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Research Article

Sensitivity Analysis of Soil Hydraulic and Crop Varietal Parameters of Infocrop Model for Wheat

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ABSTRACT

In the present study, the sensitivity of various soil, management and varietal parameters in Infocrop model were investigated to understand their impacts on yield. Infocrop model was initially calibrated to predict wheat grain yield of 22 farmers' fields of 3 blocks of Karnal growing wheat variety HD 2967 during *rabi* season of 2012-13. Observed grain yield varied from 25.0-59.3 q ha^{-1} with an average value of 50.21±8.09 q ha^{-1}. On validation, model performance was found to be good with r^2=0.81, RMSE=3.2 q ha^{-1} and ME =0.84. Sensitivity analysis was performed by successively decreasing and increasing parameter value by 5, 10 and 15% over its base value and studying its effect on wheat grain yield. Sensitivity analysis was performed for various soil parameters such as bulk density (BD), soil texture, soil organic carbon, pH, EC, volumetric water contents at saturation (WCST), field capacity (WCFC) and permanent wilting point (WCWP); plant parameters such as thermal time for sowing to germination (TTGERM), thermal time for germination to 50% flowering (TTVG), thermal time for 50% flowering to 50% physiological maturity (TTGF), specific leaf area (SLAVAR), potential grain weight (POTGWT) and index of storage organs (GNOCF), relative growth rate of leaf area (an indicator of early vigour (RGRPOT) and sowing date. Variations in wheat yield was mainly found to be sensitive to WCFC, WCWP, TTGERM, TTVG, TTGF and sowing dates. WCFC, TTVG and sowing dates were the three most sensitive parameters affecting grain yield. BD, %sand, %clay, soil OC, EC, POTGWT, GNOCF, RGRPOT, SLAVAR did not affect wheat yield significantly.

Key words: Infocrop model, Field capacity, Permanent wilting point

Introduction

InfoCrop, a generic crop model (Aggarwal *et al*., 2006) is a dynamic simulation model that simulates the interactive effects of weather, soils, agronomic management (planting, nitrogen, residues and irrigation) and major pests on crop growth, yield, soil carbon, nitrogen and water, and greenhouse gas emissions under tropical and subtropical conditions. InfoCrop has been successfully adapted, calibrated and validated for rice (Aggarwal *et al*., 2006b), wheat (Aggarwal *et al*., 2006b), potato (Singh *et al*., 2005), sorghum (Srivastava *et al*., 2010), mustard (Boomiraj *et al*., 2010) and many other crops. Aggarwal *et al*. (2006b) evaluated this model with reference to its validation for wheat crop in contrasting agro-environments of tropics.

Successful application of any crop model requires, providing accurate values of input parameters. During model calibration (the process of adjustment of the model input parameters, which may be large in number) to obtain satisfactory output, it is usually seen that the

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influence of different parameters on the model output varies. Hence it is always advisable to conduct sensitivity analysis to point out most sensitive key input parameters. Accurate measurement/estimation of these input parameters' values can improve the overall performance of model.

In the present study, the sensitivity of various soil, management and varietal parameters of wheat crop was investigated to understand their impact on yield. Higher yield variation due to change in any parameter indicated, that specific parameter is more sensitive over the other parameters.

Materials and Methods

In the present study, Infocrop model was calibrated to predict wheat grain yield of farmers' fields of Karnal block during *rabi* season 2012-13.

The model required inputs on a number of varietal coefficients i.e. base temperature for sowing to germination, thermal time for sowing to germination (TTGERM), base temperature for germination to 50% flowering, thermal time for germination to 50% flowering (TTVG), base temperature for 50% flowering to 50% physiological maturity, thermal time for 50% flowering to 50% physiological maturity (TTGF), optimal temperature for development, maximum temperature for development, sensitivity to photoperiod, relative growth rate of leaf area, specific leaf area (SLAVAR), extinction coefficient of leaves at flowering, maximum radiation use efficiency (of peak vegetative stage), root extension growth rate, index of greenness of leaves, sensitivity to flooding, index of storage organs (GNOCF) and potential grain weight (POTGWT).

Crop management input data included time of planting, seed rate, depth of planting; amount, time and depth of placement of different organic matters and nitrogen; and amount, time and type of irrigation. Soil input data required are textural parameters, thickness, bulk density, saturated hydraulic conductivity, soil organic carbon, pH, EC, volumetric water contents at saturation (WCST), field capacity(WCFC) and permanent wilting point (WCWP) for each of the three soil layers. Besides, model required daily data of weather parameters including, maximum and minimum temperature, rainfall, irradiance, wind speed and relative humidity.

The base values of all soil parameters for calibration were obtained by taking averages of measured values of soil samples collected from farmers' fields (22-24 in number) growing wheat variety- HD2967. Similarly management practices used in the model, were those practiced by farmers there.The genetic coefficients of the model were taken from Aggarwal *et al*. (2006a) and their magnitudes were optimized through inverse modelling i.e. values of the coefficients were slightly increased or decreased until difference between the predicted and observed values of grain yield showed minimum root mean square error (RMSE).

The calibrated inputs were used to simulated wheat grain yield, which was then compared with the yield measured at farmers' fields. Model performance of Infocrop was assessed by computing the r^2, root mean square error (RMSE), and ME (Nash and Sutcliffe, 1970). The r^2 of conventional statistics was calculated to estimate linearity between measured and simulated values. RMSE is a measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power. The RMSE of a model prediction with respect to the estimated variable X_{model} is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

where X_{obs} is observed values and X_{model} is modelled values at time/place i.

The Nash–Sutcliffe model efficiency is a normalized, dimensionless statistical index that indicate show well an observed variable agrees with a variable simulated by a model. It is defined as:

$$E = 1 - \frac{\sum_{i=1}^{n} (X_{obs,i} - X_{mo\ del})^2}{\sum_{i=1}^{n} (X_{obs,i} - \overline{X_{obs}})^2}$$

where X_{obs} is observed values and X_{model} is modelled values at time/place *i*.

Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of 1 (E = 1) corresponds to a perfect match between model and observations. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < E < 0$) occurs when the observed mean is a better predictor than the model.

For studying the sensitivity of a given parameter, that parameter value was changed by both successively decreasing and increasing its value by 5, 10 and 15% over its base value in the model and its effect on change in value of output parameter of the model, mainly wheat grain yield was observed.

Results and Discussion

Calibration of model

Weather parameters

During the *rabi* season (2012 –2013), - the daily maximum temperature varied from 14-31°C with an average of about 25 °C, 10 to 24°C with an average of about 19 °C and 28 to 36 °C with an average of about 30 °C during initial (mid October to December end), intermediate (January to February) and late (March to April) crop growing season, respectively. Minimum temperatures varied from 6 to 15°C with an average of about 9.6 °C, 3 to 9°C with an average of about 7 °C and 12 to 17 °C with an average of about 14 °C during the initial, intermediate and late crop growing season, respectively. Wind speed varied from 0.1 to 1.5 m s^{-1} with an average of about 0.7 m s^{-1}, 0.45 to 1.76 m s^{-1} with an average of about 1.2 m/s and 1 to 1.8 m s^{-1} with an average of about 1.4 m s^{-1} during the initial, intermediate and late crop growing season, respectively. Daily total radiation varied from 16.7 to 8.3 MJ m^{-2} with an average of about 14 MJ m^{-2}, 8.4 to 16.8 MJ m^{-2} with an average of about 13 MJ m^{-2} and 18.4 to 24.4 MJ m^{-2} with an average of about 21 MJ m^{-2} during the initial, intermediate and late crop growing season, respectively. Total rains received was 13 mm in 2 rainy days spread over 2 meteorological weeks, 181 mm in about 12 rainy days spread over 5 meteorological weeks and 6 mm in 3 rainy days spread over 3 meteorological weeks during the initial, intermediate and late crop growing season, respectively.

Soil parameters

For model calibration, the base values of all key input soil and plant parameters have been presented in table 1. The texture of the study area was clay loam and sandy clay loam. Average BD of the study region was 1.34 Mg m^{-3}, average OC was 0.5%, WCFC and WCWP were 0.21 and 0.07.

Plant varietal parameters

The magnitude of important conservative plant parameters namely TTGERM, TTVG, TTGF, were 55,780 and 580 degree days. The other important plant parameters including POTGWT (g), GNOCF (Number per kg dry matter), SLAVAR (ha leaf kg^{-1} leaf), RGRPOT (°Cd^{-1}) had magnitudes of 44, 35000, 0.0022 and 0.008.

Study site

Survey in farmers' fields in 3 blocks of Karnal district showed that at following 22 sites namely CSSRI, Kachua, Dabri, Shekhpura, Mohdinpur, Dabarki, Bhani, Uchana, Zarifa Viran, NDRI, Chidaw, Jundla, Bansa 1, Bansa 2, Munak 1, Munak 2, Picholia, Budunpur, Stundi, Phurlok, Gharonda, Kutel, farmers' were sowing HD2967 variety of wheat. Sowing date for the area varied between 23 November to 2nd December. Majority of fields were under conventional tillage. A total of 3-4 irrigations were given by farmers which included 1 pre-sowing irrigation (7-10 days) before sowing and further 2-3 applications at 25-30 days interval. There were heavy showers between February end to entire March. Farmers applied both DAP

Table 1. Base input soil and plant parameters used for calibration of model

Bulk density (Mg m^{-3})	1.34±0.02
Organic carbon (%)	0.5±0.008
Sand (%)	42±4
Clay (%)	34±3
Volumetric water content at field capacity of surface 0-30 cm layer, WCFC (unit less)	0.21±0.05
Volumetric water content at permanent wilting point of surface 0-30 cm layer, WCWP (unit less)	0.07±.004
Volumetric water content at saturation of 0-30 cm soil layer, WCST (unit less)	0.52±0.06
pH of soil	8.56±1.10
EC of surface layer	0.542±0.06
Sowing date	28-Nov-12±5
Thermal time for sowing to germination, TTGERM (°C days)	55
Thermal time for germination to 50% flowering, TTVG (°C days)	780
Thermal time for 50% flowering to physiological maturity, TTGF (°C days)	580
Potential grain weight, POTGWT (g)	44
Index of storage organs , GNOCF (Number per kg dry matter)	35000
Specific leaf area, SLAVAR (ha leaf kg^{-1} leaf)	0.0022
Relative Growth rate of leaf area (an indicator of early vigour), RGRPOT (°Cd^{-1})	0.008

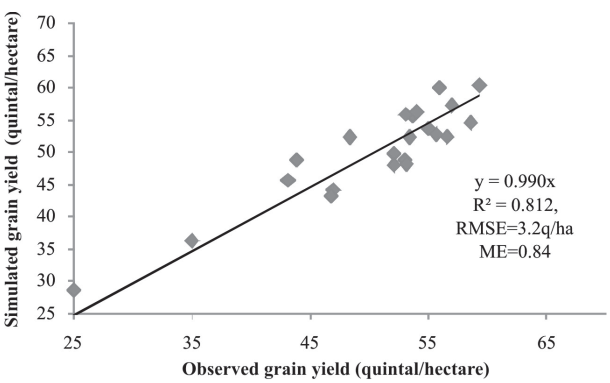

Fig. 1. Validation of model for prediction of wheat grain yield

(provided 22 kg N and 25 kg P ha^{-1}) and urea (provided 57 kg N ha^{-1}) fertilizers. DAP @ 50 kg acre^{-1} was given at all sites at the time of sowing and urea @ 50 kg acre^{-1} was given in 2-4 splits at intervals of 10-25 days during cropping season.

Validation of model

Statistical analysis of observed grain yield from 22 sites (where farmers were growing HD2967) showed that it varied from 25.00-59.30 q ha^{-1} with an average value of 50.21±8.09 q ha^{-1} Comparison of predicted grain yield with observed yield showed that model performance was satisfactory (r^2=0.81, RMSE = 3.2 q ha^{-1} and ME =0.84) (Fig. 1).

Sensitivity analysis of model

Results of sensitivity analysis of input soil hydraulic parameters revealed that increase or decrease in values of BD, OC, sand and clay by 5 to 15% did not change the yield by more than 1% (Table 2).

WCFC which is the upper limit of plant available water had significant effect on yield variation. Variation of WCFC of surface 0-30 cm layer by 5% to 15% resulted in increase of wheat yield by 10% to 30%, whereas decreasing it by 5% to 15% resulted in reduction of wheat yield by 10% to 29% (Fig. 2).

WCWP, which is the lower limit of water availability to plant, also affected yield. Increase in WCWP by5% to 15% led to reduction in wheat yield by 2% to 9% and decreasing its value by5 to 15% resulted in increase of yield by 6% to 10%.

However the variation of WCST by 5 to 15% had very little effect on yield (<1%).

Among different plant parameters, increase in the value of TTGERM from 5% to 15% resulted in decrease of yield by 1% to 2.3%. On the other

Table 2. Less sensitive parameters of Infocrop

Parameters	Change in yield with decrease in parameters (%)			Percent change in yield with base value	Percentage change in yield with increase in parameters		
	-15%	-10%	-5%	0%	5%	10%	15%
Bulk density	0.92	1.13	-0.08	0.00	0.04	0.08	0.11
Organic carbon	-0.09	-0.22	-0.06	0.00	0.04	-2.26	-2.16
Sand%	0.02	0.01	0.00	0.00	0.00	0.00	0.75
Clay%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pH of soil	1.46	1.46	1.49	0.00	3.41	3.39	1.48
EC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potential grain weight, POTGWT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Index of storage organs, GNOCF	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Specific leaf area, SLAVAR	0.82	-0.92	-0.43	0.00	1.90	2.31	2.55
Relative Growth rate of leaf area (an indicator of early vigour), RGRPOT	-0.02	-0.01	-0.01	0.00	0.01	0.01	0.02

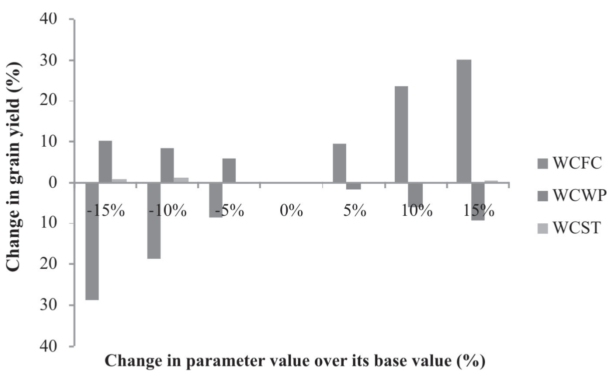

Fig. 2. Analysis of sensitive input soil hydraulic parameters

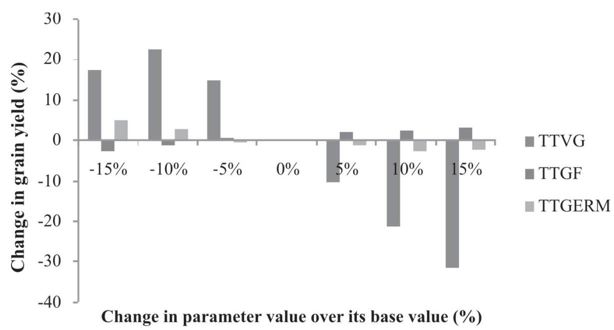

Fig. 3. Analysis of sensitive varietal parameters

hand, decrease in the value of TTGF from 5% to 15% indicated increase of yield by -0.3% to 4.8% (Fig. 3).

Similarly, increase in the value of TTVG by 5 to 15% resulted in decrease in yield by 10% to 30%,whereas decrease in its value by 5% to 15% indicated increase in yield by 14% to 22%. Higher TTVG invariably lengthens the vegetative stage of the crop, exposing it to high temperatures (>25 °C) and moisture stress which adversely affects wheat grain yield. (Warren and John, 1963, Marcellos and Singie, 1972; Rawson, 1993)

Again, increase in the value of TTGF from 5 to 15% resulted in increase of yield by 2 to 3%, whereas decrease in its value by 10% to 15% indicated decrease of yield by 1% to 3%. This is due to the fact that when plants are exposed to longer day lengths, production is often improved through a balance between photosynthesis and respiration (Mishra *et al*., 2015).

The normal date of sowing in the study area was taken as 28 November 2012. Preponing the sowing date by 10 to 30 days increased wheat yield by 9-14%. Similarly by postponing the sowing dates from 10 to 30 days from the normal date decreased the wheat yield from 6 to 25% (Fig. 4).

Increase in SLAVAR by 5 to 15% had very marginal increase in grain yield (upto 2.55%) and its decrease by 5 to 15% had very little effect (±0.92%) on grain yield. POTGWT, RGRPOT and GNOCF were also neutral and any% change

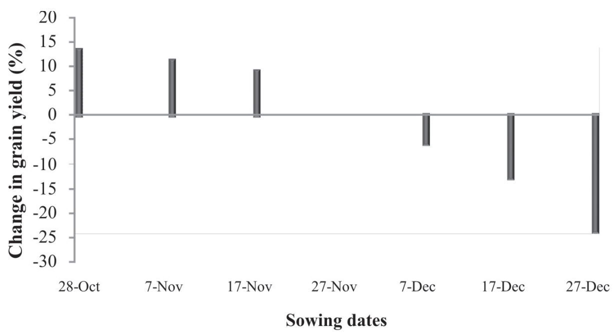

Fig. 4. Analysis of effect of sowing date on grain yield

in their values did not affect the wheat yield. Effect on grain yield by increasing potential grain weight was not observed because the model simulated grain weight did not reach its potential weight under the given input set of weather and management parameters.

Conclusions

It was observed that variation in wheat yield was mainly influenced by following input parameters - WCFC, WCWP, TTGERM, TTVG, TTGF and sowing dates. Bulk density had a very nominal impact on wheat yield. Among these parameters, WCFC and TTVG were the two most sensitive parameters. Sowing date was also another sensitive input parameter affecting yield. Postponing the sowing date caused significant reduction in wheat yield.

On the other hand, variation in 15% of the magnitude of parameters like BD, % sand, % clay, soil OC, EC, potential grain weight and index of storage organs did not affect the wheat yield.

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