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PERFORMANCE EVALUATION OF MEDIUM-RANGE WEATHER FORECAST USING CROP GROWTH SIMULATOR

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ABSTRACT

Medium range forecast, a recently introduced service in India, has not been evaluated satisfactorily in terms of agricultural applications. In this article an attempt has been made to evaluate the performance of medium range weather forecast for Delhi and Ludhiana environment in the rabi (winter) season of 1994-95 by comparing the forecasted with actual weather components, mainly maximum and minimum temperature, wind speed, sunshine hours, and rainfall. Furthermore, yield and growth response of wheat simulated under adequate, moderate, and limited irrigated conditions were compared for forecasted and actual weathers employing wheat growth simulator (WTGROWS). Medium-range forecast performance for predicting maximum and minimum temperatures for both the locations had predictability lying in the range of 70 to 85 percent. The precision was somewhat better in case of maximum temperature assessment. Wind speed for both locations was poorly assessed. Forecasted rainfall matched actual rainfall on some occasions only at Ludhiana but the performance, in terms of seventy-two hours around the forecasted time, gave better results. The observed bright sunshine hours showed poor predictability (less than 30%). Forecasted grain yields for all levels of soil moisture availability treatments at both the locations were

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higher by about 2 to 9 percent when compared with the corresponding values obtained under actual weather runs. A similar trend was noticed for above ground biomass but the degree of variation was lower. Seasonal evapotranspiration and transpiration values showed correspondence with the rains received during the crop growing period.

INTRODUCTION

Medium-range weather forecasts are defined as those made between 3 and 10 days in advance. Accurate, reliable medium-range forecasts are valuable to farmers and planners for efficient agronomic and resource management. In order to evolve a dynamic weather-based agricultural management system, it becomes mandatory that agrometeorologist, weather forecaster, and agricultural production scientist cooperate closely. This requires the prompt communication of weather prediction to farmers so that they can take proper measures with regard to irrigation scheduling, fertilizer application, fungicide/pesticide application, and other agronomic management options. A medium-range forecast service was recently introduced by India's Department of Science and Technology (DST), based in New Delhi. The service requires strong linkages with agricultural applications.

The performance of the general circulation model output for various agro-climatic zones in different seasons has to be evaluated, and necessary correction factors must be ascertained for each zone. The major task is to define the options for the farming community a way that applies the medium-range weather forecast results for optimal crop productivity. This can be achieved either through regional approaches or with a single, central decision support system. The DST's National Centre for Medium-Range Weather Forecasting Centre (NCMRWF) is presently engaged in extending the weather forecast service to various agricultural universities located in different agro-climatic zones. In each area, agricultural experts are implementing an advisory system for efficient crop management. This is a tough task, given that India is divided into many agro-climatic zones with large variabilities in soil types, cropping systems, and input resource availability. There is accordingly a need to generate a centralized decision support system for efficient and effective agricultural management exploiting the weather forecasts. This in turn requires linking of cropping system models with the medium-range weather forecast outputs.

Keeping these imperatives in view, the present investigation was carried out with the following objectives:

- to evaluate the accuracy of medium-range weather forecasts at two locations in the north Indian alluvial plains during the normal rabi (winter) season of 1994-95.

- to judge the agricultural value of the forecasts by comparing actual and forecasted weather through terminal growth response for triple gene dwarf wheat (*Triticum aestivum*) assumed to be grown under varying moisture supply situations, using the Wheat Growth Simulator (WTGROWS) [1].

MEDIUM-RANGE FORECASTING AND THE WHEAT GROWTH SIMULATOR

Global atmospheric models are in principle capable of forecasting the formation and movement of the weather systems throughout the globe. The basic equations which form the atmospheric model are based on conservation of momentum, mass, moisture, and thermodynamic energy, and on the equation of state. The main meteorological parameters used are wind vector, pressure, temperature, and humidity. The observed data for these parameters and many other related observations are available at NCMRWF through Global Telecommunication Systems (GTS). Necessary quality control checks are performed before these data are used as input to the models simulating the future state of the atmosphere. To process the huge amount of observations and solve the basic atmospheric equations for which lead to forecasts from 3 to 10 days in advance, a high power super-computing system is required, such as the CRAY X-MP/216.

The atmospheric model used at NCMRWF employs the Global Spectral Modeling technique [2] which has in the horizontal dimensions triangular truncation with 80 waves equivalent to a physical grid size 256*128, and in the vertical, 18 sigma layers. This model uses a semi-implicit scheme for time integration with a time step of fifteen minutes. This model has parametrization schemes for planetary boundary layer, land surface processes, cumulus convection, shallow convection, large scale condensation, radiation (short wave and long wave), air-sea interaction and orographic gravity wave drag. The details of the model are found in [2].

Numerical Weather Prediction (NWP) products and synoptic interpretations of the graphical output of the Global Spectral Model (T80) forms the basis for the medium-range weather forecast at NCMRWF. The model output is available at grid points at different sigma layers. The Direct Model Output (DMO) is interpolated to the station coordinates and altitude. Objective forecasts of local weather elements are obtained by using statistical methods to complement the raw output of numerical weather prediction models.

The DMO, statistical interpretations, model graphical output, and conventional synoptic techniques are used to prepare the location-specific forecast bulletin. Presently the experimental weather bulletin is given for three days only. To cover an entire week, bi-weekly forecasts are issued presently on Tuesday and Friday. The bulletin contains information on quantitative rainfall, cloud cover, predominant wind direction, mean wind speed, and maximum and minimum temperature trends.

Success in predicting weather parameters in a medium range depends on how best to predict the genesis and movement of transient disturbances from the global circulation model at NCMRWF. The performance of the model during monsoon 1994 and winter 1994-95 is instructive [3]. During the monsoon season of 1994, there were seventeen low pressure areas/depressions/ cyclonic storms formed over the Indian region. The model was able to predict the genesis of systems seventy-two hours in advance in 29.4 percent of the cases, forty-eight hours in advance in 35.3 percent of the cases, and twenty-four hours before in 76.5 percent of cases. About 23.5 percent of the systems were not predicted by the model at all. The mean RMSEs in respect of the position of the system's center, for the twenty-four hour, forty-eight hour, and seventy-two hour forecasts, were found to be 2.0, 2.2. 3.0, and 3.9 degrees, respectively.

In the winter of December 1994 to February 1995, there was significant western disturbance activity over the country. At 850 hPa, the average RMSEs in respect of their positions in the forecast products were found to vary from 1.1-1.8 degrees to 1.9-3.4 degrees in seventy-two hour forecasts. During this 100 day period, forty-four days had scattered to widespread rainfall of 1 cm or more in one or more subdivisions. A comparison of the seventy-two hour rainfall forecast for each of the rainy days with observed rainfall distribution shows that in eighteen of forty-four cases, the extent of the predicted rainfall matched 75 percent or more of the area of the observed rainfall. In nineteen out of forty-four cases, the predicted extent was found to match 51 to 74 percent of the observed rain belt area. Further, the above analysis revealed that weak events of rainfall are not well represented in the forecasts. There were ten major spells of cold conditions during the period considered in the study; of these, several fell in December 1994 but none in January or February 1995. For seventy-two hour predictions of cold wave conditions during December 1994, the model was able to capture the fall in minimum temperature over a large area in the western and southern parts of the country; this compared well with the observed falls in minimum temperature. The model predicted 67 percent (for the Delhi region) and 70 percent (for the Calcutta region) of the epochs of sudden fluctuations (rise and fall) of minimum and maximum temperatures within 1°C with seventy-two hours advance warning.

Wheat Growth Simulator (WTGROWS)

Several models have been developed for winter and spring wheat. Most assume a constant radiation efficiency in predicting daily biomass production. This over-simplification is often subject to errors due to feedbacks between plant sources and carbon sinks, and to the changing chemical composition of plant organs. None of the models have been well validated in the tropical and sub-tropical environments such as those of India. WTGROWS was developed to analyze effects of climatic variables and crop management on productivity of wheat in tropical and sub-tropical wheat regions of India [4].

The principal objective of WTGROWS was to develop a management tool to determine potential yields and to analyze the effect of climatic variables, water management, and nitrogen availability on productivity. The model, written in CSMP and FSE, simulates daily dry matter production as a function of radiation, temperature, water, and nitrogen availability. Crop aspects of the model are arranged in submodels covering development, photosynthesis, respiration, carbohydrate partitioning, dry matter production, leaf area, grain growth, and transpiration. A soil water balance model is attached to simulate water uptake and to estimate water stress. Another sub-model determines nitrogen uptake, distribution and stress. Depending on their severity, water and nitrogen stresses affect various physiological processes.

The model requires inputs of daily weather data, management practices and cultivar-specific coefficients. Because these are not precisely known for most cultivars, one may have to employ standard set of inputs known for medium-duration high yielding cultivars, most commonly used in different experiments. Switches allow water and/or nitrogen stresses to be terminated to establish climatically-determined potential grain yield. The performance of this model has been evaluated using a large and diverse database assembled from published and unpublished studies conducted by independent workers [1]. In general, the model is able to simulate well the trends in water and nitrogen uptake, dry matter growth and productivity. The simulation results are very sensitive to the prediction of flowering time. Therefore, correct simulation of phenology is extremely important in all production systems. The simulation results are also very sensitive to correct initialization and weather data. If the model is to serve its purpose of being a useful management tool, it is essential to have precise and reliable descriptions of field environments and cultivars for initialization of the model, and reliable inputs of weather data.

MATERIALS AND METHODS

The two north Indian fertile plains locations chosen for the present study were New Delhi and Ludhiana. Daily values of actual and forecasted weather were collected for the optimal 1994-95 rabi season (November 14, 1994 to mid-April 1995). Weather parameters studied were maximum and minimum temperatures, wind speed, rainfall, and bright sunshine hours. The cloud cover forecast given by NCMRWF was extrapolated to compute the bright sunshine hours following conventional Indian Meteorological Department procedure. Performance of the medium-range weather forecast was then evaluated using standard statistical procedures. Weather files required for running WTGROWS were formulated on the basis of actual and forecasted weather results. The physiological and genetic coefficients of triple gene dwarf wheat were used [5]. Normal agronomic management practices (except for irrigation options) were used for running WTGROWS. The date of sowing was taken as November 14, 1994. At the time of sowing, the profile moisture up to the 150 cm soil zone was assumed to be charged to 75 percent of the field capacity (equivalent to one presown irrigation). The following irrigation treatments were simulated for the terminal growth response under actual and forecasted weather conditions:

I_a—adequately irrigated (5 irrigations: crown root initiation, early and late vegetative phases, flower initiation and milk formation)
I_m—moderately irrigated (2 irrigations: crown root initiation and flower initiation)
I_s—limited moisture availability (1 irrigation: crown root initiation only)

WTGROWS was run for the various irrigation treatments at both locations. Forecaster performance was evaluated in terms of grain yield, final above ground biomass, and seasonal evapo-transpiration and transpiration.

RESULTS AND DISCUSSION

Weather Forecast Performance

Comparison of forecasted and actual weather during the wheat growing season of 1994-95 in terms of maximum and minimum temperatures, wind speed and rainfall for Delhi and Ludhiana are shown in Figures 1 and 2, respectively. Medium-range forecast performance for predicting maximum and minimum temperatures for both locations had predictability lying in the range of 70 to 85 percent. Daily average wind speed predictabilities fell between 24 percent and 29 percent. The poor wind speed forecasts may be due to difficulties in extrapolating wind speed from the first sigma level (50 m height) of the GCM to the reference height (3 m) at which regular observations are recorded. The diurnal variations in temperature and turbulence near the canopy level are significant for defining the correction factor; this may lead to errors due to spatial uncertainties involved. Forecasts of rainfall matched with actual rainfall events on a few occasions at Ludhiana, but no matches were seen at Delhi. Nevertheless, if predicted rainfall events are checked against actual rains received within seventy-two hours of the actual rainfall, predictability improves. Predictability falls below 30 percent when the observed bright sunshine hours (BSS) are compared to predicted sunshine hours (not shown in Figures 1 and 2). For Delhi and Ludhiana, the regressions are given in equations (1) and (2), respectively:

$$Y = .488\,X + 5.075 \tag{1}$$

$$Y = .505\,X + 3.546 \tag{2}$$

(Y = forecasted, and X = observed values).

Actual sunshine hours is derived from average daily cloud cover predicted using the relation (BSS = 1 − m/8), wherein m is predicted cloud cover in okta. The poor assessment of BSS may reflect the lowest predicted cloud counts, latitudinal and seasonal factors in the definition of BSS hours, and the fact that a small overhead cloud mass moving may obscure radiation completely yet have little effect on BSS when it is not directly overhead.

Crop Growth Response

"Forecasted" wheat yields for all levels of soil moisture availability treatments at both the locations were approximately 2 to 9 percent higher than the corresponding values obtained under actual weather runs (Table 1). This merely reflects the higher level of forecasted rains during the wheat-growing season. The disparity was highest in the case of limited water availability (I_s treatment). The same trend occurred in the case of above-ground biomass, but with smaller disparities with grain yields. Differences between forecasted and actual weathers appear to have the greatest effect during the post-anthesis phase, particularly in the case of severely water stressed treatment.

Seasonal evapo-transpiration values for all moisture availability treatments were lower for forecasted weather for the New Delhi environment. This may be due to unpredicted post-anthesis rains. For Ludhiana, the forecasted rains and the number of rainy days were higher than the actual ones. Thus there is a need to study inter-stage evapo-transpiration demands with a view to explaining the higher forecasted yields and final above ground biomass values. Seasonal

Table 1. Simulated Grain Yield, (GY, t/ha), Above Ground Biomass, (TDM, t/ha), Evapo-Transpiration (ET, mm) and Transpiration (Tr, mm) Grown Under Varying Levels of Water Application for Observed (Obs.) and Forecasted (Pre.) Weather of New Delhi and Ludhiana Environments

	GY		TDM		ET		Tr	
	Obs.	Pre.	Obs.	Pre.	Obs.	Pre.	Obs.	Pre.
Delhi								
Ia	5.61	5.71	13.08	13.37	379	351	299	286
Im	5.28	5.65	11.94	12.72	344	331	270	271
Is	3.78	4.82	10.44	11.68	306	301	236	248
Ludhiana								
Ia	6.61	6.64	15.51	15.66	368	382	312	310
Im	6.05	6.39	14.72	14.94	349	363	295	295
Is	4.57	4.99	13.23	13.52	314	333	263	267

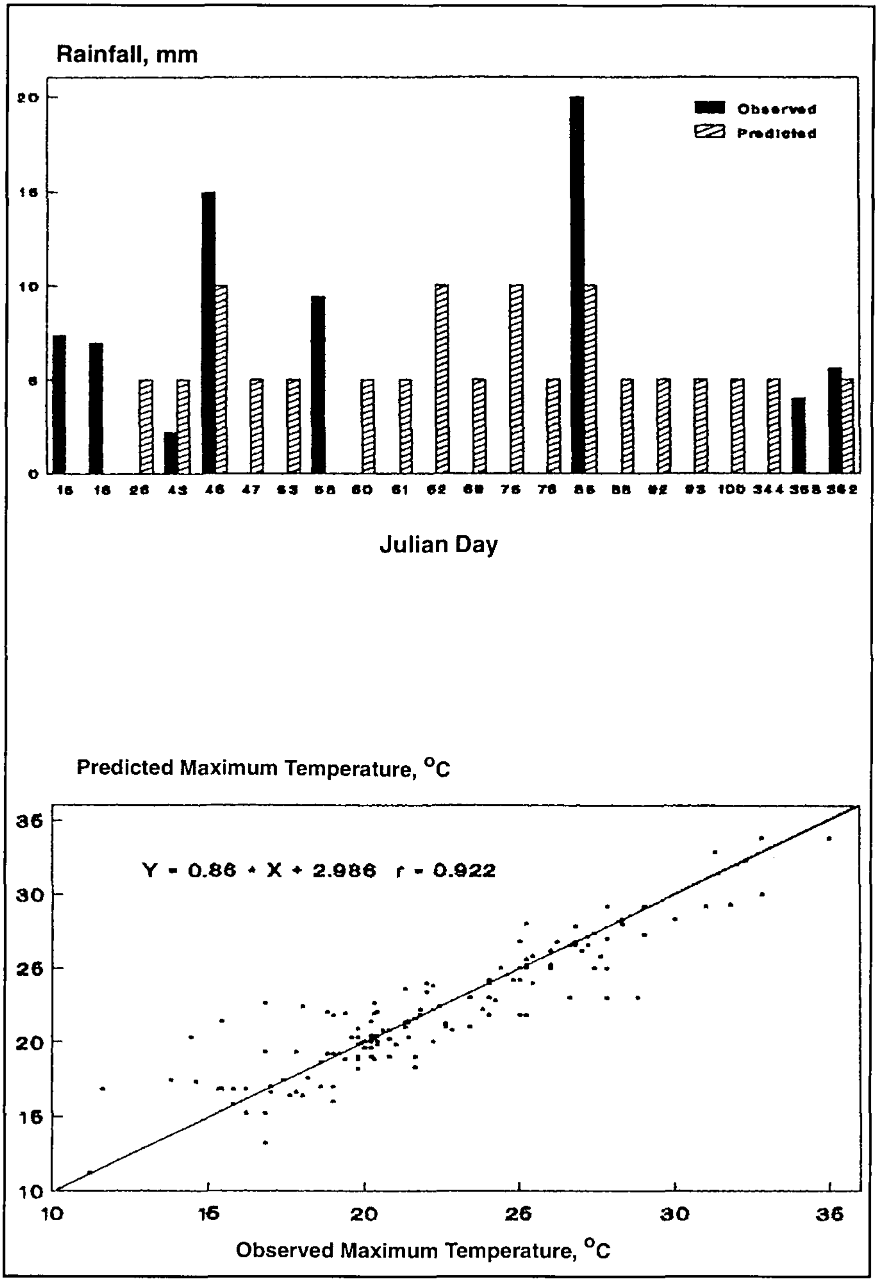

Figure 1. Performance evaluation of medium range weather forecast for New Delhi environment.

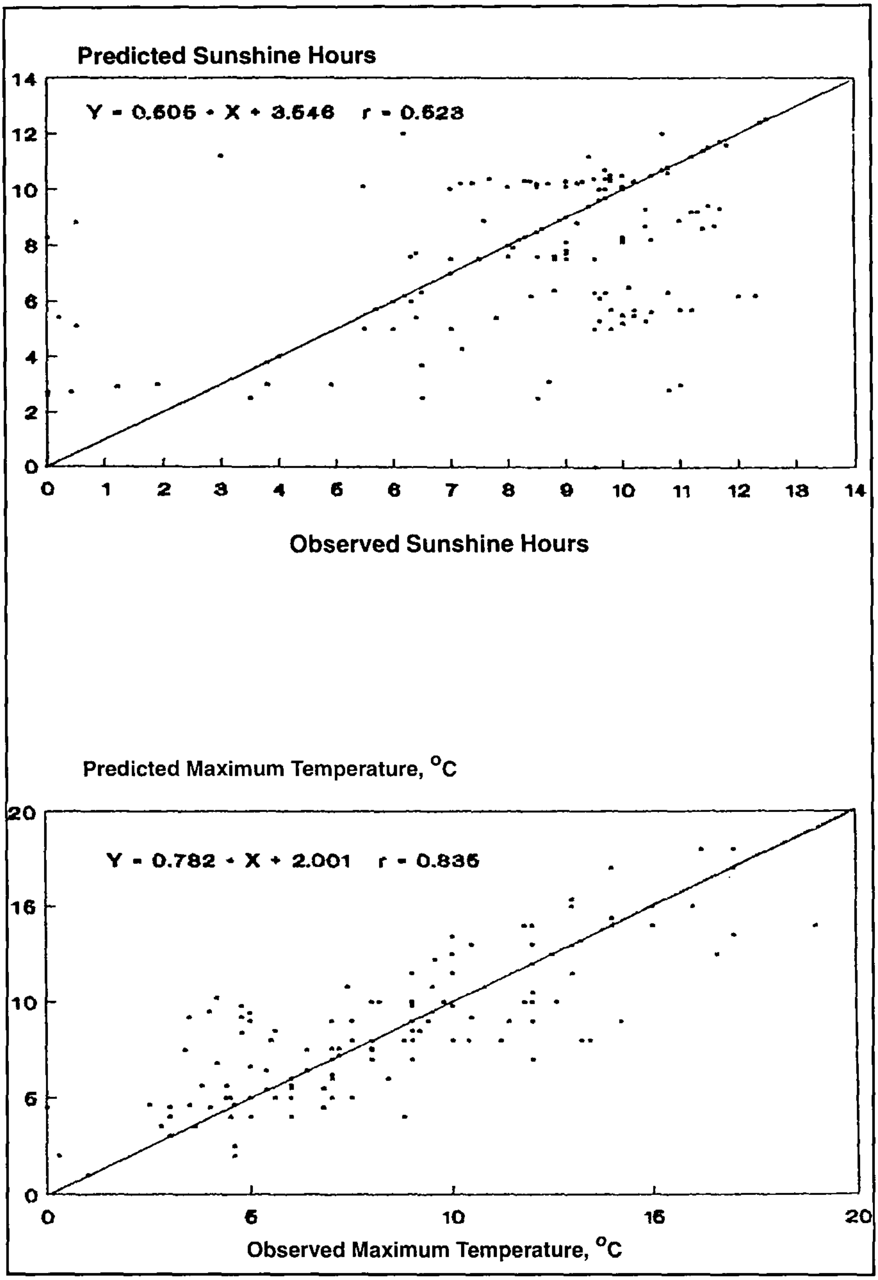

Figure 1. (Cont'd.)

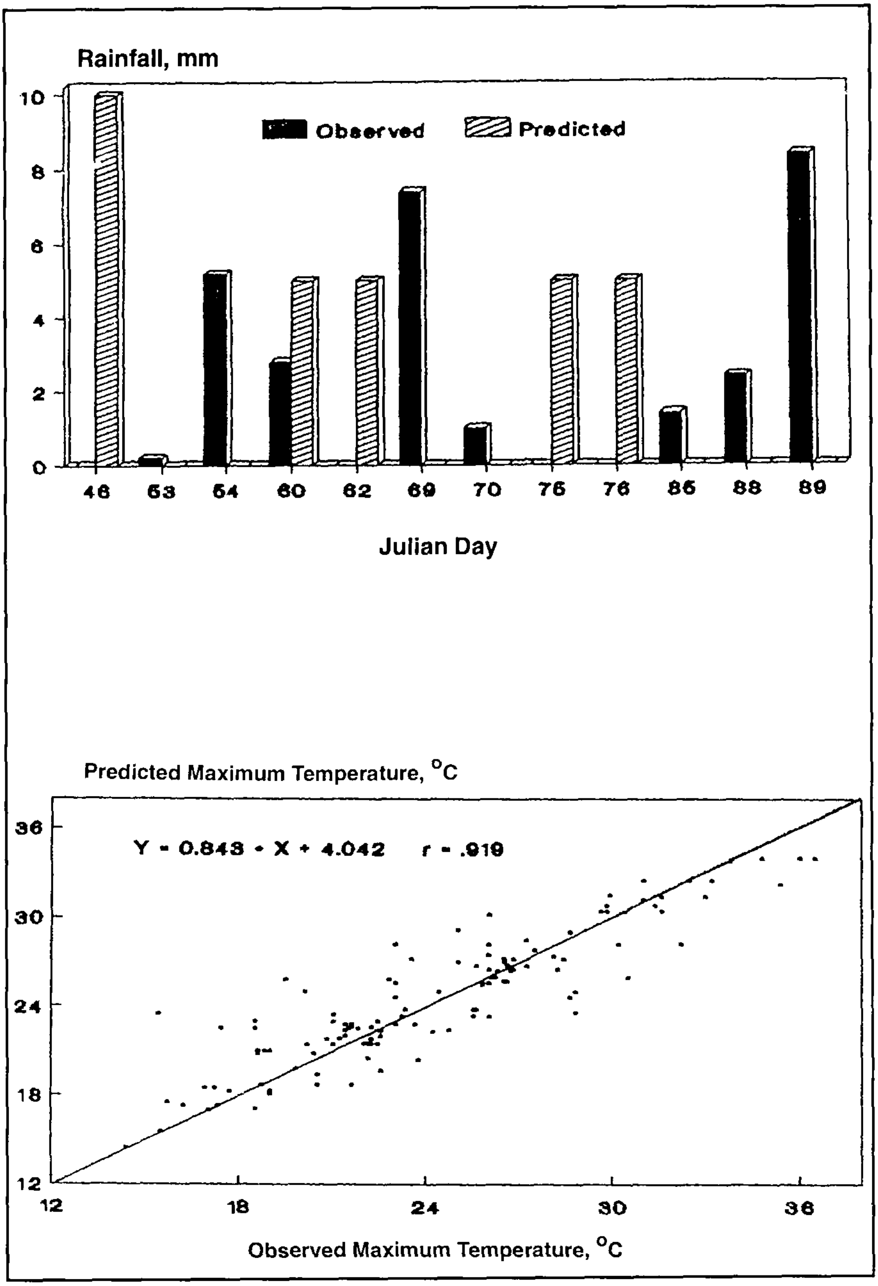

Figure 2. Performance evaluation of medium range weather forecast for Ludhiana environment.

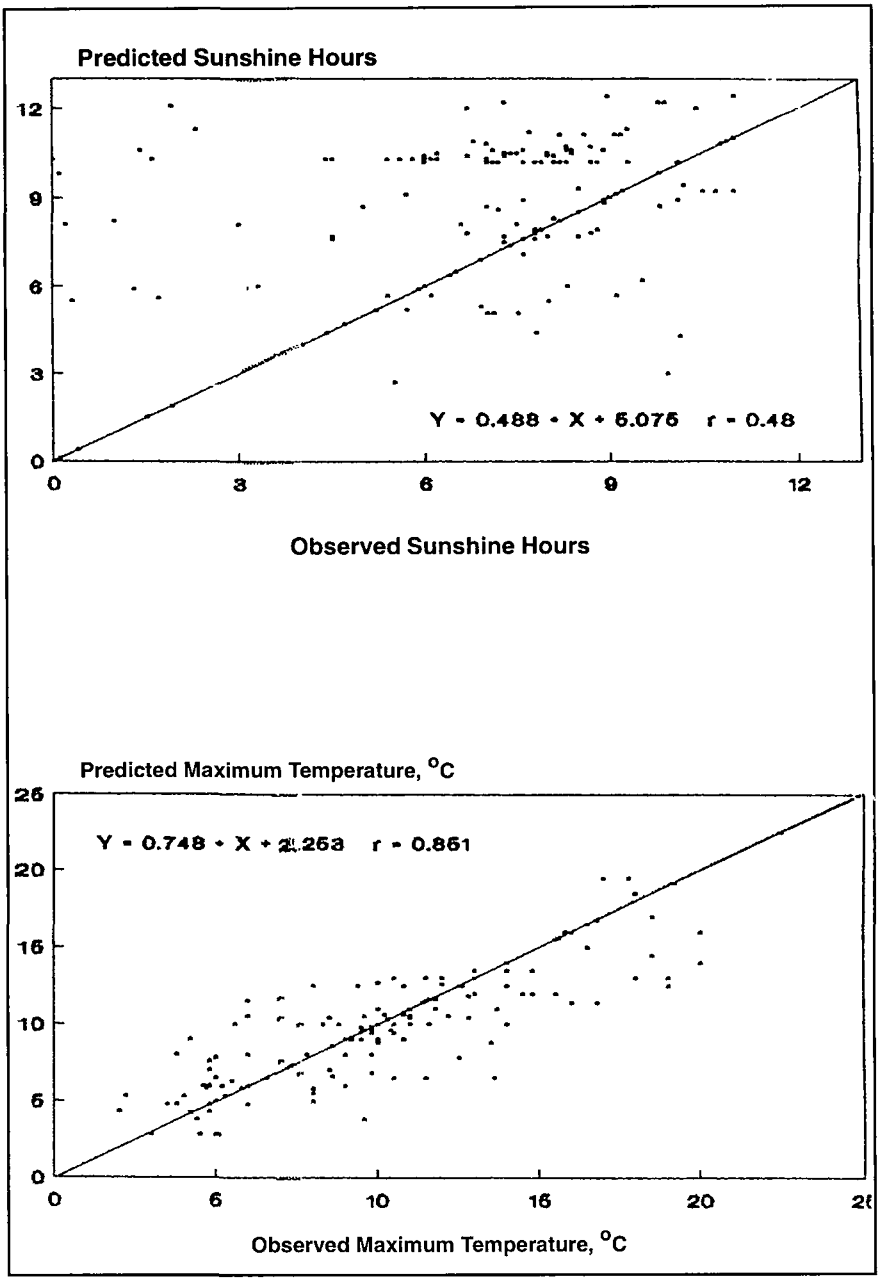

Figure 2. (Cont'd.)

transpirational values for forecasted and actual weather runs did not differ significantly except under the moisture stress regime, where the values were relatively higher for forecasted weather runs.

CONCLUSION

In its first trials, the medium-range forecast service predicted maximum and minimum temperatures reasonably well. There is a need for significant improvement in predicting capabilities for wind speed and sun shine hours. Forecasted rainfall events did correlate reasonably well with actual events within the seventy-two hour "window." There is a great need to evaluate the performance of the forecasted output for the many agro-climatic zones of India. The forecasted output, in terms of wheat growth under varying moisture application levels, shows somewhat higher grain yield and final above-ground biomass than obtained by simulating with actual weather data. There also is a need to develop links between the forecasted output and actual agricultural practices so as to optimize the cropping system's productivity with minimum input requirements.

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