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Impact of Change in Temperature on Yield and Water Requirement of Winter Maize using FAO-AquaCrop Model for North Bihar

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Abstract: The simulation analysis was made for three *winter* seasons 2016-17,2017-18 and 2018-19 and for five levels of maximum and minimum temperature increase and compared with the performance of *winter* maize crop with actual temperature level using the FAO-Aquacrop model. The five levels of maximum and minimum temperature increases were T_{max}+1°C, T_{max}+2°C, T_{max}+3°C,T_{max}+4°C, T_{max}+5°C and T_{min}+1°C, T_{min}+2°C, T_{min}+3°C,T_{min}+4°C, T_{min}+5 °C respectively. For *winter maize*, model prediction for the future temperature increases in maximum temperature for five levels T_{max}+1°C, T_{max}+2°C, T_{max}+3 °C,T_{max}+4°C, T_{max}+5 °C showed a positive response on simulated crop yield and biomass. The increase in yield and biomass of *winter* maize varied from 5.6 to 23.7 % for 2016-17, 4.3 to 19.6 % for 2017-18 and 6.4 to 27.3 % for 2018-19 for five levels of temperature increase T_{max}+1°C, T_{max}+2°C, T_{max}+3°C,T_{max}+4°C, T_{max}+5°C respectively. The average increase in simulated yield and biomass of *winter* maize was found to be 3.73 % for 2016-17, 3.06 % for 2017-18 and 4.19 % for 2018-19 for one degree (1°C) rise in maximum temperature. Model prediction for the future temperature increase in minimum temperature for five levels also showed a positive response on simulated crop yield and biomass. But the predicted yield and biomass increase are more pronounced in case of increase due to maximum temperature elevation. The average increase in simulated yield and biomass of *winter* maize was found 4.07 % for 2016-17, 3.37 % for 2017-18 and 4.47 % for 2018-19 for one degree (1°C) increase in minimum temperature. Crop water requirement increased with increasing level of maximum temperature for all three years. With the increase in temperature simulated yield also increased for winter maize alongside crop water requirement.

Keywords: Aquacrop model, Winter maize, Simulation model, Crop water requirement, IPCC

Water is an important resource for all life forms and will become a scarce natural resource in the future due to climate variability/change. Climate change has become very important for the farming sector in India. The persistent dry seasons and floods threaten the sustenance of billions of individuals who rely on land for their future requirements. Relationships between crop, climate, water and soil are complicated and many biological, physiological, physical and chemical processes are involved. These changes occur with average warming of just 1.1 degrees C (1.98 degrees F) above pre-industrial levels. The IPCC sixth assessment report reveals that the world is likely to reach or exceed 1.5 degrees Celsius (2.7 degrees Fahrenheit) of warming in just the next two decades (IPCC Sixth Assessment Report 2021). Global warming has been observed over the past decades and is consistently associated with changes in various components of the water cycle and hydrological systems, such as: Climate change Precipitation patterns, intensity and extremes; increased atmospheric water vapor; increased evaporation; and changes in soil moisture and runoff.

Maize (*Zea mays* L.) is a significant crop of the globe with the highest production and profitability when compared with rice and wheat, possessing an area of 193 m ha with a creation of 1147 m tonnes and mean productivity of 5.92 t ha^{-1} (FAOSTAT, 2018). Maize positions 3rd among grain crops in India after rice and wheat, with a region of 9.47 million hectares, with a production of 28.72 m tones (Directorate of Economics Statistics 2017-18). There are three distinct seasons for the cultivation of maize in India: *Kharif* , *Rabi* in Peninsular India and Bihar, and *Spring* in northern India. Bihar is a significant maize-producing state, accounting for approximately 6.6 % of total national maize production, with nearly 0.65 million hectares of maize planted each year. *Winte*r maize is grown on a land area of 0.46 million hectares, with a grain production of 1.86 million tonnes and a normal yield of 4.1 t/ha in 2020-21 (Ministry of Agriculture & Farmers Welfare, Govt. of India-ON2930). Winter maize in Bihar state has a larger region with a normal productivity of 4.1 t/ha and Autumn*/kharif* maize with a normal productivity of 2.85 t/ha. There is a big difference between potential and actual grain yield of *winter* maize in Bihar and growth and yield largely depends on climatic factors such as temperature, rainfall etc. that prevails during the crop growth period. FAO- Aquacrop model can be useful in evaluating the impact of climate change on crop yield and biomass for winter maize. Aquacrop models have been successfully used for simulating growth and yield parameters of various crops (Kumar and Chandra 2018, Chandra et al 2021, Chandra and Kumari 2021). The precipitation during *winter* is very deficient for the effective development of high-yielding maize hybrids. Actually, ideal accessibility of assured irrigation water is one among the central point deciding the accomplishment of the yield. Therefore, there is a need for proper management of existing water resources and the development of future water resources. Keeping the importance of climate change and its impact on crop growth and water requirement the present investigation was undertaken with the objective of study of impact of the increase in maximum and minimum temperature on crop growth, yield and crop water requirement of *winter* maize using FAO-AquaCrop model.

MATERIAL AND METHODS

The study on "Assessment of impact of climate change on water requirement and yield of winter maize using FAO-Aquacrop model for Pusa, Bihar." was conducted during *winter* season for the three years 2016-17, 2017-18 and 2018-19. The present investigation was conducted with a view to estimate the effect of rise in temperature on yield, biomass and crop water requirement of *winter* maize using FAO Aquacrop model. The present study was extended to simulate *winter* maize yield, biomass and crop water requirement using latest version FAO- Aquacrop model (version 6.1) under climate change scenario.

Study area: The study region is situated at *Pusa* block of Samastipur district of North Bihar (Fig. 1). The investigation area is encircled by southern and western bank of the waterway Burhi Gandak at 25°59'N latitude and 85°48'E longitude. The elevation above (MSL) is 52.92 m.

Climatic condition: The study area has the humid sub-tropical atmosphere, which is significantly affected by south-west rainstorm. The normal precipitation of the region is 1276 mm out of which almost 1026 mm is received during the storm between June to September. Winter showers infrequently happen in this district from December to the main portion of January. The blistering climate begins from early March and it lasts up to the end of May. The mean maximum average temperature May-June ranges between 37.5°C to 40.6°C and the mean minimum average temperature for the period varies from 17.0°C to 21.8°C.

Aquacrop model: AquaCrop is a crop growth model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

Different scenario for simulation: To assess future climate change impact analysis, the changed scenario of increasing maximum temperature by 1, 2, 3, 4 and 5^{0}C was studied. The daily maximum temperature was increased by 1, 2, 3, 4 and 5^{0}C and keeping the other parameters same the yield, biomass and water requirement was simulated. Similarly, the daily minimum temperature was increased by 1, 2, 3, 4 and 5^{0}C and keeping the other parameters same the yield, biomass and water requirement were simulated. Table 1 displays the different scenario of increased maximum temperature. The simulation model was run for three years 2016-17, 2017-18 and 2018-19.

Crop parameters adopted for the Study: The crop input component of AquaCrop contains both user-specific and conservative parameters, which can be categorized into crop parameters, phenology, development, and water stress groups).Crop data input for the FAO-Aquacrop model are

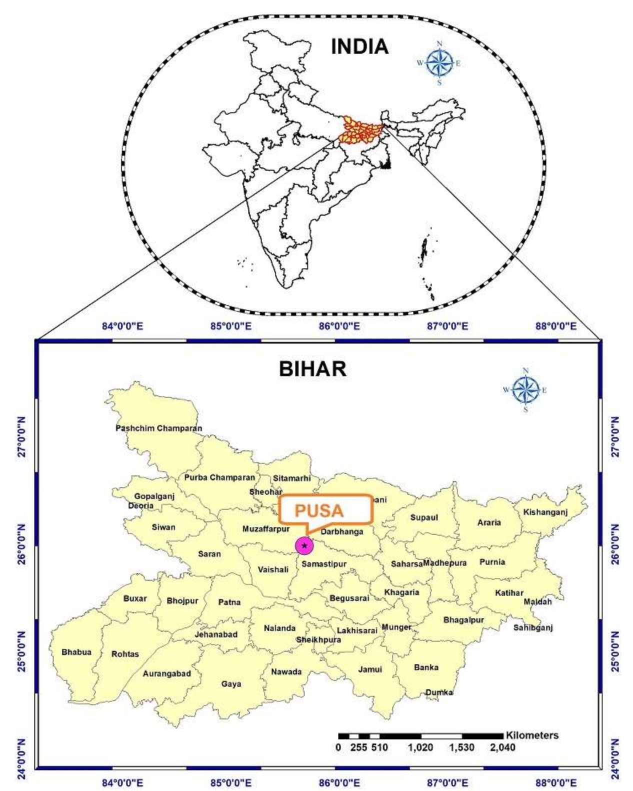

Fig. 1. Map of study area

plant density, emergence time, canopy senescence and maturity time, flowering period and yield formation duration, rooting depth, and reference HI, duration of crop, irrigation water management and agronomic practices. FAO-AquaCrop uses less crop parameters that describe the plant physiological and growth attributes. The crop parameters for winter maize were adopted from Kumar and Chandra 2018.

RESULTS AND DISCUSSION

Effect of increase in maximum temperature on simulated crop yield and biomass: The simulation analysis was made for three *winter* seasons 2016-17,2017-18 and 2018-19 and for five levels of maximum temperature increase and compared with the performance of *winter* maize crop with actual temperature level. The simulated crop yield and biomass increases as maximum temperature increases (Table 2). The simulated studies for *winter* maize revealed an increase in crop yield from baseline for all the three winter seasons. The increase in simulated yield and biomass for winter season 2016-17, 2017-18 and 2018-19 ranged from 5.6 to 23.7, 4.3 to19.6 and 6.4 to 27.3 %, respectively (Table 2). The increase in simulated yield and biomass was most prominent for the year 2018-19. The increase in maximum temperature is actually helping the *winter* maize to perform

Table 1. Different Scenario with increased maximum and minimum temperature for winter maize

2016-17	2017-18	2018-19
Tmax. +0°/Tmin. + 0°	Tmax. +0°/Tmin. + 0°	Tmax. +0°/Tmin. + 0°
Tmax. +1°/Tmin. + 1°	Tmax. +1°/Tmin. + 1°	Tmax. +1°/Tmin. + 1°
Tmax. +2°/Tmin. + 2°	Tmax. +2°/Tmin. + 2°	Tmax. +2°/Tmin. + 2°
Tmax. +3°/Tmin. + 3°	Tmax. +3°/Tmin. + 3°	Tmax. +3°/Tmin. + 3°
Tmax. +4°/Tmin. + 4°	Tmax. +4°/Tmin. + 4°	Tmax. +4°/Tmin. + 4°
Tmax. +5°/Tmin. + 5°	Tmax. +5°/Tmin. + 5°	Tmax. +5°/Tmin. + 5°

Table 2. Effect of change in maximum temperature on simulated crop yield and biomass of winter maize during crop growing season

Weather parameter (Maximum temperature)	Crop yield (t ha^{-1})	% increment	Biomass (t ha^{-1})	% increment
2016-17				
$T_{max.}$ +0°C	10.52	-	21.91	-
T_{max}+1°C	11.11	5.60	23.14	5.61
T_{max}+2°C	11.66	10.83	24.30	10.90
T_{max}+3°C	12.17	15.68	25.35	15.70
T_{max}+4°C	12.62	19.96	26.30	20.03
T_{max}+5°C	13.01	23.66	27.10	23.68
2017-18				
$T_{max.}$ +0°C	10.07	-	22.09	-
T_{max}+1°C	10.51	4.36	23.04	4.30
T_{max}+2°C	10.93	8.54	23.96	8.46
T_{max}+3°C	11.32	12.41	24.83	12.40
T_{max}+4°C	11.70	16.18	25.65	16.11
T_{max}+5°C	12.05	19.66	26.42	19.60
2018-19				
$T_{max.}$ +0°C	10.64	-	22.16	-
T_{max}+1°C	11.32	6.39	23.59	6.45
T_{max}+2°C	11.97	12.50	24.94	12.54
T_{max}+3°C	12.57	18.13	26.20	18.23
T_{max}+4°C	13.10	23.12	27.29	23.14
T_{max}+5°C	13.55	27.34	28.23	27.39

better. If the comparison is made between three distinct *winter* seasons of different years it is evident from the analysis that increases in simulated yield and biomass is lesser for the year 2017-18 compared to 2016-17 and 2018-19. The actual mean maximum temperature for the f January in the winter season 2017-18 was 26.8^{0}C compared to 22.4^{0}C and 22.8^{0}C for winter season 2016-17 and 2018-19 respectively. The threshold temperature set for winter maize was 30^{0}C and with an increase in temperature up to 5^{0}C particularly for the year 2017-18. The simulated yield gain was lower compared to 2016-17 and 2017-18. In climate change scenario rise in maximum temperature might prove beneficial for winter maize during three growing seasons of 2016-17, 2017-18 and 2018-19. The similar results have been reported by Chabra and Haris (2014). In winter maize season, model prediction for the future temperature increase shows a positive response with increase in maximum temperature by 1,2,3,4 and 5^{0}C. However positive response becomes less sensitive with increase in maximum temperature 4-5^{0}C. The high-quality yield response is probably because of growth in thermal time as temperature decided plant growth. The higher temperature has simulated the photosynthetic procedure resulting in higher simulated yield. The study area experiences low maximum temperature during winter season and rise in maximum temperature might be proving beneficial to the crop. The increase in yield is attributed to positive effect of comparatively high minimum temperature for winter maize crop. This may be because of decline in damaging impact of low temperature on crop during development stages.

Effect of increase in minimum temperature on simulated crop yield and biomass: The percentage increase in simulated crop yield and biomass for five levels of increase in minimum temperature i.e., $T_{min.}$+1^{0}C to T_{min}+5 ^{0}C were 5.8 to 26.1 % for 2016-17, 9.9 to 26.8 % for 2017-18 and 6.6 to 28.9 % for 2018-19.In winter season, the model prediction for the increasing level of minimum temperature shows a positive response. The percentage increase in crop yield was higher for 2018-19 compared to 2016-17 and 2017-18. The average minimum temperature during January, February and March for the year 2018-19 was lower compared to the other two seasons which might may be due to higher

Table 3. Effect of change in minimum temperature on simulated crop yield and biomass of winter maize during crop growing season

Weather parameter (Minimum temperature)	Winter maize			
	Crop yield (t ha^{-1})	Increment (%)	Biomass (t ha^{-1})	Increment (%)
2016-17				
$T_{min.}$+0^{0}C	10.52	-	21.91	-
T_{min}+1^{0}C	11.13	5.79	23.18	5.79
T_{min}+2^{0}C	11.71	11.31	24.40	11.36
T_{min}+3^{0}C	12.27	16.63	25.56	16.65
T_{min}+4^{0}C	12.79	21.65	26.65	21.65
T_{min}+5^{0}C	13.27	26.14	27.65	26.19
2017-18				
$T_{min.}$+0^{0}C	10.07	-	22.09	-
T_{min}+1^{0}C	11.07	9.93	23.07	4.43
T_{min}+2^{0}C	11.52	14.39	24.00	8.64
T_{min}+3^{0}C	11.96	18.76	24.91	12.76
T_{min}+4^{0}C	12.37	22.84	25.77	16.65
Tmin+5^{0}C	12.77	26.81	26.60	20.41
2018-19				
$T_{min.}$+0^{0}C	10.64	-	22.16	-
T_{min}+1^{0}C	11.34	6.57	23.63	6.63
T_{min}+2^{0}C	12.01	12.87	25.02	12.90
T_{min}+3^{0}C	12.64	18.79	26.34	18.86
T_{min}+4^{0}C	13.21	24.15	27.53	24.23
Tmin+5^{0}C	13.72	28.94	28.59	29.01

percentage of increase for the year 2018-19 compared to other two seasons. The positive yield reaction may be because of an increment in thermal time just as an increment in temperature decided plant development. The higher temperature might have invigorated photosynthetic cycles and harvest improvement and brought about higher recreated yield. The minimum temperature increase has responded more positively than the maximum temperature increases of winter maize. The better temperature regime has simulated photosynthetic procedure which brought about higher simulated yield.

Response of increase in maximum temperature on crop water requirement: The crop water requirement increase as maximum temperature increases (Table 4). The analysis of the data revealed that crop water requirement is increasing with increasing level of maximum temperature for all three years and with increase in temperature simulated yield also increased for winter maize but crop water requirement also increased. The percentage increase in crop water requirement for five levels of increase in maximum temperature i.e., T_{max}+1^{0}C to T_{max}+5 ^{0}C varied from 2.0 to 10.9 % for 2016-17, Similarly 2017-18 and 2018-19 varied from 1.9 to 10.4 % and 2.2 to 10.6 % respectively. Parekh and Prajapati (2018) and Chowdary and Abbas (2016) also observed similar trend.

Table 4. Effect of change in maximum temperature on crop water requirement of winter maize during crop growing seasons

Weather parameter (Maximum temperature)	Crop water requirement (mm)	increase (%)
2016-17		
$T_{max.}$ +0^{0}C	334.10	-
T_{max}+1^{0}C	340.80	2.00
T_{max}+2^{0}C	347.90	4.13
T_{max}+3^{0}C	355.40	6.37
T_{max}+4^{0}C	359.90	7.72
T_{max}+5^{0}C	370.50	10.89
2017-18		
$T_{max.}$ +0^{0}C	327.30	-
T_{max}+1^{0}C	333.80	1.98
T_{max}+2^{0}C	339.90	3.84
T_{max}+3^{0}C	348.00	6.32
T_{max}+4^{0}C	354.50	8.31
T_{max} +5^{0}C	361.50	10.44
2018-19		
$T_{max.}$ +0^{0}C	338.90	-
T_{max}+1^{0}C	346.10	2.21
T_{max}+2^{0}C	352.80	4.10
T_{max}+3^{0}C	360.00	6.22
T_{max}+4^{0}C	367.60	8.47
T_{max} +5^{0}C	375.00	10.65

CONCLUSIONS

The FAO-Aqucrop model was used to predict the response of increase in maximum and minimum temperature on yield, biomass and crop water requirement of *rabi* maize crop for *Pusa* region for three seasons. The effect of change of maximum and minimum temperature up to + 5^{0}C on simulated crop yield and biomass of *rabi* maize was analyzed. For *rabi* maize, model prediction for the future temperature increases in maximum temperature for five levels T_{max}+1^{0}C, T_{max}+2 ^{0}C, T_{max}+3 ^{0}C,T_{max}+4^{0}C, T_{max}+5 ^{0}C showed a positive response on simulated crop yield and biomass. However positive response is more sensitive for T_{max}+1^{0}C, T_{max}+2 ^{0}C, T_{max}+3^{0}C and becomes less sensitive with increase in maximum temperature by 4-5 ^{0}C (T_{max}+4^{0}C, T_{max}+5^{0}C).Model prediction for the future temperature increase in minimum temperature for five levels $T_{min.}$+1^{0}C, T_{min}+2^{0}C, T_{min}+3^{0}C,T_{min}+4^{0}C, T_{min}+5 ^{0}C also showed a positive response on simulated crop yield and biomass. But the predicted yield and biomass increase are more pronounced than the increase due to maximum temperature elevation. Crop water requirement increased with increasing level of maximum temperature for all three years. With increase in temperature, simulated yield and crop water requirement, both, increased for winter maize. The FAO-Aqucrop model can be used effectively to estimate the agricultural crop water requirement, crop yield and irrigation scheduling for different crops for North Bihar conditions under changing climatic scenario.

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