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Application of the CERES–Wheat model to yield predictions in the irrigated plains of the Indian Punjab

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SUMMARY

The crop–environment resource synthesis model for wheat, CERES–Wheat, was used to simulate yields from 1985 to 1993 at Ludhiana, India. The simulated anthesis and physiological maturity dates, grain and total biomass yields of wheat were compared with actual observations for the commonly grown cultivar, HD–2329. The simulated and actual dates of phenological events showed deviations from only -9 to $+6$ days for anthesis and -6 to $+3$ days for physiological maturity of the crop. The model estimated the kernel weight within 88–113% (mean 100%) of the actual kernel weights. The model predicted the grain yields from 80 to 115% (mean 97·5%) of the observed grain yield. Biomass yields were predicted from 93 to 128% (mean 110·5%) of the observed yields. The results obtained with the model for the eight crop seasons demonstrated satisfactory predictions of phenology, growth and yield of wheat. However, the biomass simulations indicated the need for further examination of the factors controlling the partitioning of photosynthates during crop growth. The results of this study reveal that the calibrated CERES–Wheat model can be used for the prediction of wheat growth and yield in the central irrigated plains of the Indian Punjab.

INTRODUCTION

Reliable crop yield forecasting is being sought by scientists and government policy-makers in order to predict the availability of food grains. To achieve this, several computer simulation models have recently been developed to predict crop growth on a daily basis for estimating large area crop production. Whisler *et al*. (1986) reviewed 30 simulation models for various crops, including three for wheat. Porter *et al*. (1993) compared three wheat simulation models, AFRCWHEAT2, CERES–Wheat and SWHEAT under non-limiting nitrogen and water availability conditions using two cultivars and found that the best prediction for all growth parameters was not always given by the same model. Otter-Nacke *et al*. (1986) reported a satisfactory performance of the CERES–Wheat model under diverse environments. Dynamic growth simulation models based on the plant's physiological response are reported to have universal applicability compared with statistical models which are largely site-specific (Jamieson *et al*. 1991).

The Crop Environment REsource Synthesis (CERES)–Wheat model (version 2.10) described by Ritchie & Otter (1985) and Ritchie (1986), which forms the basis of IBSNAT, the International Benchmark Sites Network for Agrotechnology Transfer (Uehara 1985), can be used to simulate the growth and yield of wheat under different environments. The model simulates the effects of variation in weather, crop genotypes, soil properties and crop management practices. The simulation of growth and yield is based on the quantification of phasic development; photosynthesis; respiration; morphogenesis; growth; biomass accumulation and partitioning; extension growth of leaves, stem, roots and grain; soil water extraction; evapotranspiration and plant nitrogen status. However, the effects of insect pests, diseases and natural calamities, such as wind and hailstorm damage, are not accounted for in this model.

Wheat is the most important cereal crop in the state of Punjab, India, occupying nearly 3·3 million ha (45% of the annually cropped area in the state). The state contributes nearly 70% to the central reserve pool of wheat stocks in India. The wheat crop is grown mainly under irrigated conditions (74·6%) in India while, in the Punjab, 97% of the crop area is irrigated. Considering the importance of wheat for the economy and food requirements of the state, there is a need for reliable estimates of wheat production

Table 1. *Summary of initial input data used for the* CERES–*Wheat model*

Initial data
1. Soil profile properties
2. Planting date
3. Planting density and depth
4. Irrigation date and amount
5. N-fertilizer date and amount
6. Latitude
7. Cultivar genetic constants
Daily data
1. Solar radiation
2. Maximum temperature
3. Minimum temperature
4. Precipitation

Table 2. *Soil physical characteristics for the study area, Ludhiana, India*

Soil albedo (shortwave radiation reflection coefficient)	0·20
Coefficient for the upper limit of stage 1 evaporation	5·0 (mm)
Whole profile drainage rate coefficient	0·60
Runoff curve number	60
Soil layer thickness	210 (cm)
Lower limit of plant-extractable water (LL)	0·047 (cm^3/cm^3)
Drained upper limit (UL)	0·225 (cm^3/cm^3)
Water content at saturation	0·405 (cm^3/cm^3)
Initial water content	0·200 (cm^3/cm^3)

under varied environments. The CERES–Wheat model was selected for validation and application to environmental conditions in the Punjab.

MATERIALS AND METHODS

Site description

The soil, crop and weather data used in the study were collected at Punjab Agricultural University, Ludhiana (30° 54′ N, 75° 48′ E, 247 m above mean sea level). This area, which is representative of the central irrigated plains of the Indian Punjab, is characterized by a sub-tropical, semi-arid climate. The average temperature during the wheat crop season (November–April) is 16·9 °C and the mean rainfall during the crop season is 126 mm.

Data description

The structure of the IBSNAT CERES–Wheat model (V 2.10) is similar to other IBSNAT simulation models. Input requirements are described according to the IBSNAT standard input/output formats and file structures (IBSNAT 1990). The input data required to run the model are listed in Table 1. The weather data used for the crop growth period of the eight consecutive years 1985/86 to 1992/93 included daily solar radiation, maximum and minimum temperatures and precipitation. The data on soil physical characteristics of the experimental field are given in Table 2. The crop management data were obtained from field experiments conducted with three dates of sowing each year, except in 1986/87 and 1987/88 when five sowing dates were used (Anon. 1991). The resulting 28 data-sets were used to compare the field-observed and simulated results. The wheat cultivar HD–2329, a dwarf, high-yielding variety that covers nearly 75% of the wheat growing area in the Punjab, was grown under the recommended nutrient and management practices. Wheat is sown after a pre-sowing irrigation and the crop is given 4–5 additional irrigations of 75 mm each until maturity. The crop was given 120 kg N/ha (1/2 basal and 1/2 applied with the first post-sowing irrigation at crown root initiation stage) and 27 kg P/ha as a basal application. The crop was sown in rows 22 cm apart at a sowing rate of 100 kg/ha.

Model calibration

In order to evaluate the applicability of the CERES–Wheat model to the irrigated central plain region of the Indian Punjab, calibration of the model was required (Jagtap *et al*. 1993). CERES–Wheat requires six variety-specific genetic parameters (Godwin *et al*. 1990). Three of these are related to developmental aspects and the remaining three to the growth of the crop. P1V and P1D define the sensitivity of a variety to vernalization and photoperiod. The third developmental parameter, P5, is the grain-filling duration coefficient. G1, G2 and G3 are the kernel number coefficient, kernel weight coefficient and spike number coefficient, respectively.

The published values of these six genetic coefficients (Godwin *et al*. 1990) were calibrated to simulate the growth and development of wheat using the field-observed crop data of the 1990/91 season experiment. In this crop season, the wheat was sown on three different dates (323, 339 and 354 Julian day). Each of the six genetic coefficients was interactively increased/decreased from the given value and the predicted values of the relevant growth and yield parameters were compared with the observed values. Then those values of the coefficients which most realistically simulated the growth and yield of wheat were selected. The genetic coefficients finally selected for cultivar HD–2329 were: P1V = 0·5; P1D = 2·5; P5 = 3·5; G1 = 2·5; G2 = 2·9 and G3 = 4·0.

Table 3. *Comparison of observed and simulated anthesis and physiological maturity dates of wheat for different crop years and sowing dates in India*

Crop year	Sowing date (Julian day)	Anthesis date (Days after sowing)		Deviation (No. of days)	Physiological maturity date (Days after sowing)		Deviation (No. of days)
		Observed	Simulated		Observed	Simulated	
1985/86	310	101	94	−7	136	136	0
	325	99	99	0	131	134	+3
	347	93	94	+1	126	125	−1
1986/87	308	90	91	+1	135	130	−5
	324	94	96	+2	135	130	−5
	338	91	94	+3	130	125	−5
	354	84	88	+4	118	118	0
	002	81	82	+1	114	110	−4
1987/88	311	95	91	−4	136	130	−6
	325	96	95	−1131	130	−1	
	338	92	93	+1	131	126	−5
	353	88	89	+1	118	119	+1
	002	79	83	+4	114	112	−2
1988/89	312	96	95	−1	137	135	−2
	333	95	101	+6	136	133	−3
	354	92	94	+2	123	124	+1
1989/90	310	95	90	−5	136	130	−4
	332	94	97	+3	137	131	−6
	353	88	90	+2	122	122	0
1990/91*	323	100	97	−3	135	132	−3
	339	95	97	+2	139	128	−4
	354	90	91	+1	122	121	−1
1991/92	311	105	96	−9	135	136	+1
	332	98	99	+1	133	132	−1
	352	94	95	+1	123	124	+1
1992/93	310	95	91	−4	134	129	−5
	331	104	95	−9	142	143	+1
	352	89	90	+1	128	130	+2

* Crop season data used for calibration of model.

RESULTS AND DISCUSSION

Crop phenology

Overall, the field-observed and model-simulated anthesis dates were in close agreement (Table 3). The model predicted the anthesis dates between −9 to +6 days of the observed dates. The largest underestimation was for the crop sown in early November during various crop years, which was possibly the effect of variable weather conditions during those years. Some differences were also observed for the various sowing dates across the years. However, the deviations were inconsistent.

The physiological maturity dates simulated by the model corresponded reasonably well with that actually observed in the field (Table 3). Physiological maturity dates were estimated between −6 and +3 days of the field-observed dates. Modelled results gave both overestimations and underestimations of physiological maturity dates. The underestimation of physiological maturity was generally observed in the earlier sown crops, while the model predicted the physiological maturity more realistically under later sowings (i.e. December).

Crop growth and yield

Biomass yield ranged from 7·83 to 12·92 t/ha for different treatments (Fig. 1). However, wheat sown in the first week of November gave the maximum yield of observed biomass which decreased with delayed sowing. Biomass at maturity was, however, somewhat overestimated by the model, but the trend noted for the field-observed and model-simulated biomass yields

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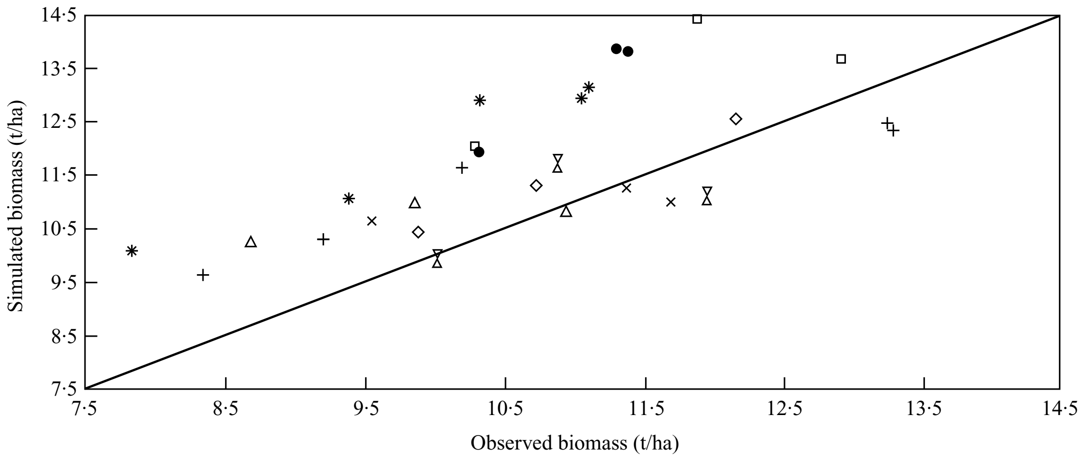

Fig. 1. Comparison of observed and simulated biomass yield of wheat for different crop years; 1985/86 (●), 1986/87 (+), 1987/88 (∗), 1988/89 (□), 1989/90 (×), 1990/91 (◇), 1991/92 (△), 1992/93 (⧖).

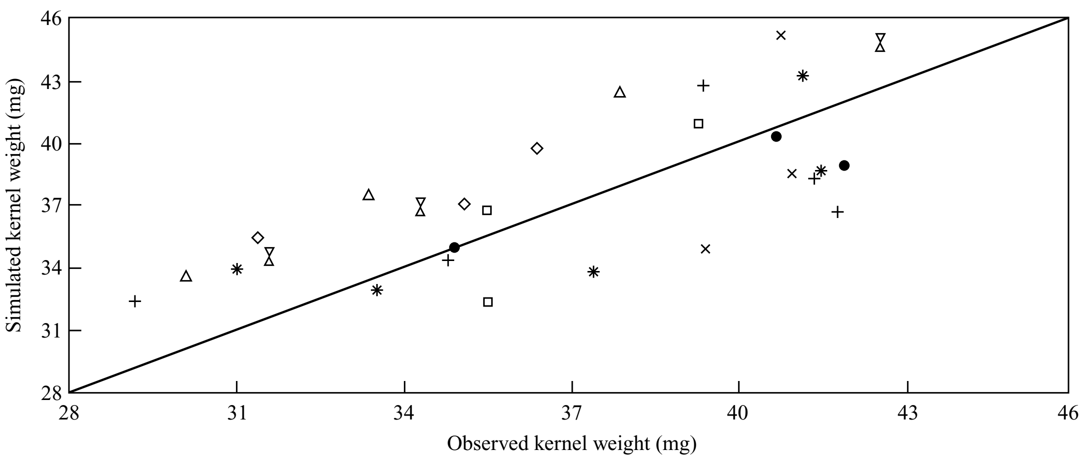

Fig. 2. Comparison of observed and simulated kernel weight of wheat for different crop years: 1985/86 (●), 1986/87 (+), 1987/88 (∗), 1988/89 (□), 1989/90 (×), 1990/91 (◇), 1991/92 (△), 1992/93 (⧖).

was similar. The model estimated the total biomass within the range 93–128% (mean 110·5%) of the observed biomass yield. The model predicted biomass within ±10% for 12, and ±20% for 23, out of the 28 environments. Overestimation of biomass was noticed under both early and delayed sowing of the wheat crop.

Kernel weight, an important yield attribute, ranged from 29·2 to 41·8 mg for the different treatments (Fig. 2). Earliest sown wheat attained physiological maturity in 130–136 days while later sowings revealed a progressive hastening of maturity. As a result, larger and healthier kernels were produced in earlier sown wheat. The kernel weight decreased with delay in sowing for all the crop years. Overall, a close resemblance was observed between the actual and simulated kernel weights. The model estimated the kernel weight to be within the range 88–113% (mean 100%) of the actual kernel weight. For comparable dates of sowing, relatively lesser differences were observed in kernel weight across various crop years.

Grain yield ranged from 3·02 to 5·16 t/ha for the different treatments (Fig. 3). The grain yield was maximum for the earliest sown (early November) treatment each year and decreased progressively with delay in sowing. The comparison of observed and predicted grain yield revealed both overestimation and underestimation by the model; however, the trend noted for the field-observed and model-simulated grain yields was similar. The model predicted grain yields to be within ±10% for 15, ±15% for 23, and ±21% for all 28 environments. Under-

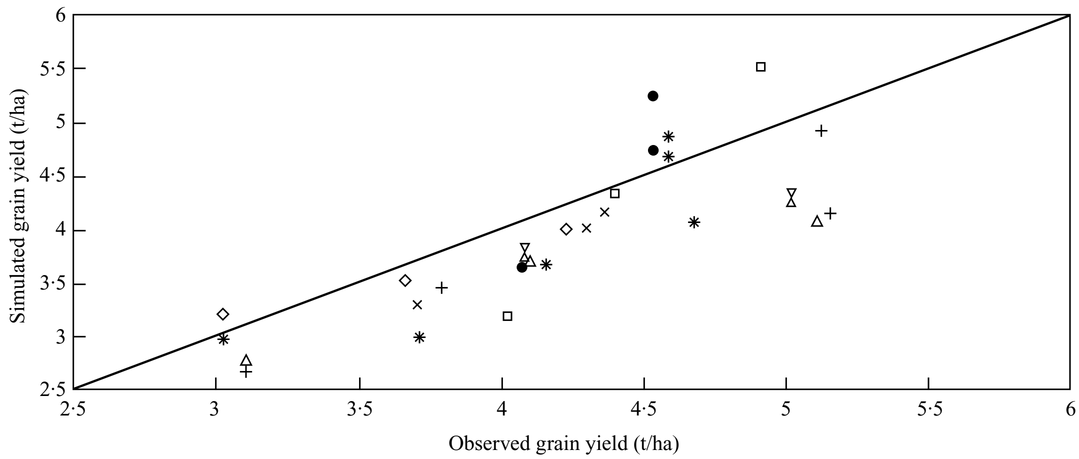

Fig. 3. Comparison of observed and simulated grain yield of wheat for different crop years: 1985/86 (●), 1986/87 (+), 1987/88 (∗), 1988/89 (□), 1989/90 (×), 1990/91 (◇), 1991/92 (△), 1992/93 (⧗).

estimation of grain yields was noted under both early and delayed sowing of the wheat crop. The model simulated the grain yield to within 80–115% (mean 97·5%) of the actual yield.

The model does not account for losses from insect pests and diseases but this was not a serious limitation because the cultivar used in the study is fairly resistant to the common diseases of wheat, while insect pests of the crop are not usually a major problem in the region. The simulations used in the study employed recommended irrigation and nitrogen requirements for optimum yield; however, it is possible that the observed crop yields in some cases could be influenced by some degree of water or nitrogen stresses as well as extreme weather events over different years leading to overestimation of yield by the model. The underestimation of grain yield and overestimation of biomass by the model reflects the need for a closer examination of quantitative relationships governing the partitioning of photosynthates into biomass and grain yield.

This study revealed that the CERES–Wheat model can be used to estimate the potential production of wheat under different environments in the central irrigated plain areas of the Indian Punjab. Similar attempts were made by Hodges *et al*. (1987), Liu *et al*. (1989) and Wu *et al*. (1989) for the application of the CERES–Maize model to yield forecasting in the US cornbelt, Brazil and the North China Plains, respectively.

Anthesis and physiological maturity dates were satisfactorily simulated by the model. Kernel weight and grain yield were also closely estimated by the model. However, the total biomass and straw yields were somewhat overestimated by the model.

The results indicate that the accuracy of the model would be improved with a greater knowledge of the genetic coefficients governing the partitioning of photosynthates to the various plant components. In view of the findings reported in this paper, the CERES–Wheat model can be applied in the irrigated plains of the Indian Punjab to estimate crop productivity on a large scale. The model can act as a useful tool for informing policy-makers about the extent of variation in wheat yields that can be expected within seasons.

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