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Simulation of wheat (*Triticum aestivum* L.) yield using WOFOST model under different management levels

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Abstract
A field experiment was conducted at Agrometeorology Research Farm, Narendra Deva University of Agriculture & Technology, Narendra Nagar (Kumarganj), Faizabad (U.P.) during Rabi season 2012 and 2013 to study the "Simulation of wheat (*Triticum aestivum* L.) Yield using WOFOST model under different management levels". The experiment consisted of 12 treatment combinations in tested Split plot design with three replications. Experiment consisted of three irrigations at different stage i.e. First Irrigations (CRI+ Tillering+ Ear Head Emergence +Milking, Second irrigation (CRI+ Ear Head Emergence + Milking) and Third irrigation (CRI+ Milking) and two date of sowing i.e. first is normal sowing (15 November) and second is delayed sowing (15 December) and two fertilizer doses higher dose (150:75:75 NPK kg ha^{-1}) and optimum dose (120:60:60 NPK kg ha^{-1}). Sensitivity of WOFOST model simulated grain yield to incremental units of maximum air temperature showed a gradual decrease in yield while, the down scaled maximum temperature increased the yield. The wheat yield increased due to decreased temperature ranged 5.7 to 25.4. While the reduction of yield due to increase of temperature from -8.8 to 26.3.Every 1^0C decrease in the minimum temperature increased the grain yield of wheat was 5.6, 12.1, 19.4, 23.9 and 26.8 respectively while increase in temperature from 1^0C to 5^0C wheat yield decrease from -11.0 to 37.9 percent.

Keywords: Wheat, WOFOST model, irrigation levels, CO_2 levels

Introduction
In crop growth modeling schemes, the various components of the water balance in an agro ecological system are the most important physical and physiological factors for calculations (Aggarwal, 1995; Addiscott *et al.*, 1995) [2, 1]. Spatial and temporal variation of soil moisture is one of the main causes of crop production variation (Shepherd *et al.*, 2002; Anwar *et al.*, 2003; Patil and Sheelavantar, 2004) [9]. Meanwhile, actual evaporation and transpiration, which determine the soil moisture profile, are the main processes for water loss in a soil–plant system (Burman and Pochop, 1994; Monteith and Unsworth, 1990) [3, 7]. Crops can only absorb the soil moisture present within reach of their roots. These processes could be represented in hydrologic models. Therefore, the coupling of hydrologic and crop growth models connects hydrology and agronomy quantitatively and provides a bridge across the boundaries of the two subjects. In the last several years, numerous studies have been conducted to understand the complex interactions between ecological systems and the hydrologic cycle, resulting in the development of ecohydrologic models and soil–plant–atmosphere models (Smettem, 2008) [10]. Simulation modeling can be used to understand the relationships among crop production, groundwater recharge, soil evaporation, and crop transpiration (Engel and Priesack, 1993) [5]; used a numerical model to evaluate groundwater recharge in an irrigated cropland. By coupling hydrologic and crop growth models, (Eitzinger *et al.* 2004) [4] studied soil water movement during crop growth stages and concluded that the coupled modeling approach was better than a single-model method. A few studies have been conducted to investigate the effects of the soil moisture distribution along a vertical soil profile during crop transpiration (e.g., Varado *et al.*, 2006) [11]. The model coupling studies have generally focused on the effect of crop growth on soil moisture, and much less attention has been paid to improving crop growth models by properly modelling the root growth algorithm and root water uptake. In this study, we developed a modeling approach to simultaneously estimate crop production, soil moisture dynamics, evaporation, and transpiration by coupling HYDRUS with WOFOST. The soil moisture dynamic movements are simulated through the Richards equation (in the HYDRUS model), while root water uptake and transpiration are calculated according to the method of (Feddes *et al.* 1978) [6].

Materials and Methods

An experiment was conducted during *Rabi* seasons of 2012 & 2013 and 2013 & 2014 at student instructional farm NDUA & T Kumarganj Faizabad (U.P.), India on the topic entitled "Simulation of wheat (*Triticum aestivum* L.) yield using WOFOST model under different management levels" The experimental site is located in the main campus of NDUA & T, Kumarganj, (Faizabad) situated at a distance of about 42 km. away from Faizabad district headquarter on Faizabad Raibarelly road. The geographical situation of experimental site lies at latitudes 26^0 47' North longitude 82^0 12′ east and altitude of 113 meter from mean sea level in the Indo genetic alluvium of eastern Uttar Pradesh. The details of materials and methods employed & techniques adopted during the course of experimentation has been described in this paper. The experiment was conducted in Split Plot Design (S.P.D) and replicated the three times. The different growth parameters studied were white as Irrigation.

Results

The simulated and observed wheat yield 4 Irrigation (CRI+ Tillering + Ear Head Formation + Milking) and error percent are presented in table 4.10. The result noticed that the error percent under first irrigation level was ranged 1.99 to 6.92. The highest error was found in D_1Y_2 and lowest was found in D_2Y_1. The simulated and observed wheat yield at I_2: 3 Irrigation (CRI+ Ear Head Formation + Milking) and error percent presented in table 4.10. The result noticed that the error percent under second irrigation level was ranged 3.86 to 5.54. The highest error was found in $D_2Y_1$and lowest was found in D_2Y_2. The simulated and observed wheat yield at $I_{3:}$ 2 Irrigation (CRI+ Milking) and error percent presented in table 4.10. The result noticed that the error percent under third irrigation level was ranged 4.35 to 6.37. The highest error was found in D_2Y_2 and lowest was found in D_2Y_1.

Effects of bright sun shine hours understanding the reaction of local wheat cultivars to varying photoperiod conditions as manifested in the grain yield and grain quality can improve regionally wheat yield and grain quality. The examination of the data on presented in (Fig.1). Sensitivity of WOFOST model for wheat cultivar simulated grain yield under altered weather parameters indicated that with incremental unit increase in day length, the simulated yield increased linearly and *vice versa*. The WOFOST model simulated results showed that the wheat yield under altered bright sun shine duration from -0.5 to -02.5, the yield was decreased by -3.0 to -24.8 percent. While, incremental day length by 0.5, 1.0, 1.5, 2.0 and 2.5 hours from normal the respective yield was increased by extent of 4.8, 11.3, 13.9, 21.6 and 23.8 respectively.

Effects of maximum air temperature he effects of altered maximum air temperature (($\pm$ 1 to $\pm 5\ ^0$C) on simulated grain yield of various wheat cultivars under optimal date of sowing and the comparison of this simulated grain yield with base yield and it's percent change from base yield are presented in (Fig.2). Sensitivity of WOFOST model simulated grain yield to incremental units of maximum air temperature showed a gradual decrease in yield while, the down scaled maximum temperature increased the yield. The wheat yield increased due to decreased temperature ranged 5.7 to 25.4.while the reduction of yield due to increase of temperature from -8.8 to 26.3. Pathak *et al.* (2003) [8] also stated on the basis of sensitivity analysis of CERES-Wheat that elevated maximum temperature decreased wheat yield significantly.

Effects of minimum air temperature the result of simulated yield when examined in relation to minimum temperature indicated decrease in yields with increase in temperature above that corresponding to potential conditions. But, the magnitude of change from base yields in terms of percentage was almost similar to that corresponding to the preceding level in all the increased level of maximum temperature (Fig.3). Every 1^0C decrease in the minimum temperature increased the grain yield of wheat was 5.6, 12.1, 19.4, 23.9 and 26.8 respectively while increase in temperature from 1^0C to5^0C wheat yield decrease from -11.0 to 37.9 percent. It was also noticed that the effect of incremental units in minimum temperature adversely affected the grain yield by more extent while, decreased minimum temperature by same unit the lesser quantity of increased grain yield was noticed. Such behaviour shown by the crops might be due to dual effects of higher rate of respiration during night time resulted in to comparatively higher loss of photosynthates than that was ^{0}C occurred during day time due to increased maximum temperature and differential reduction in crop duration of different cultivars of wheat.

Effect of elevated carbon dioxide global warming and the greenhouse effect, the present buzz words among the scientific community invoked interest to the behavior of the model to elevated level of CO_2. The effect of elevated carbon dioxide (380, 410, 440 and 470 ppm) on simulated grain yield of various cultivars of wheat under optimum condition in relation to base yield have been depicted in Fig. 4.4. Elevated levels of CO_2 by 380, 410, 440 and 470 ppm increased 16.9, 21.9, 26.9 and 32.8% yield in wheat (fig.4). Researchers indicated that increase in CO_2 levels would increase photosynthetic rates resulting in increased biomass and yield production of not only agricultural crops but also naturally grown plants.

Table 1: Simulation of wheat yield by WOFOST model at different irrigation levels

Sowing dates	I_1			I_2			I_3		
	Obs	**Sim**	**Error**	**Obs**	**Sim**	**Error**	**Obs**	**Sim**	**Error**
D_1Y_1	4655	4879	4.81	4120	4322	4.90	3566	3744	4.99
D_2Y_1	4322	4621	6.92	3611	3811	5.54	3311	3455	4.35
D_1Y_2	4432	4520	1.99	3824	4022	5.18	3451	3651	5.80
D_2Y_2	4231	4321	2.13	3574	3712	3.86	3122	3321	6.37

I_1: 4 Irrigation (CRI + Tillering+ Ear Head Formation + Milking)
I_2: 3 Irrigation (CRI+ Ear Head Formation + Milking)
I_3: 2 Irrigation (CRI+ Milking)

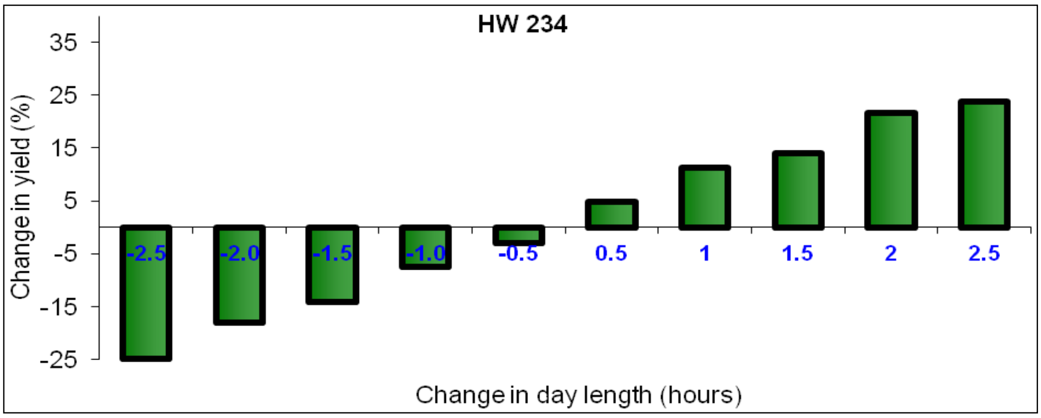

Fig 1: Effect of altered sunshine hours on grain yield of wheat cultivars as compared with base yield (kg/ha)

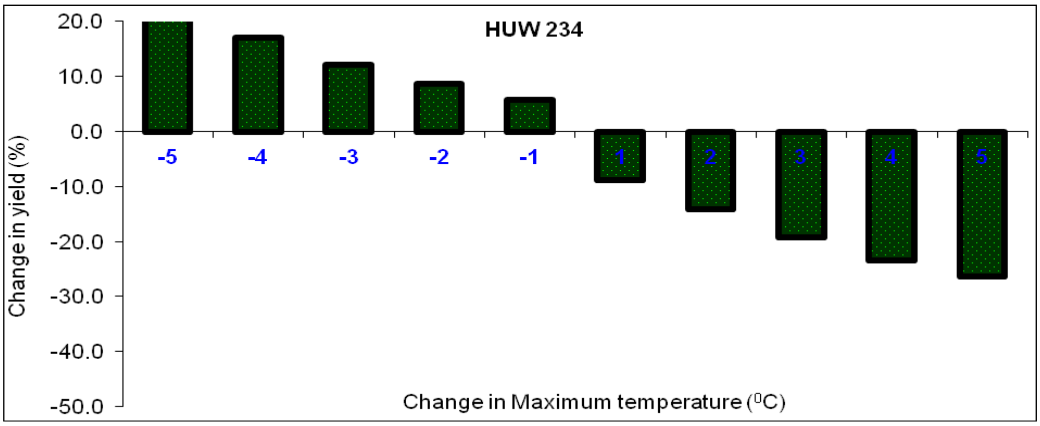

Fig 2: Effect of altered maximum temperature on grain yield of wheat cultivars as compared with base yield (kg/ha)

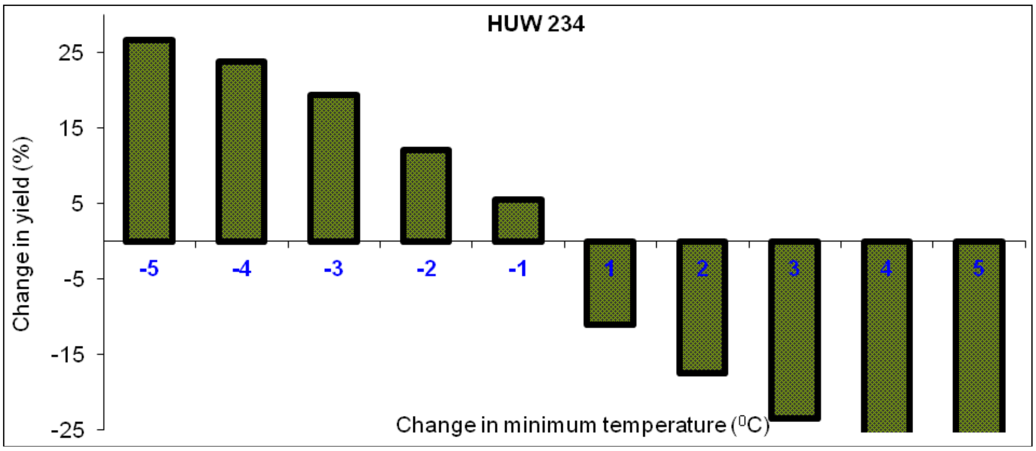

Fig 3: Effect of altered minimum temperature on grain yield of wheat cultivars as compared with base yield (kg/ha)

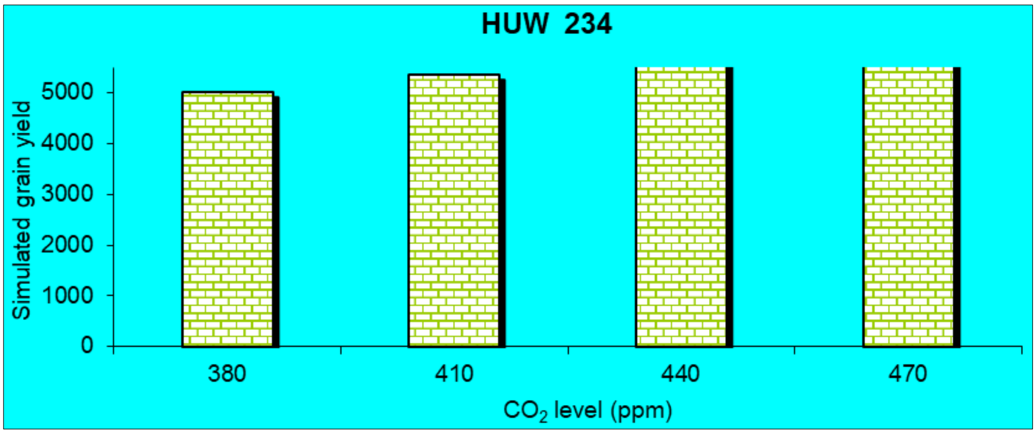

Fig 4: Effect of altered CO_2 levels on grain yield of wheat cultivars as compared with base yield (kg/ha)

Conclusion

It is concluded that study in Sensitivity of WOFOST model simulated grain yield to incremental units of maximum air temperature showed a gradual decrease in yield while, the down scaled maximum temperature increased the yield. The wheat yield increased due to decreased temperature ranged 5.7 to 25.4.

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