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# Use of CERES-wheat model for predicting wheat yields of Ninital District (U.P.) India

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## ABSTRACT

CERES-Wheat model was investigated for its ability to simulate weather induced year-to-year yield variability (1980-1994) and to provide wheat yield prediction (1994-1998) over Nainital district (U.P.). Wheat yield of the district has increased from 1180 to 2912 kg ha$^{-1}$ between 1970 and 1998. Published genetic coefficients, dominant soil hydrological properties and daily weather measurements at Pantnagar were inputs for simulation. Yield deviations (YDOBS) from segmented linear technology trends ($\hat{Y}$OBS)(Period I: 1970-1987, Period II: 1988-1994) were used along with year-wise deviations in simulated yields (YDSIM) from its fifteen-year trend ($\hat{Y}$SIM) (1980-1994) for yield prediction. Deviations of yearly-simulated wheat yields during 1980-1994 could explain about 33 percent of variation in observed yield from the technology trend, while segmented technology trends combindly explained about 58% variability in observed wheat yield. Comparison of two approaches of yield prediction for the period 1995-1998 namely direct use of YDSIM and using relation between YDSIM and YDOBS gave RMSE of 163.3 kg ha$^{-1}$ and 212.2 kg ha$^{-1}$, respectively.

***Key words* :** CERES-Wheat, DSSAT 3.5, Simulation model

Weather plays a dominant role in determining year-to-year yield variability in the crops. A number of statistical techniques such as multiple regression, principal components (Jain *et al.* 1984) and Markov chain (Ramasubramanian & Jain, 1999) and agro-meteorological models (Walker, 1989) have been used to quantify the response of crops to weather. These techniques are limited by availability of only short period historical data series; limited weather variables at specific periods are used for yield prediction, while change in variety and cultural conditions, non-linear and interaction effects among weather variables are generally ignored.

Several crop simulation models have been developed based on physical

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relationship between crop growth and weather input interaction (Whisler *et al.*, 1986). These require crop specific parameters, soil characteristics, cultural practices and daily weather inputs to simulate crop growth and yield. These models are generally calibrated and validated using observations from experimental plots and can mimic crop response to various inputs at plot level (Kenneth *et al.*, 1996). Currently simulated models are being investigated for regional yield prediction (Supit, 1997) as well as for projecting crop response to future climate (Lal *et al.*, 1999).

In this study, CERES-Wheat (Ritche and Otter, 1985) model has been used to simulate crop growth and yield over a period of 19 years from 1980 to 1998 for Nainital district. Using an approach for relating simulated yield deviation to regional yield variation (1980-1994), yield forecasts were made for the period of 1995 to 1998.

## MATERIALS AND METHODS

### *Model description*

The CERES-Wheat (Crop Estimation through Resource and Environment Synthesis) model was developed in the U.S.A. as a general simulation tool for the wheat crop (Godwin *et al.* 1990) and has now been included in DSSAT (Decision Supporting System for Agro technology Transfer, Hunt *et al.*, 1994) version-3.5. It employs canopy photosynthesis, water uptake and evapotranspiration modules to compute dry matter production and its partition along with temperature and photosynthesis based phenology and phylochron development. The model has been successfully tested and calibrated in a multi-year experiment for wheat cultivation at Ludhiana (Hundal & Kaur, 1997) in India.

### *Inputs*

Daily weather data were collected from the Agro-meteorological observatory of Govind Ballabh Pant University of Agriculture and Technology (G.B.P.U.A. & T.), Pantnagar, district Udham Singh Nagar (Uttar Pradesh). Solar radiation was estimated from recorded sunshine hours using Angstrom relationship with coefficients a and b, 0.256 and 0.448, respectively (Mani and Rangarajan 1982). Crop genetic coefficients of the popular wheat variety HD-2329 published by Hundal and Kaur. (1997) were adapted for use. The PHINT (Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances) value for the model has been used as 75 (Table 1). The average crop yields (1970-1998) for the Nainital district were obtained from State Agricultural Department.

Soil input data, which included soil water availability, bulk density, total carbon in the soil profile and soil pH were obtained from published information (Murthy *et al.*, 1982 and Arya *et al.*, 1984). The initial water status of the soil in each year was assumed at drained upper limit (0.03 Mpa) in a fallow field.

**Table-1 :** Genetic coefficients used in model (Adapted from Hundal and Kaur, 1997)

| Parameter | Description of parameter | Coefficient |
|---|---|---|
| P1V | Relative amount that development is slowed for, each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars. | 0.5 |
| P1D | Relative amount that development is slowed when plants are grown in a photoperiod 1 hour shorter than optimum (which is considered to be 20 hours). | 2.5 |
| P5 | Relative grain filling duration based on thermal time (degree days above a base temperature of $10^0$C). Where each unit increase above zero adds 20 degree days to an initial value of 430 degree days. | 3.5 |
| G1 | Kernel numbers per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis ($1g^{-1}$). | 2.5 |
| G2 | Kernel filling rate under optimum conditions (mg $day^{-1}$). | 2.9 |
| G3 | Non-stressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases (g). | 4.0 |
| PHINT | Phyllochron interval: the interval in thermal time between successive leaf tip appearances. | 75 |

Crop management data related to agronomic practices such as sowing, fertilizer amount and application date, irrigation quantity and time and harvesting date and method were kept constant at optimal recommended guideline for the region given by G.B.P.U.A. & T, Pantnagar. The year-to-year variability in sowing dates was generated by using auto sowing option providing the sowing limits as Nov 15 to Dec 15, in DSSAT 3.5 modelling environment. Nitrogen at 120 kg $ha^{-1}$ and Phosphorous at 40 kg $ha^{-1}$ were applied (half of nitrogen and full dose of phosphorous at the time of sowing and remaining amount of nitrogen as top dressing, 50 days after sowing). Three irrigations of 60 mm each at Crown Root Initiation, Jointing and Dough stage were prescribed in simulation.

***Yield simulation and historical yield data analysis***

A consistent wheat yield series (YOBS) of Nainital for period 1970 to 1998 was generated by combining acreage and production of Udham Singh Nagar and New Nainital for the period 1996-1998 with earlier yield series of erstwhile Nainital district (Year indicates sowing, thus 1970 indicates crop season 1970-71). Wheat yield simulation was done using daily weather observations for the period 1980-1998. Simulated wheat yields (YSIM) were compared against observed district average yield for the period 1980-1994 for developing yield prediction approach involving six steps as given below:

*(a) Computation of trend yield*

Observed yields (YOBS) for the period 1970-1994 were regressed with time to obtain contribution of technological improvement in observed yield. A segmented regression for 1970-1987 and 1988-1994 was found suitable for calculating trend yields. The technology trend of later period was used to predict trend yields ($\hat{Y}OBS$) for the years of 1995 to 1998.

For single trend

$\hat{Y}OBS = a_1 + b_1 * Year$ ....... (1)

For segmented trend

$\hat{Y}OBS1 = a_0 + b_0 * year$ (when year = 1987) ....... (2)

$\hat{Y}OBS2 = a_1 + b_1 * year$ (when year > 1987 ....... (3)

*(b) Estimation of observed yield deviation*

Deviation in observed yield (YDOBS) from its technology trend ($\hat{Y}OBS1$, if year is = 1987 and $\hat{Y}OBS2$, if year is > 1987) represents the yield variability due to varying weather conditions in different crop seasons and was computed as

$YDOBS(\%) = ((YOBS - \hat{Y}OBS) / \hat{Y}OBS) * 100$ ....... (4)

*(c) Simulation of wheat yields and estimation of simulated trend yield*

Wheat yield was simulated (YSIM) from 1980 to 1998, using CERES-Wheat model incorporated in DSSAT-3.5 modelling environment. The simulated wheat yields are expected to capture the deviation in yield arising from year-to-year variability in weather condition. Simulation yields (YSIM) have been regressed with years for calculating simulated trend yield ($\hat{Y}SIM$).

$\hat{Y}SIM = a_2 + b_2 * Year$ ....... (5)

*(d) Estimation of simulated yield deviation*

Deviation in simulated yield (YDSIM) from its average/trend ($\hat{Y}SIM$) show the likely effect of weather on average wheat yield as identified by CERES-Wheat model and was computed as:

$YDSIM(\%) = ((YSIM - \hat{Y}SIM) / \hat{Y}SIM) * 100$ ...... (6)

*(e) Prediction of yield deviation*

To predict the yield deviation ($\hat{Y}D$), observed yield deviations (YDOBS) were regressed with simulated yield deviations (YDSIM) and estimated regression coefficients $a^3$ and $b^3$ were used for prediction of yield deviation as:

$\hat{Y}D(\%) = a_3 + b_3 * YDSIM(\%)$ ...... (7)

*(f) Yield forecast*

Likely increase in crop yield due to technological advancement was obtained using step (a), and likely impact of current year weather on crop performance have been judged using step (d)(method I) or step (e)(method II). The yield prediction for the period 1995-1998 were generated by these two methods as:

Method I:

$YP1 = \hat{Y}OBS + (YDSIM(\%) * \hat{Y}OBS) / 100$ ....... (8)

Method II:

$$\hat{Y}P2 = \hat{Y}OBS + (\hat{Y}D(\%) * \hat{Y}OBS) / 100 \quad \ldots\ldots \quad (9)$$

## RESULTS AND DISSCUSSION

### *Analysis of wheat yield*

The historical wheat yield series for Nainital district for the period 1970-1998 is given in Figure- 1. The wheat yields increased from 1180kg $ha^{-1}$ in 1970 to 2912 kg $ha^{-1}$ in 1998. A single linear trend indicates an increase in wheat yield by 62.9 kg $ha^{-1}year^{-1}$, with RMSE (Root Mean Square Error) 275.25, and $R^2$ 0.87 (F = 192.3, P<0.0001). The plotted data (Figure 1) indicates higher variability and decreased rate of technology trend since late eighties. In order to capture weather caused yield variability, yield series was split in two parts from 1970-1987 and 1988 to 1994 (Figure 2). Use of segmented regression with two linear technology trends, decreased RMSE to 248.4. In the period I (1970-1987) wheat yield increased at 64.06 kg $ha^{-1}year^{-1}$ ($R^2$ 0.657)(F = 208, P<0.0001), while in period II (1988-1998) yearly technological trend decreased to 43.39 kg $ha^{-1}year^{-1}$ ($R^2$ 0.087) (F = 1.021, P<0.33). Low $R^2$ in period II indicates decreased technology trend and an increase in year-to-year yield variability in the last decade. Trend yields have been calculated from 1994 to 1998 (Figure 2) using following equation:

$$Y = 43.393 * X + 1679.5 \text{ (where X is year)} \quad \ldots\ldots \quad (10)$$

### *Analysis of simulated wheat yields and yield deviation*

Simulation of wheat yield over the 19 years period from 1980 to 1998 gave yield range from 3877 kg $ha^{-1}$ (1983) to 5289 kg $ha^{-1}$ (1996) and mean yield of 4445 kg $ha^{-1}$. A plot of simulated yield against time indicated a small trend of $\hat{Y}SIM$ = 17.344 * X + 4259.6 (X=year) and $R^2$ 0.081 (F = 1.49, P<0.25). The yearly simulated yields (YSIM) were transformed to simulated yield deviation ($\hat{Y}DSIM$) from the simulated trend ($\hat{Y}SIM$) using eqs 6.

Deviations of simulated yields (YDSIM) from simulated trend were regressed with deviation of observed yield (YDOBS) from technology trend (Figure 3). The simulated and actual deviations were positively correlated (r = 0.577), and a linear regression equation $\hat{Y}D(\%)$ = 0.6405 * YDSIM(%) + 2.6061, with $R^2$ 0.3324 (F = 6.5, P<5%) could be fitted. This result reveals that about 33 % deviation in wheat yield from trend could be captured by simulated yield deviation with a common set of cultivar and cultural inputs and information on year wise variable inputs of management practices from field surveys, the simulation would be needed to capture higher variability.

### *Forecast of wheat yields (1995–1998)*

The forecasts of wheat yield for the period 1995 to 1998 were generated using three steps approach, comprising (a) prediction of trend yields ($\hat{Y}OBS$) from equation 3, (b) simulation of wheat yields (YSIM) and estimation of simulated wheat

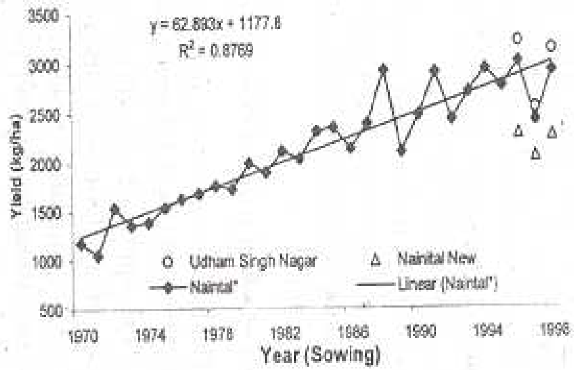


Fig.1: Yield series of districts of Nainital, New Nainital and Udham Singh Nagar
* Consistent yield series of Nainital Districted

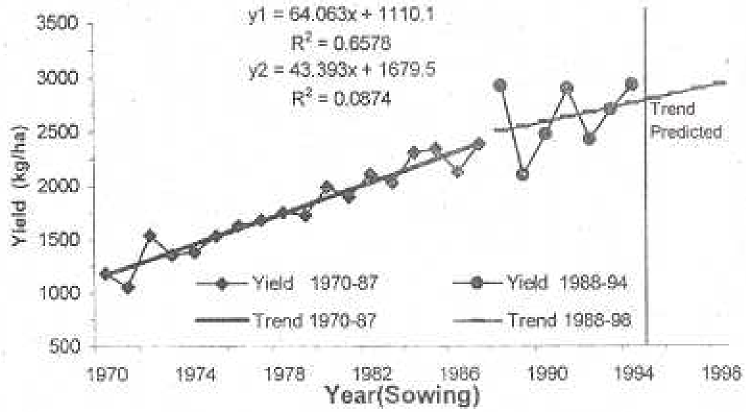


Fig.2: Segmented Trend yields (1970-1987 & 1988-1994) and trend yield predicted (1995-1998)

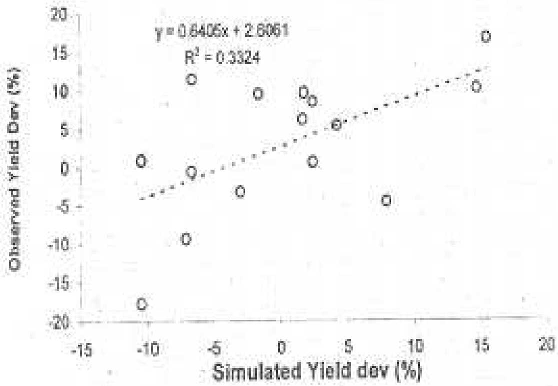


Fig.3: Relationship between observed yield deviations (YDOBS) from trend and simulated yield deviations (YDSIM) from trend

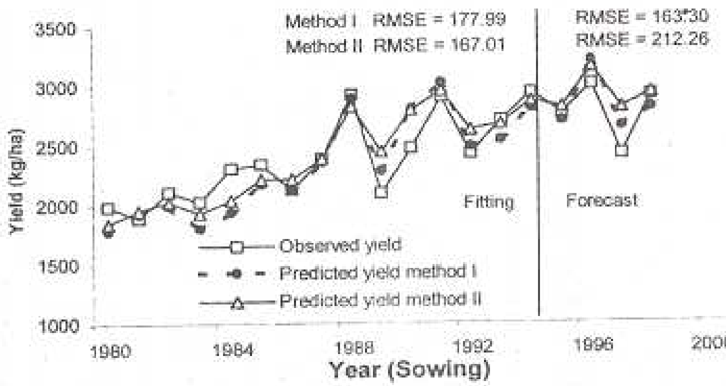


Fig.4: Relationship between observed yield deviations (YDOBS) from trend and simulated yield deviations (YDSIM) from trend

**Table 2 :** Observed and predicted yield during 1980 to 1998.

| Year of sowing | Observed yield(kg ha$^{-1}$) | Trend yield(kg ha$^{-1}$) | Predicted yield | | | |
|---|---|---|---|---|---|---|
| | | | Method I | | Method II | |
| | | | kg ha$^{-1}$ | Dev.% | kg ha$^{-1}$ | Dev.% |
| Fitting period | | | | | | |
| 1980 | 1986 | 1815 | 1785 | -10.12 | 1843 | -7.19 |
| 1981 | 1889 | 1879 | 1924 | 1.86 | 1957 | 3.59 |
| 1982 | 2105 | 1943 | 1990 | -5.46 | 2024 | -3.86 |
| 1983 | 2025 | 2007 | 1797 | -11.24 | 1925 | -4.93 |
| 1984 | 2306 | 2071 | 1935 | -16.11 | 2038 | -11.64 |
| 1985 | 2339 | 2135 | 2172 | -7.12 | 2215 | -5.31 |
| 1986 | 2127 | 2199 | 2133 | 0.30 | 2214 | 4.10 |
| 1987 | 2381 | 2263 | 2358 | -0.95 | 2383 | 0.08 |
| 1988 | 2917 | 2504 | 2891 | -0.87 | 2817 | -3.41 |
| 1989 | 2095 | 2547 | 2282 | 8.92 | 2444 | 16.64 |
| 1990 | 2470 | 2591 | 2795 | 13.18 | 2789 | 12.93 |
| 1991 | 2897 | 2634 | 3021 | 4.28 | 2951 | 1.85 |
| 1992 | 2425 | 2678 | 2487 | 2.56 | 2625 | 8.26 |
| 1993 | 2704 | 2721 | 2540 | -6.06 | 2676 | -1.03 |
| 1994 | 2931 | 2764 | 2810 | -4.13 | 2865 | -2.23 |
| RMSE | | 219.5 | 177.99 | | 167.01 | |
| Forecasting period | | | | | | |
| 1995 | 2764 | 2808 | 2699 | -2.36 | 2811 | 1.70 |
| 1996 | 3002 | 2851 | 3199 | 6.56 | 3148 | 4.87 |
| 1997 | 2415 | 2895 | 2645 | 9.53 | 2810 | 16.40 |
| 1998 | 2912 | 2938 | 2809 | -3.53 | 2932 | 0.69 |
| RMSE | | 252.6 | 163.3 | | 212.26 | |

For method I, and method II see equations 8 and 9, respectively, in text.

yield deviations (YDSIM) and predicted yield deviations ($\hat{Y}D$), and (c) forecast of final yields using equations 8 and 9. In the calibration period (1980-1994) RMSE between observed and predicted yields for method I & II were 177.99 and 167.01, respectively, however in the forecasting period (1995-1998) RMSE were 163.25 and 212.26, respectively. This suggests that method II performs better while fitting, but for the purpose of forecasting it could not reduce the biases. Year-wise comparison of the forecast by the two procedures indicate (Table 2) that in three out of four years, method II have higher accuracy. The performance of the approaches in fitting and forecast periods is summarized in Figure 4.

The study demonstrates that CERES-Wheat model could simulate the pattern of weather induced yield variability in district yield series over the long period of 19 years (1980-1998). Use of simple linear technology trends and simulated yield deviation (YDSIM) can be adopted for yield prediction. In this approach daily weather data of the entire season determine final yield. The cultural practice and technology inputs were kept constant in the period. However, using appropriate field survey data, these inputs could be specified as applied by farmers, thereby eliminating the need for linear modelling of technology trends.

The important issues in use of crop simulation model for regional yield prediction which have not been considered in this study, are (a) Spatial variability in cultural practice, (b) Spatial variability in soil properties, and (c) Spatial variability of weather. Current research efforts are addressing these issues by adopting use of GIS and remote sensing data. Spatial variability of weather and soil were included for sorghum yield prediction by linking simulation data to GIS (Rosenthal *et al.*, 1998). Use of direct observations on crop growth from remote sensing data at field to regional scales as inputs to simulate models has been reviewed by Moulin *et al.*, (1998). Thornton *et al.*, (1997) used remote sensing derived rainfall and GIS with crop simulation model to predict pearl millet yield in Burkina Faso. A similar extension of the current study for use of GIS in regional wheat yield prediction is in progress.

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