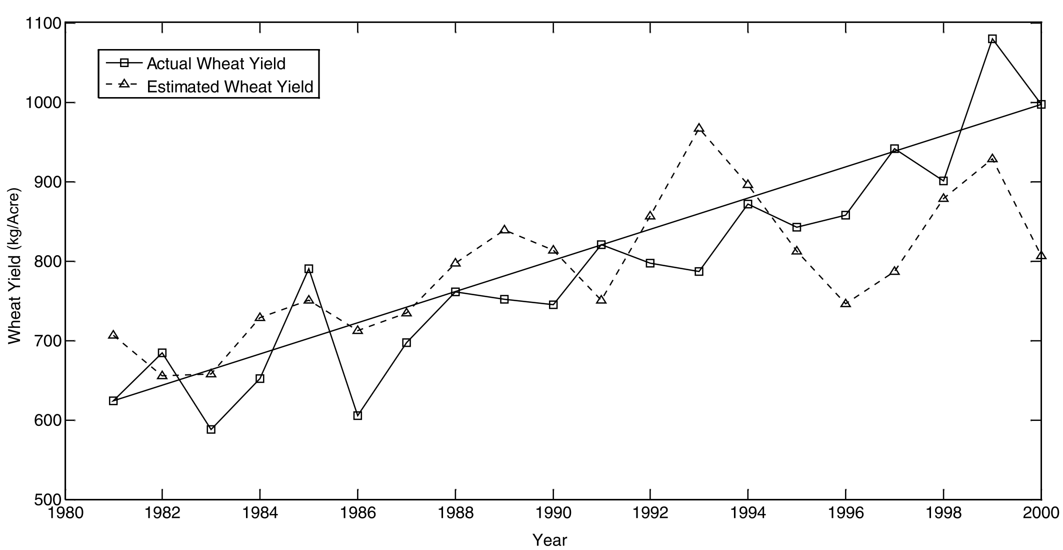

Fig. 10. A comparison of actual wheat yield with estimated wheat yield.

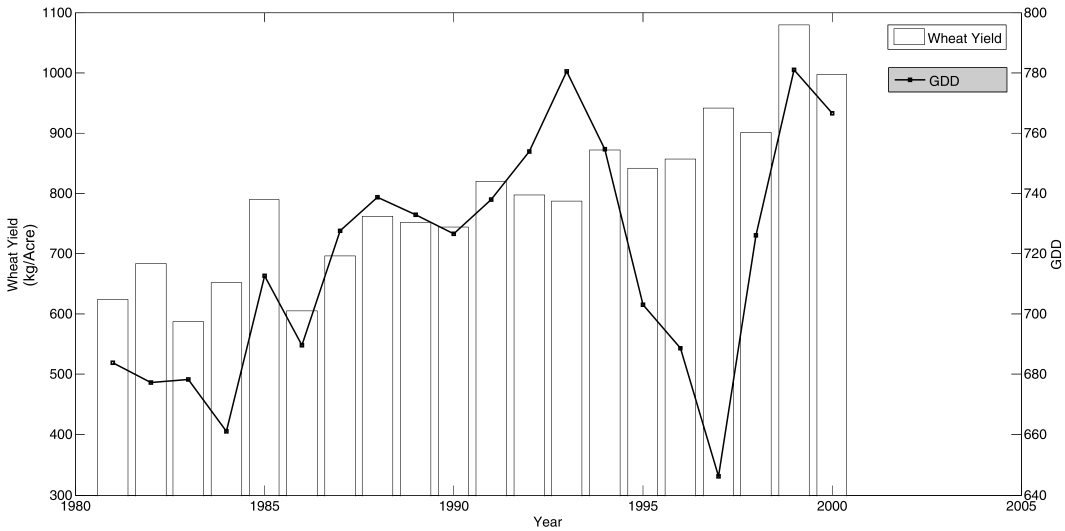

Fig. 8. Variability of wheat yield with GDD in the Punjab.

independent. The statistical model of wheat yield in the Punjab province for was constructed with two independent parameters (i.e. NDVI and GDD) by using multi-regression analysis. The regression equation was:

$$Y = 587.54*X_1 + 1.34*X_2 - 717.06$$

where Y = Wheat Yield in kg/acre

X_1 = Seasonal average of NDVI of Punjab for the months from January to March

X_2 = Seasonal average of Growing Degree Day Temperature of Punjab for the months from November to December

Table 2. Correlation coefficients (r).

Parameter	NDVI	GDD	SOI
NDVI	1.00	0.22	Correlation coefficient 0.20, Significance level 0.40
GDD	0.22	-	Correlation coefficient 0.41, Significance level 0.08
SOI	0.20	0.41*	-

*significant at $P < 0.1$

The correlation coefficient (r) of the linear model was +0.65. Thus, our model explained 43% variability of wheat yield for the period from 1980 to 2000. Fig. 10 shows the comparison of actual wheat yield and estimated wheat yield. The maximum difference was approximately 190.82 kg in the year 2000 which was less than actual wheat yield.

4. CONCLUSIONS

This study demonstrated the impact of regional meteorological parameters (i.e., NDVI and SOI) and the sea level pressure at the Pacific Ocean on wheat yield in Punjab province of Pakistan. The wheat yield was not dependant on rainfall; also Nino 3 SST had no explanation with regard to wheat productivity in the Punjab. However, South oscillation exhibited some relationship with wheat yield, but it was not included in the model because it has relationship with GDD ($P < 0.1$) NDVI and GDD temperature had greater impact on wheat yield. NDVI had a stronger correlation with wheat yield, compared to other parameters. Thus, we construct a multi-linear model for wheat yield by employing NDVI and GDD. This model explains the 43% variability of wheat yield for the 1980–2000 period.

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