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MODELLING WHEAT YIELD RESPONSE TO WATER UNDER CHANGING CLIMATE

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ABSTRACT

A study was performance on three different seasonal yield response models for spring wheat with regard to their applicability and transferability under different environmental conditions. The models were validated with two years field data and those models were analysis with different statistical parameter. And best suitable model was used to predict of wheat yield form year 2019-20 to 2099-2100 (10 years interval) at two location Jabalpur and Powerkheda. Validation of models shows value of R^2 as 0.61, 0.81 and 0.50 of models like Stewart model, Generalised Rajput and Singh model and AquaCrop model respectively. Generalised Rajput and Singh model shows highest value of R^2 was 0.81, so it concluded that generalised Rajput and Singh model was best fit model and that model use in future wheat yield predication under changing climate. In future reduction rate of wheat yield at different evapotranspiration rate in 01 Dec date of sowing was 4.08% at Jabalpur and 12.82% at Powerkheda. With analysis study revealed that predicted wheat yield reduction rate was more in Powerkheda as compared to Jabalpur and 01 Dec date of sowing most suitable for wheat productivity for future years.

KEY WORDS
AquaCrop
crop yield
Generalished Rajput
Singh model

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INTRODUCTION

Climate change is one of the major challenges facing humanity in the future and effect of climate change has been detrimental to agricultural industry. Although the climate change in some areas of the world, particularly the areas located within the northern widths above 55º will have positive effects on agricultural production (Ewert *et al.*, 2005) but the negative impacts severe in hot and dry areas (Parry *et al*., 2004 and Gregory *et al*., 2005). In India at the end of century mean average temperature is likely to be increased by 3.3ºC and minimum and maximum temperature will be increases by 2.7ºC and 4.7ºC (Christensen *et al*., 2007). Water supply stress due to increased in temperature and vagaries rainfall results in reduced crop yield and reduced water availability could result in the wilting of the plant. In global study wheat production is estimated to fall by 6% for each ºC increase in temperature (Asseng, 2015) and in India 1ºC increase in temperature may reduce yield of wheat, soybean, mustard, groundnut and potato by 3-7% (Jamwal, 2014). Also rising temperature during the maturity period may significantly reduced wheat yield in India including Madhya Pradesh (Kumar *et al*., 2014, Rao *et al*., 2015).

Many researchers found that relation between seasonal evapotranspiration (ET) and yield of crop can be represented as linear function until maximum yield is obtained under optimal irrigation schedule (Stewart and Hagan, 1973; Doorendos and Kassam, 1979; Wenda and Hanks, 1981; Fapohunda *et al*., 1984; Vaux and Pruitt, 1983). Evapotranspiration under ideal crop growth condition varies with the time, space, local climatic condition and crop condition. In increasing temperature future warming leads to increase the evapotranspiration and its result shows that reduces the crop yield (Chattopadhyay *et al.,* 1997). The hypothesis that, functional relationship of crop yield to evapotranspiration, needed to evaluate yield-water response model that can predict the crop yield with reasonable degree of accuracy under changing climate. Considering all facts in the view, the present study on modeling wheat yield responses to water under changing climate has been undertaken.

MATERIALS AND METHODS

Model validated

Validation of three yield-water response model on the seasonal basis as:

Stewart model developed by Stewart *et al.* (1977) adopted by FAO (1997).

Generalized Rajput and Singh model developed by Rajput and Singh (1987).

AquaCrop model developed by Steduto and Raes (2009) adopted by FAO(2009).

Stewart Model

Stewart Model developed by Stewart *et al.,* in 1997. The model shows the relation between crop yield and evapotranspiration. The relationship between relative yield decrease and relative evapotranspiration deficit shows as

$$\left(1-\frac{Y_a}{Y_m}\right)=K_Y \times \left(1-\frac{ET_a}{ET_M}\right)$$

Where, Y_a = grain yield of a crop corresponding to any evapotranspiration (ET_a) level, Y_m = maximum crop yield, ET_a= crop evapotranspiration corresponding to Y_a, ET_m = maximum crop evapotranspiration corresponding to Y_m, K_y = crop sensitivity factor. Doorenbos and Kassam (1979) reported that crop sensitivity factor (K_y) as 1.15 for the spring wheat.

Generalized Rajput and Singh model: Rajput and Singh (1987) developed generalised Rajput and Singh model based on all India data for wheat, it expresses relative yield decreased in term of relative ET- deficit, at relative period during the maximum temperature below 27⁰C, relative vapour pressure deficit and finer soil fraction.The generalised model function given as,

$$\left(1-\frac{Y_a}{Y_m}\right)=13.07\left(1-\frac{ET^a}{ET_m}\right)^{0.89} X \left(1-\frac{e_a}{e_g}\right)^{0.84} X \left(1-\frac{T_{27}}{T_g}\right)^{0.20} X\,(CS)^{-0.41}$$

Where,

Y_a = grain yield of a crop corresponding to any evapotranspiration (ET_a) level, Y_m = maximum crop yield, ET_a= crop evapotranspiration corresponding to Y_a, ET_m = maximum crop evapotranspiration corresponding to Y_m, e_a = mean actual vapour pressure (Mbar), e_s = mean saturation vapour pressure (Mbar), T_{27} = total number of days with maximum temperature below 27⁰C, T_s= crop period (days), CS= percentage of clay plus silt in the root zone. The generalized function had been found to be statistically acceptable at one percent probability a can be used in predicting wheat yield in India under constrained water supply.

AquaCrop Model

Aqua Crop model developed by Steduto and Raes in 2009 and it is adopted by FAO (2012). The model is based on the crop growth engine which is basically water driven, in which the crop growth and production are driven by the amount of water used through consumptive use of the plant. AquaCrop (Steduto *et al.,* 2007; Raes *et al.,* 2009) evolves from the K_y approach by separating the actual evapotranspiration (ET) into soil evaporation (E) and crop transpiration (T_r) and final yield (Y) into biomass (B) and harvest index (HI). The changes describe leads to the following equation at the core of the AquaCrop growth engine,

$$B = WP \times T_r$$

Where, T_r is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced).

Model evaluation strategy

Model evaluation strategy was based on the comparison of the statistical characteristics of estimated data with that of the observed field data. These statistics are defined as,

$$\text{Coefficient of determination}(R^2): R^2 = \left(\frac{\sum (O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum (O_i-\bar{O})^2 X \sum (P_i-\bar{P})^2}}\right)^2$$

$$\text{Root mean squre error(RMSE)}: RMSE = \sqrt{\frac{\sum (P_i-\bar{O})^2}{n}}$$

$$\text{Normalized root mean square error}: NRMSE = \frac{\sum (P-\bar{O})^2}{n} X \frac{100}{\bar{O}}$$

$$\text{Willmott's index of agreement(d index)}: d = 1-\frac{\sum_{i=1}^{n} (Pi-Oi)^2}{\sum_{i=1}^{n} (|P_i-\bar{O}|+|O_i-\bar{O}|)^2}$$

$$\text{Coefficient of variation(CV)}: CV = \frac{RMSE}{\bar{O}}$$

Where, O_i is observes values of crop yield during the field experiment, P_i is the estimated values of yield by model, n is the number of observation.

Future Wheat Yield Prediction

The best suitable model was selected for projection of wheat yield at ten years intervals from 2019-20 to 2099-2100. Prediction were made for different sowing date viz. 01 Nov, 15 Nov, 01 Dec, 15 Dec and that crop season harvesting was decided on the basis of standardize method of growing degree day as follows,

$$GDD = \frac{(T_{max}-T_{min})}{2} - Tb$$

Where,

T_{max} =maximum daily temperature, T_{min} = minimum daily temperature and T_b = base temperature (Threshold temperature). Threshold temperature of 0⁰C was considered for wheat crop. (Baker *et al.*,1986; Cao and Moss, 1989; Karimi and Siddique,1991; Cook *et al.,* 1994; Klepper *et al.*,1998; Miller *et al.,* 2001; Wilkens 2001, Steduto and Raes, 2009; Yousef *et al.,* 2013).

Potential Wheat Yield Calculation: The possible production potential for a given climate is calculated for a standard crop by De-Wit (1965), using radiation and evapotranspiration data. The maximum attainable yield of crop adopted by FAO (1979, Drainage and irrigation paper no. 33) and express as,

$$Y_{me} = 1.17 x cH x cT x G x y_0 x \frac{ETm}{(e_g-e_a)}$$

Where, Y_{me}= maximum attainable yield of crop in kg ha^{-1} $period^{-1}$, cH= correction for harvested part of crop, cT = correction for temperature, G = total growing period in days, Y_o = gross dry matter production of standard crop in kg ha^{-1}

day^{-1}, e_s = mean saturation vapour pressure (Mbar) and e_a = mean actual vapour pressure (Mbar). For gross dry matter production of standard crop (Y_o) calculated based on the level of incoming active radiation (De-Wit , 1965).

Maximum Evapotranspiration: Evapotranspiration calculated the effect of climate on the different level of crops. FAO (1979, Drainage and Irrigation paper no. 33) gives the maximum evapotranspiration (ET_m) in mm day^{-1} of the period can be express by,

$$ET_m = K_c . ET_0$$

Where, ET_m = maximum evapotranspiration mm day^{-1}, Maximum evapotranspiration was great importance for the management of present and future water resources (Khedkar *et al.*, 2015), K_c = crop coefficients, ET_o = reference evapotranspiration mm day^{-1}. And Actual evapotranspiration are selected on five different ET levels that is seasonal maximum evapotranspiration on No ET deficit, 15% ET deficit, 30% ET deficit, 45% ET deficit and 60% ET deficit.

RESULTS AND DISCUSSION

Validation and Comparison of Model

The selected three models were run with help of two years validation data. The models give the estimated wheat yield, that estimated wheat yield was compared with the experimental observed wheat yield. The relation between estimated wheat yield and observed wheat yield are shows in Fig. 1 to 3. And Table 1. shows the comparative performance of all three models in year 1987-88, 1988-89 and with both years' pooled data (1987-88 and 1988-89).

From table 1, observed that when both years pooled data, Generalised Rajput and Singh model show the better result as compare to the other models. In pooled data Rajput and Singh mode show the R^2 as 0.81 that is closer to 1 as compare to other model, the similar result was observed Rajput (1982), Rajput and Singh (1987). Also other parameter shows the best result in year 1987-88 and 1988-89 and also both year pooled data, so that it conclude Rajput and Singh model is best suitable model for the future wheat yield predication.

Wheat crop season

The data collected for future prediction on basis of climatic parameter from the ear 2019-20 to 2099-2100 (IITM, Remo – 9, CORDEX data) wheat crop season was decided on the base of growing degree days (GDD). It was observed that number of days required to complete maturity of crop at both locations are gradually decreased 15-20 day from 2019-20 to 2099-2100. Also it decreased when the date of sowing are shifted 01 Nov to onwards. This is agreement with valizadeh et al. (2014), Jalota *et al.* (2013) with the reason that the increases in temperature rate accelerate growth stages of wheat.

Wheat yield Predication at different ET deficits

Wheat yield predicted for the future years at different ET-levels

Table 1: Comparative performance of different ET models

Statistical tools	Stewart Model			Generalised Rajput and Singh Model			AquaCrop model		
	1987-88	1988-89	Pooled data	1987-88	1988-89	Pooled data	1987-88	1988-89	Pooled data
R^2	0.64	0.75	0.60	0.75	0.86	0.81	0.84	0.55	0.50
RMSE (qha^{-1})	10.02	5.71	8.15	2.10	3.11	2.65	8.94	10.34	9.66
CV	0.25	0.14	0.20	0.05	0.07	0.06	0.22	0.25	0.23
d-agreement	0.49	0.89	0.74	0.88	0.95	0.97	0.58	0.70	0.89
NRMSE (%)	25	14	20	9.50	16.29	13.55	28.36	32.66	30.95

Table 2: Variation trend in ET and wheat Yield at Jabalpur and Powerkheda from 2019-20 to 2099-2100

Location	Parameters	Date of sowing			
		01 Nov	15 Nov	01 Dec	15 Dec
Jabalpur	Maximum ET (%)	-2.00	-2.15	-2.68	-2.91
	Maximum wheat yield (%)	-5.40	-8.50	-4.08	-4.89
Powerkheda	Maximum ET (%)	-11.6	-16.9	-14.3	-17.22
	Maximum wheat yield (%)	-13.62	-15.78	-12.82	-19.87

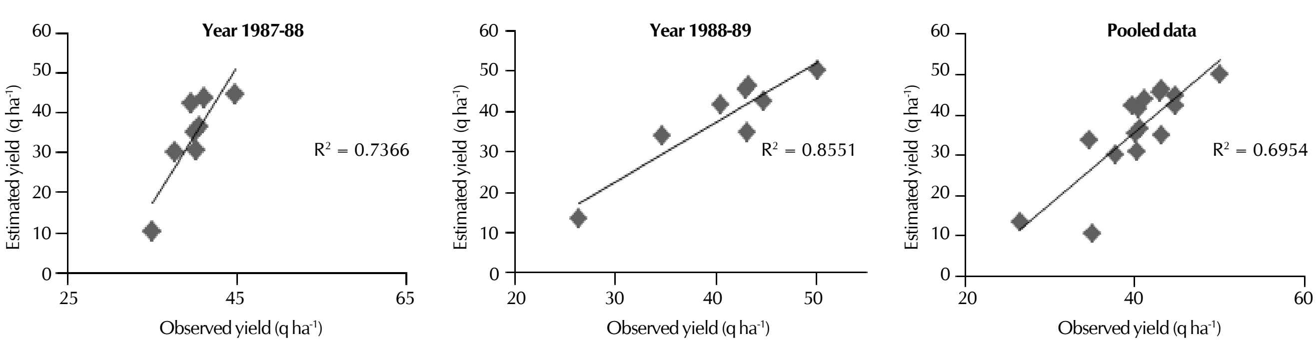

Figure 1: Relationship between observed yield and estimated yield by using Stewart model in year 1987-88, 1988-89 and pooled data at Jabalpur

Table 3: Predicted wheat yield under different level of ET- deficit for date of sowing on 01-Dec at Jabalpur in future years

Prediction years	Different level of ET deficit					
		No ET deficit	15% ET deficit	30% ET deficit	45% ET deficit	60% ET deficit
2019-20	ET (cm)	44.52	37.84	31.16	24.48	17.8
	Y (qha^{-1})	47.1	40.93	35.67	30.7	25.92
2029-30	ET (cm)	53.71	45.65	37.59	29.54	21.48
	Y (qha^{-1})	42.12	34.94	28.82	23.05	17.49
2039-40	ET (cm)	42.2	39.29	32.34	25.41	18.48
	Y (qha^{-1})	48.47	44.75	37.44	30.77	24.39
2049-50	ET (cm)	48.86	41.53	34.2	26.87	19.54
	Y (qha^{-1})	54.91	47.03	40.3	33.96	27.85
2059-60	ET (cm)	48.53	41.25	33.97	26.69	19.41
	ET (cm)	48.99	41.4	34.93	28.82	22.94
2069-70	Y (qha^{-1})	40.14	34.11	28.09	22.07	16.05
	ET (cm)	50.83	44.72	39.51	34.6	29.87
2079-80	Y (qha^{-1})	42.28	35.93	29.59	23.25	16.91
	ET (cm)	44.08	37.96	32.74	27.82	23.08
2089-90	Y (qha^{-1})	35.4	30.09	24.78	19.47	14.16
	ET (cm)	40	33.26	27.51	22.08	16.85
2099-2100	Y (qha^{-1})	42.97	36.52	30.07	23.63	17.18
	ET (cm)	43.59	37.04	31.46	26.2	21.12

Table 4: Predicted wheat yield under different level of ET- deficit for date of sowing on 01 Dec at Powerkheda in future years

Prediction years		Different level of ET deficit				
		No ET deficit	15% ET deficit	30% ET deficit	45% ET deficit	60% ET deficit
2019-20	ET (cm)	45.14	38.37	31.60	24.83	18.06
	Y (qha^{-1})	50.30	42.07	35.05	28.42	22.04
2029-30	ET (cm)	54.70	46.50	38.29	30.09	21.88
	Y (qha^{-1})	51.79	41.00	31.79	23.10	14.73
2039-40	ET (cm)	44.19	37.56	30.93	24.30	17.68
	Y (qha^{-1})	53.20	44.75	37.53	30.72	24.17
2049-50	ET (cm)	39.02	33.17	27.31	21.46	15.61
	ET (cm)	52.52	45.02	38.61	32.57	26.75
2059-60	Y (qha^{-1})	47.76	40.60	33.43	26.27	19.10
	ET (cm)	54.60	45.92	38.52	31.53	24.80
2069-70	Y (qha^{-1})	40.54	34.46	28.38	22.30	16.22
	ET (cm)	47.39	40.26	34.17	28.42	22.89
2079-80	Y (qha^{-1})	41.93	35.64	29.35	23.06	16.77
	ET (cm)	46.58	38.05	30.77	23.91	17.29
2089-90	Y (qha^{-1})	39.53	33.60	27.67	21.74	15.81
	ET (cm)	38.82	29.83	22.16	14.92	7.94
2099-2100	Y (qha^{-1})	38.40	32.64	26.88	21.12	15.36
	ET (cm)	36.54	29.31	23.14	17.32	11.71

by using generalised Rajput and Singh model (1987). Clay plus silt percentage in the root zone as 89% and 66.5% for Jabalpur and Powerkheda, respectively. Wheat yield predicted for the date of sowing on 01 Nov, 15 Nov, 01 Dec, 15 Dec for the different years from 2019-20 to 2099-2100 under different ET-deficit. In Generalized Rajput & Singh model use various input parameter which is the directly affected the wheat yield, like crop growing period, no. of day when temperature below 25ºC, Soil parameter and vapour pressure deficits. This model use prediction at date of sowing 01 Nov, 15 Nov, 01 Dec & 15 Dec. Result obtain at date of sowing 01 Nov at Jabalpur decrease in yield with respected to the future years from 2019-20 to 2099-2100 appears to be attributed to increased in seasonal mean temperature 4.5%, decreased in vapour pressure deficit 0.3 to 0.25, decreased in number of days for which maximum temperature exceeding 27ºC as 92 days to 42 days and decreased value of evapotranspiration 36.85 cm to 34.52 cm. This agreement with Jolota *et al.* (2013) reported that changed climate not only reduced the crop yield but also reduced the evapotranspiration. This result also agreement with Mandel and Roy (2012), they reported that the impact of climatic factor on the yield of pigeon pea and chick pea crop was highly sensitive to water logging which could result in loss of stand of crop and yield. Similar decreasing trend in projected yield are observed for different dates of sowing, because of variation input parameters for Jabalpur and Powerkheda.

However the relative magnitudes in reduction of projected yield levels are more for Powerkheda in comparison to Jabalpur at the end of century. Variation trend in ET and wheat Yield at Jabalpur and Powerkheda from 2019-20 to 2099-2100 shows in table 3.1. From the projections it is observed that under non constraint water supply wheat yield reduction in Jabalpur will be 5.40%, 8.50%, 4.08% and 4.89%; and in Powerkheda will be 13.62%, 15.78%, 12.82% and 19.87%

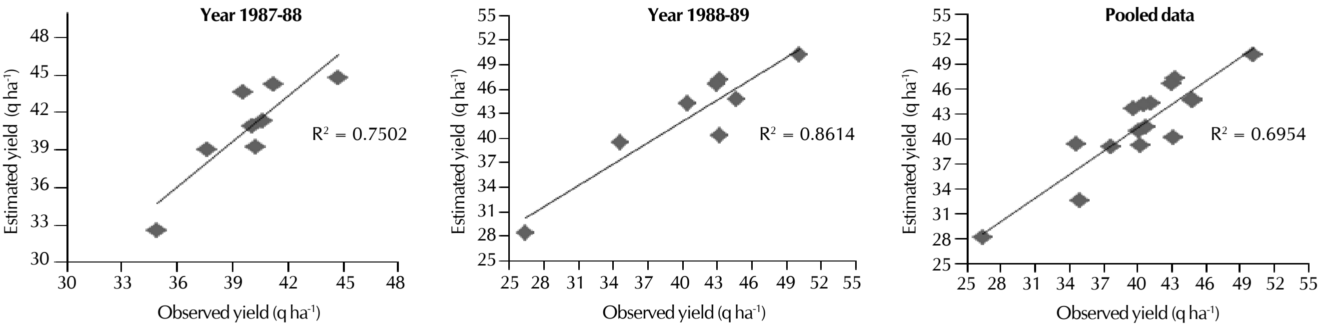

Figure 2: Relationship between observed yield and estimated yield by using generalised Rajput and Singh model in year 1987-88, 1988-89 and pooled data at Jabalpur

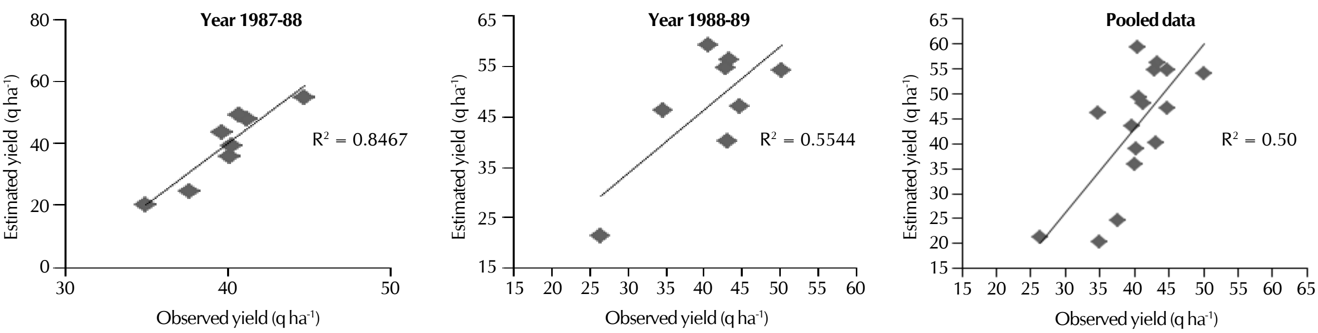

Figure 3: Relationship between observed yield and estimated yield by using wheat AquaCrop model in year 1987-88, 1988-89 and pooled data at Jabalpur

for respective dates of sowing. It can be seen that wheat yield reduction rate will be lower for date of sowing on 01 Dec as compared to other dates of sowing for the both location. Prediction of wheat yield under different level of ET- deficit for date of sowing on 01 Dec in future years shows in Table 3.2 and 3.3 for Jabalpur and Powerkheda and similar results also finding out in rest of date like 01 Nov, 15 Nov, 15 Dec.

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