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Evaluation of dynamic simulation model for wheat genotypes under diverse environments in India

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सार – भारत के गेहूँ उत्पादक क्षेत्रों में गेहूँ की विविध जीनी संरचनाओं के लिए सक्रिय उपज वृद्धि अनुकरण निदर्श (सी.ई.आर.ई.एस.-गेहूँ वी. 3.5) के कार्य का मूल्यांकन किया गया है। इस शोध-पत्र में जीनी संरचना के लिए आनुवांशिक सहसंबंध विकसित किए गए और संवेदनशीलता संबंधी विश्लेषण किए गए। अनुकरित घटना विज्ञान और उपज, प्रेक्षित मानों के अनुरूप पाए गए हैं जिसके आधार पर यह सुझाव दिया गया है कि नियमित रूप से प्रेक्षित मृदा, फसल और मौसम प्राचलों के साथ अंशशोधित निदर्श का प्रचलानात्मक उपयोग किया जा सकता है।

ABSTRACT. Performance of dynamic crop growth simulation model (CERES - Wheat v3.5) has been evaluated for various wheat genotypes in wheat growing regions of India. The genetic coefficients were developed and sensitivity analysis was carried out for the genotypes under study. The simulated phenology and yield were found in agreement with observed ones suggesting that calibrated model may be operationally used with routinely observed soil, crop and weather parameters.

Key words – Genotype, Dynamic, Simulation, Phenology, Yield.

1. Introduction

Wheat is one of the most important staple food crops of India grown in diverse agroclimatic conditions from 11° N- 35° N and 72° E-92° E. The rate of annual growth of wheat production and yield showed a peak during early years of green revolution but since then there has been a decline in its growth rate. Wheat productivity may be enhanced by minimising 'Research gap' (Potential yield-Experimental yield) and Management gap (Actual experimental yield-Farmer field yield) through improving efficiency of present agricultural system and stabilising the productivity level with appropriate management practices. Newly framed Agricultural Policy by the Govt. of India has projected 4% growth rate in agricultural sector by introducing 'rainbow revolution' in next two decades and due focus on accurate weather forecast and agro-technology has been spelled in the policy. Improved production technology at the farm level is the most crucial starting point for the fulsome future growth of wheat which can be achieved by adopting suitable crop growth simulation models.

These models possess maneuverable capabilities to simulate a living plant through mathematical and conceptual relationships that govern its growth in the soil-plant-atmosphere continum. They are widely used as management tools for understanding growth behaviour and analysing the effect of current management decisions against various probable future events to aid in determination of best course of action. They are also capable for evaluating long term management strategies (Hoogenboom, 1991), environmental characterisation and agro-ecological zoning (Aggarwal, 1992), defining research priority and technology transfer (Jones and O' Toole, 1987), estimating production potential (Aggarwal, 1988), strategic and tactical decision making (Rathore *et al.*, 1994) and for predicting effects of climate

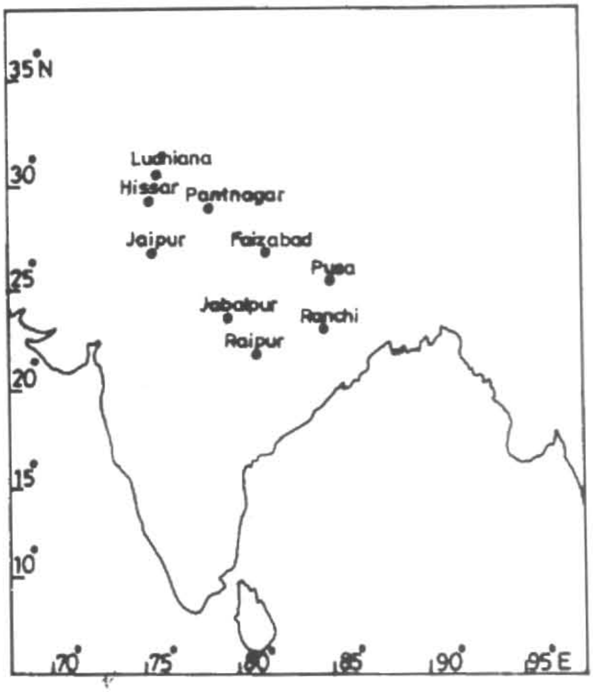


Fig. 1. Station network of Wheat growing regions

change and variability (Lal *et al.,* 1997). The simulation of growth and yield is based on the quantification of phasic development, photosynthesis, respiration, morphogenesis, growth, bio-mass accumulation and partitioning, extention growth of leaves, stem, roots and grain, soil water extraction, evapotranspiration and plant nitrogen status.

Dynamic crop growth models require information, in general, on soil, weather, cultivar and management practices. The cultivar is characterised in term of genetic coefficients which explain the response of a cultivar to its environment. The model technology can be transferred to any environments for a particular cultivar once its genetic coefficients are developed or the model is validated. The major limitation of adoption of simulation wheat models for Indian farmers is lack of genetic coefficients of popular Indian wheat genotypes. The focus of present study is, therefore, to develop genetic coefficients of different wheat cultivars and evaluate their performance in diverse environments of wheat growing regions of India using CERES-Wheat Model V3.5 so that model may be operationally used with routinely observed soil, crop and weather parameters.

2. Data and methodology

CERES-Wheat (Crop Estimation through Environment and Resource Synthesis -Wheat) is a process oriented management level model which has the capability to simulate growth, development and yield of wheat genotypes under diverse environments (Ritchie and Otter, 1985; Otter *et al.,* 1986; Ritchie, 1991). The model has a balanced approach in terms of its emphasis on the biophysics of crop growth and development, including weather effects on phenology and water and nitrogen stresses on general growth. The major components of the model are the vegetative and reproductive development, carbon balance, water balance and nitrogen balance modules which relate the mass flow and information transfer between different modules. However, it does not simulate impact of phosphorous, weeds; and pest and diseases on growth and assumes that they are taken care of by management practices.

The model requires input data on soil, crop and weather for its calibration in different environments. Crop Data for one to three years for validating the model were collected from experimental fields/stations for various cultivars in wheat growing regions of India (Fig. 1) *viz.* Sonalika (Pantnagar), HD 2285 (Faizabad, Ranchi), Sonali and Rajesh (Pusa), HD 2329 (Jabalpur, Jaipur, Ludhiana) , WH-147 and WH-542 (Hisar) and Raj 3077, Raj 3765 and UP 2338 (Jaipur). The cultivars namely RAJ 3077, RAJ 3765, HD 2285, Sonalika and Sonali are genetically late sown and early maturing while the rest of the cultivars fall in early/timely sown and late maturing group. Detailed data set on weather (Radiation, maximum and minimum temperatures and rainfall), soil (Layer wise information on saturation, field capacity, wilting point, texture and hydraulic conductivity, albedo, first stage evaporation, drainage, USDA Soil Conservation Service Curve Number for runoff) and crop management (Dates of sowing, plant and row spacing, irrigation, fertiliser etc.) were collected for the locations under study.

2.1. *CERES-wheat modules*

The core of the model is comprised of different subroutines to simulate crop phenology, growth, organ development, soil water and nitrogen balance in soil-plant-atmosphere continuum which are described in the following sections:

2.1.1. *Water balance*

The upper-most soil layer receives additions of water from rain, melted snow and/or irrigation. The proportion of rainfall that runs-off the soil is calculated from the USDA Soil Conservation Service Curve Number technique. The balance plus any irrigation infiltrates the soil surface. The distribution of infiltrated water through the profile is based on a cascading layer model, with

TABLE 1

Characterisation of Genetic coefficients

	Coefficients related to development aspects
Phyllochron interval (PHINT)	It describes the thermal time required between emergence of two successive leaves and its value is taken 95 for spring cultivar.
Vernalisation coefficient (P1V)	It ranges from 0-9 and describes the relative amount of slowing down the development for each day of unfulfilled vernalisation assuming that 50 days of vernalisation are sufficient for all cultivars.
Photoperiodism coefficient (P1D)	The coefficient governs the relative amount that development is slowed when plants are grown in a photoperiod 1 hour shorter than the optimum (which is considered to be 16 hours, Chipanshi *et al.* 1997).
Grain filling duration coefficient (P5)	It accounts for thermal time in degree days above a base of 1°C where each unit increase above zero adds 20 degree days to the initial value of 430 degree days.
	Coefficients related to growth aspects
Kernel number coefficient (G1)	The coefficients controls the kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (g^{-1}).
Kernel weight coefficient (G2)	It is related to kernel filling rate under optimum conditions (mg/day).
Spike number coefficient (G3)	It accounts for the non-stressed dry weight (g)of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases.

drainage calculated as a function of the water content above the field capacity.

Model separates soil evaporation from plant transpiration (Ritchie, 1972). The potential evaporation (EO) calculation is based on the Priestly-Taylor method. The equilibrium evaporation rate (EEQ) is calculated from daily solar radiation, the combined crop and soil reflection coefficient and the weighted mean daily temperature. Potential evaporation is then calculated from EEQ and the maximum air temperature. Soil evaporation is computed as a function of EO and Leaf Area Index (LAI) in two stages.

Roots growth into the profile is computed as a function of daily thermal time and soil water content. The root length density in each soil layer is calculated as a function of root dry weight accumulation and a root weighing function. This is used in determining root water uptake from each layer as a function of soil water content.

2.1.2. *Phenology*

Essentially, plant development from sowing to physiological maturity is divided into seven stages. Two extra stages in the model allow for pre-sowing simulation of the soil water balance and grain dry-down to harvest. From sowing to physiological maturity, the main driving force is temperature, but during stage 1 (emergence to terminal spikelet), vernalization, photoperiod and phyllochron also influence the rate of development. New leaves appear in first two actively growing stages as a function of air temperature and a cultivar specific phyllochron interval.

2.1.3. *Growth*

Potential dry matter is calculated as a function of intercepted photosynthetically active radiation (PAR), where PAR is set equal to 0.5× SOLRAD (Daily total solar radiation). The daily potential dry matter production (PCARB, g plant^{-1}) is

$$\text{PCARB} = \frac{7.5\times\text{PAR}^{0.6}\times[1\text{-EXP}(-0.85\times\text{LAI})]}{\text{PLANTS PER SQUARE METRE}}$$

The actual rate of dry matter production (CARBO) is usually less than PCARB due to the effects of non-optimal temperature and water stress. CARBO is apportioned between shoots and roots with a growth stage dependent partitioning coefficient. Plant biomass comprised of dry weights of roots, leaves, stem and grains is determined using genetic coefficients.

The model requires seven cultivar specific genetic coefficients (Godwin *et al.*, 1990). The genetic coefficients are represented by "scale values" ranging

TABLE 2

Genetic coefficients of various wheat cultivars

S.No.	Cultivar	Station	P1V	P1D	P5	G1	G2	G3
1	RAJ 3077	Jaipur	0.5	2.5	3.2	3.6	2.4	4.0
2	RAJ 3765	- do -	0.5	2.3	3.5	3.2	2.9	4.0
3	UP 2338	- do -	0.5	4.3	5.9	3.7	2.4	4.0
4	HD 2285	Faizabad, Ranchi	0.5	2.1	2.3	3.8	3.2	4.2
5	Sonalika	Pantnagar	0.5	2.5	3.5	2.5	2.9	4.0
6	Sonali	Pusa	0.5	2.8	1.9	4.1	2.0	7.2
7	Rajesh	-do-	0.5	2.8	4.1	3.9	3.4	5.3
8	C-306	Raipur	0.5	3.9	8.9	2.3	3.1	4.0
9	HD 2329	Jabalpur,Jaipur	0.5	3.2	3.6	2.4	3.5	4.2
10	WH 542	Hisar	0.5	3.3	2.3	5.5	3.5	7.5

from zero/ one to an uppermost value (9) for a genotype which shows the maximum known expression of the trait (Chipanshi *et al*., 1997). The "scale values" are converted to "biological values" within the model. The details of these coefficients are presented in Table 1.

The genetic coefficients were derived iteratively (Hunt *et al*., 1993) with independent data sets *viz*. dates of sowing, anthesis and maturity, grain yield, above ground biomass and grain density and weight. This involved determining first values of phenology coefficients, (PHINT, P1V, P1D and P5), and then values of the coefficients describing growth and grain development, (G1, G2 and G3) so as to achieve the best possible correlation between predicted and observed data for the selected phenotypic and yield component variables. The procedure for determining genetic coefficients involved running the model initially with values derived elsewhere in India for similar genotype, then rerunning the model using a range of values of each coefficient until the desired level of agreement between simulated and observed values was reached. Iteration for coefficients were stopped when the agreement reached ±10%.

From the yield component data, the first genetic coefficient set in the model was G1 that gives the number of grains/m^2 (GPSM) when multiplied by plants. From the first approximation of GPSM with an estimated coefficient, $G1_{est}$, G1 was calculated from the averaged observed ($GPSM_O$) and predicted ($GPSM_P$) data as under :

$$G1 = G1_{est} \times GPSM_O / GPSM_P$$

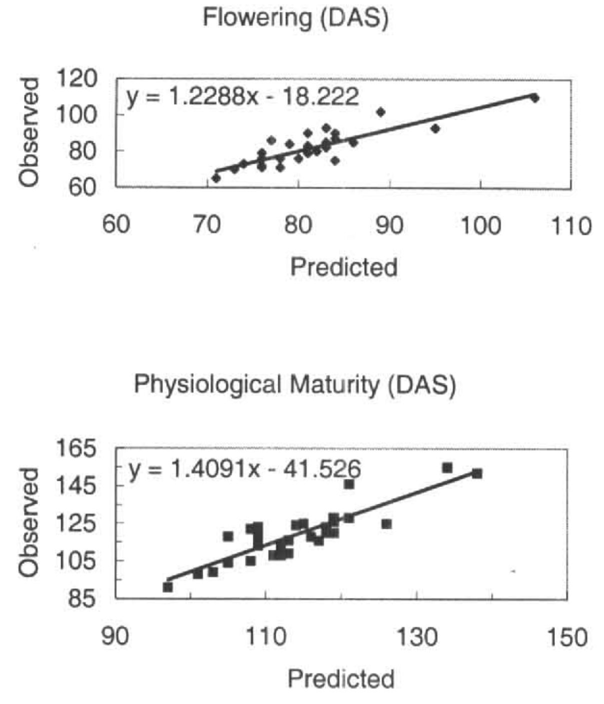
G3 coefficient, which determines tiller production and ear density (TPSM) was the next coefficient, set. Once a reasonable agreement between observed and predicted TPSM was obtained, G2 was adjusted to improve the prediction of kernel mass. The coefficients P1V (0.5, 0.5), P1D (3.3, 2.5), P5 (2.3, 3.5), G1 (5.5, 2.3), G2(3.5 2.5) and G3 (2.5, 4.0) have been reported by Bishnoi *et al*. (1996) for WH 147 at Hisar and Hundal and Kaur (1997) for HD-2329 at Ludhiana respectively.

3. Results and discussions

3.1. *Estimation of genetic coefficients*

With the present state of art technology, it is convenient to genetically categorise cultivar coefficients related to development aspects than to growth. The genetic coefficients which reflect the effects of climatic gradient for various wheat cultivars in different agroclimatic zones are illustrated in Table 2. In India, only spring wheat is cultivated whose P1V is very low. The value for all the cultivars was found to be 0.5.

Wheat cultivars considered in the study include both timely and late sown. Timely sown varieties are genetically more sensitive to photoperiod and late maturing while late sown varieties are less sensitive to photoperiod and early maturing. Values of photoperiod sensitivity coefficient (P1D) derived for various cultivars exhibit similar traits. Late sown varieties have lower sensitivity (≤ 2.5) with least value for HD 2285 while timely sown varieties are more sensitive (>2.5) with highest values for C 306 (3.9) and UP 2338 (4.3).



DAS = Days after sowing

Fig. 2. Comparison of predicted and observed dates of flowering and physiological maturity

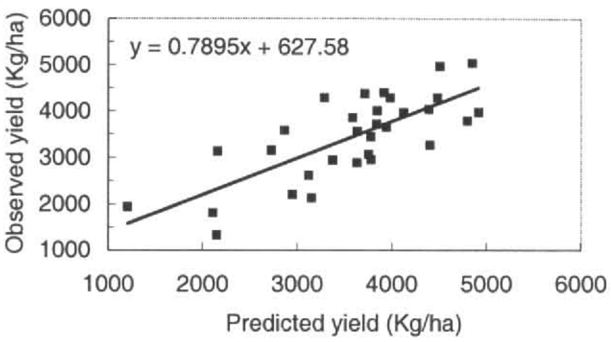


Fig. 3. Observed and predicted yield of wheat genotypes

Thermal time coefficient (P5) governing grain filling period ranges from lowest value of 1.9 to highest value of 8.9. Early maturing varieties are generally characterised by lower range of values indicating shorter grain filling period and the late maturing ones are with higher values. Early maturing characteristics of the cultivars like HD 2285, Sonali, Sonalika, RAJ 3077 and RAJ 3765 are reflected in lower values of P5 (≤ 3.5) simulated by the model. Rest of the varieties generally possessing values greater than 3.5 except WH 542 fall in mid-late/late maturity group.

The coefficient controlling grain number /m^2 was maximum in WH 542 and minimum in C 306. The grain filling rate coefficient was found higher in WH 542 and HD 2329 than other cultivars with Sonali possessing least ability for this trait. The value of coefficient controlling stem weight was higher in WH 542, Rajesh and Sonali while it was more and less same in other genotypes.

3.2. *Evaluation of phenological development*

The derived genetic coefficients were used to simulate phenological events and results of predicted and observed dates of flowering and physiological maturity for all the varieties except WH-147 (Hisar) and HD 2329 (Ludhiana) are depicted in Fig. 2. The results indicate that simulation of main physiological events *viz.* flowering and physiological maturity are in close agreement with observed ones and lie within range of 9% and 12%, respectively. Similar results have been reported by Bishnoi *et al.* (1996); Hundal and Kaur (1997). Accurate prediction of different stages may help farmers to take decisions on crop management operations linked to crop phenology. Satisfactory simulation of phenology is also evident from the following high correlation coefficients and fitted regression equations :

Flowering	$Y = 1.2288X - 18.222$ (r=0.84)
Physiological Maturity	$Y = 1.3014\,X - 29.265$ (r=0.83)

3.3. *Assessment of grain yield*

Grain yield which is the end result of interaction of plant, soil and environment is given in Fig. 3. Yield of all cultivars has been clubbed for evaluating their performance in different environments. The simulated yields lie within range of 4-15% of observed ones at different locations with average variation of 8%. Results are in agreement with that reported by Lal *et al.* (1997), Bishnoi *et al.* (1996) and Hundal and Kaur (1997). The performance of the model may be explained in terms of high correlation coefficient and fitted regression equation as under: $Y = 0.8048\,X - 559.74$ (r=0.82).

4. Conclusions

(*i*) CERES-Wheat is capable of simulating crop development and yield of different cultivars in wheat growing regions of India.

(*ii*) Genetic coefficient developed for different genotypes may be used with routinely observed crop, soil and weather data for predicting phenophases and yield.

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