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Simulation of climate change impact on water productivity of maize in central Punjab

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सार – 2016 और 2017 के दौरान खरीफ अनुसंधान फार्म, जलवायु परिवर्तन और कृषि मौसम विज्ञान विभाग, पंजाब कृषि विश्वविद्यालय, लुधियाना में फील्ड प्रयोग किए गए। मक्का की किस्म पीएमएच -1 को पंक्तियों में 60 सेमी की दूरी पर और पौधे के बीच 20 सेमी की दूरी पर तीन तिथियों को बोया गया। अर्थात D_1- मई का तीसरा सप्ताह, D_2- जून का दूसरा सप्ताह और D_3- जुलाई का पहला सप्ताह दो सिंचाई स्तरों के तहत यानी सिंचाई का अनुपात IW:CPE1.00 (I_1) और 0.75 (I_2) और गीली घासपतवार तथा उप-भूखंडों,मुख्य भूखंडों और सिंचाई स्तरों में बुवाई की तारीखों और गीली घासपतवार के साथ स्प्लिट प्लॉट डिजाइन (एसपीडी) में 5 टन प्रति हेक्टेयर (M_1) और बिना घासपतवार (M_2) में सूखे घासपतवार का उपयोग किया गया। विभिन्न उपक्रियाओं के तहत फसल द्वारा वास्तविक नमी की कमी को मृदा की नमी की कमी विधि द्वारा दर्ज किया गया।बुवाई की तारीखों में, D_1 (540.5 और 477.5 मिमी) के अंतर्गत नमी की निकासी सबसे अधिक देखी गई, जबकि दोनों मौसमों के दौरान सिंचाई और गीली घास के स्तर में, यह आईडब्ल्यू / सीपीई = 0.75 (461.2 और 376.9 मिमी) और गीली घासपतवार के उपयोग से 5 टन प्रतिहेक्टेयर (473.0 और 387.1 मिमी) के दर से हुई। ET_0 की गणना खुलापात्र वाष्पीकरण, प्रीस्टली-टेलर, एफएओ-56, पापदाकिस और क्रॉपवाट मॉडल द्वारा की गई थी। सभी चार विधियों में से, प्रीस्टले-टेलर विधि ने बुवाई की तीनों तिथियों में उच्च ET_0 दिया और यह 2016 के दौरान बुवाई की पहली तारीख को छोड़कर खुलापात्रवाष्पीकरण मानों के करीब था, जिसमें एफएओ-56 (602.4 मिमी) में ET_0 अधिक था। पापड़ाकिस विधि द्वारा परिकलित फसल गुणांक क्रॉपवाट विधि (1.2 और 1.0 मिमी) द्वारा की गई गणना की तुलना में तुलनात्मक रूप से अधिक (1.3 और 1.1 मिमी) थे और एफएओ-56 (1.0 और 1.1 मिमी) विधियों की तुलना में DSSAT मॉडल की प्रीस्टले-टेलर विधि (1.0 और 0.9 मिमी) में फसल गुणांक के अधिक मान दिए गए थे। मक्का में जल उपयोग क्षमता D_2(11.02 किग्रा/हेक्टेयर-मिमी, 12.97 किग्रा/हेक्टेयर-मिमी) में अधिक थी जबकि अनाज की उपज की दृष्टि से वर्ष 2016 और 2017 में हुई उपज क्रमश: D_3(10.72 किग्रा/हेक्टेयर-मिमी, 12.97 किग्रा/हेक्टेयर-मिमी) और D_1(9.69 किग्रा/हेक्टेयर-मिमी, 10.65 किग्रा/हेक्टेयर-मिमी) थी। दोनों वर्षों में घासपतवार और सिंचाई अभिक्रिया M_1 और I_2 स्तरों में अधिक था। सिमुलेशन परिणामों से पता चला है कि तापमान में वृद्धि से मक्का की उत्पादकता में जल की कमी आएगी, लेकिन इस कमी की भरपाई कार्बनडायऑक्साइड (CO_2) सांद्रता में वृद्धि से की जा सकती है।

ABSTRACT. Field experiments were conducted at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *kharif* 2016 and 2017. Maize variety PMH-1 was sown with a row spacing of 60 cm and plant spacing of 20 cm on three dates *viz*., D_1-Third week of May, D_2-Second week of June and D_3- First week of July under two irrigation levels *i.e.*, irrigation at IW: CPE of 1.00 (I_1) and 0.75 (I_2) and mulch *viz.* application of straw mulch @ 5 t ha^{-1} (M_1) and without mulch (M_2) in split plot design (SPD) with dates of sowing and mulch in main plots and irrigation levels in the sub-plots. Actual moisture depletion by the crop under different treatments was recorded by soil moisture depletion method. Among the dates of sowing, moisture extraction was observed to be highest under D_1 (540.5 and 477.5 mm), whereas among the irrigation and mulch levels, it was lower under IW/CPE = 0.75 (461.2 and 376.9 mm) and mulch application @ 5t/ha (473.0 and 387.1 mm) during both the seasons. The ET_0 was calculated by open-pan evaporation, Priestley-Taylor, FAO-56, Papadakis and CROPWAT models. Among all the four methods, the Priestley-Taylor method gave higher ET_0 in all three dates of sowing and it was close to open-pan evaporation values except in first date of sowing during 2016, in which ET_0 was higher in FAO-56 (602.4 mm).

The crop coefficients calculated by Papadakis method were comparatively higher (1.3 and 1.1 mm) as compared to that calculated by CROPWAT method (1.2 and 1.0 mm) and FAO-56 (1.0 and 1.1 mm) methods gave higher values of crop coefficients as compared to Priestley-Taylor method of DSSAT model (1.0 and 0.9 mm). The water use efficiency of maize was higher in D_2 (11.02 kg/ha-mm, 13.43 kg/ha-mm) w.r.t grain yield as compared to D_3 (10.72 kg/ha-mm, 12.97 kg/ha-mm) and D_1 (9.69 kg/ha-mm, 10.65 kg/ha-mm) w.r.t grain yield, during 2016 and 2017 respectively. Among mulch and irrigation treatment was higher in M_1 and I_2 levels in both the years. Simulation results showed that rise in temperature would result in decreased water productivity of maize, but this decrease could be compensated by increase in CO_2 concentration.

Key words – Evapotranspiration, CROPWAT, DSSAT, Water Productivity, Maize, Crop Coefficient.

1. Introduction

Maize (*Zea mays* L.) plant is the one of the best nature's efficient and amazing energy storing devices. Maize crop has adapted well to the divergent climatic conditions prevailing in the tropical to temperate regions. It is world's third major food crop after wheat and rice and is also called as "Queen of Cereals" due to its high productivity (FAO, 2013). Maize production and productivity are prone to quick and continuous changes in weather conditions due to global warming related environmental alterations. Prospective effects of climate change are difficult to assess, not only because of the uncertainty in the magnitude of changes in climatic variables, but also because of uncertainties in crop responses to weather, soil and management factors. Maize crop is highly sensitive to temperature and water stress. High temperature and low rainfall are found to adversely affect the maize yield. Being a C_4 plant, maize is capable of utilizing solar energy more efficiently and can withstand comparatively high temperature. Climate change refers to the increase in earth's surface temperature due to the release of gases such as CO_2, CH_4, CFC's, NO_2 and O_3 into the earth's atmosphere (IPCC, 2007). Climate change is likely to increase water scarcity and changes in pattern of precipitation due to increase in temperature in the coming decades.

The crop water requirement gives the quantity of water that is essential for compensation of the fraction of water lost through evapotranspiration from crop fields (Onyancha *et al*., 2017). Various models are used to estimate the crop water needs for a number of crops grown under irrigation such as FAO-CROPWAT, DSSAT (Decision Support System for Agrotecnology Transfer). In these, models computer programme is used to calculate the crop water requirements and the amount of water that is vital for an irrigation to take place, taking into account the charactertics of the soil data, crop data and data collected on the prevailing climate and that of crops grown in the study area (FAO water, 2015).

Crop modeling that provides a robust framework on interaction of crop and environments can be used to improve the prediction of maize growth and yield under water-limited conditions (Boote *et al*., 2001; Hammer *et al*., 2002). Increased water requirements for growing populations and environmental restoration, along with declining groundwater supplies, will result in reduced water supply for irrigated agriculture in areas of the world. However, the productivity of irrigated agriculture must be sustained and increased to meet increasing global food needs. Thus, irrigated agriculture must become more productive with reduced water supplies.

Crop evapotranspiration (ET_a) is an important parameter in hydrological, environmental and agricultural studies and plays a key role in designing and managing irrigation projects and water management under irrigated and rainfed agriculture. Evapotranspiration is a key process of water balance and also an important element of energy balance. Its precise estimation is not only of vital importance for the study of climate change and evalution of water resources, but also has much application value in crop water requirement management. Efficient irrigation water use depends on correct irrigation scheduling to meet, but not exceed, crop water requirements. A common way to predict crop water requirements for irrigation scheduling is the two-step method described in Food and Agriculture Organization of the United Nations Irrigation and Drainage Paper #56 (FAO-56) (Allen *et al*., 1998). This method relates the crop evapotranspiration, ET_c, to that of a reference crop, ET_0, with a crop coefficient, Kc. To cope with the aforementioned climatic conditions and the future projection, accurate estimation of crop water use may be a priority for water management and planning under conservative agriculture.

The state of Punjab is suffering from limiting water availability for agriculture as the water table is depleting at alarming rates in most parts of the state. So there is a need to increase water use efficiency of field crops which is possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration providing irrigation at critical growth stages. So, there is dire need to examine the climate variability impact on evapotranspiration and water productivity of maize. Keeping this in view, the present research investigation was carried out to estimate the crop water requirements.

2. Materials and method

2.1. *Experimental details*

The present investigation was carried out during *kharif* 2016 and 2017 at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. Maize variety PMH-1 was sown with a row spacing of 60 cm and plant spacing of 20 cm on three dates, *viz.*, D_1-Third week of May, D_2-Second week of June and D_3- First week of July under two irrigation levels, *i.e.*, irrigation at IW: CPE of 1.00 (I_1) and 0.75 (I_2) and mulch, *viz.*, application of straw mulch @ 5 t ha^{-1} (M_1) and without mulch (M_2) in split plot design (SPD) with dates of sowing and mulch in main plots and irrigation levels in the sub-plots.

2.2. *Meteorological data collection*

Meteorological data w.r.t. maximum temperature, minimum temperature, relative humidity, wind speed, sunshine hours for *kharif* 2016 and 2017 was collected from the Agrometeorological observatory located at the research farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, which was used to compute reference evapotranspiration.

2.3. *Computation of reference evapotranspiration (ET_0)*

ET_0 during both the crop seasons was estimated by using the following models:

2.3.1. *Papadakis model*

Papadakis model (1965) for computation of daily PET was used to compute ET_0 by using the following formula:

$$PET = \frac{0.5625(e_{max} - e_{min-2}) \times 10}{\text{No. of days in month}} \text{mm day}^{-1}$$

where,

e_{max} = SVP (mb) at daily maximum temperature

e_{min-2} = SVP (mb) at dew point temperature

0.5625 = Papadakis constant

Saturation vapour pressure can be calculated from temperature from the following formula:

$$e_s = 0.61078 \exp [17.269\ T /(T + 237.3)]$$

where,

T = Temperature (°C)

2.3.2. *Crop Simulation Models*

Crop simulation models, *viz.*, CROPWAT version 8.0 and DSSAT version 4.6 (Hoogenboom *et al.*, 2015) were used to compute ET_0 during both the maize growing seasons. CROPWAT model uses FAO-PM method for ET_0 computation, whereas DSSAT CERES-Maize model calculates by Priestley Taylor as well as FAO-PM models. The parameters required by CROPWAT Model to calculate ET_0 are minimum temperature, maximum temperature, mean relative humidity, wind speed in km/day and sunshine hours. The daily ET_0 values were then cumulated for the entire growing period of maize crop sown on three dates for both the years.

2.4. *Measurement of Soil Moisture retention and depletion*

The soil moisture retention in 120 cm soil profile was measured by gravimetric method from each treatment at fortnightly interval from sowing to harvesting as well as before and after each irrigation. The soil samples for different layers, *viz.*, 0-15, 15-30, 30-60, 60-90 and 90-120 cm were dried in oven at a temperature of 105 °C after recording their fresh weight. The percent moisture on dry weight basis was calculated by Standard Gravimetric Method as given below (Dastane, 1967).

$$\text{Soil moisture}(\%) = \frac{\text{Fresh weight of soil} - \text{Dry weight of soil}}{\text{Dry weight of soil}} \times 100$$

The depth of water was obtained as under:

$$P_v = \frac{P_w \times BD \times d}{100}$$

where,

P_V = Depth of water in cm

P_W = Percent moisture on weight basis

BD = Bulk density

d = Depth of soil in cm

Total water use during growth season of crop was obtained from summation of root zone soil water

TABLE 1

Computation of crop coefficient during growing period of maize under different dates of sowing, irrigation and mulch treatments during *kharif* 2016 and 2017

Treatments	Actual water Depletion (mm)		Open Pan Evaporation (mm)		Reference ET: Papadakis method (mm)		Reference ET: CROPWAT model (mm)		Reference ET: Priestley-Taylor (mm)		Reference ET: FAO-56 (mm)		Crop Coefficient: Papadakis method (mm)		Crop Coefficient: CROPWAT model (mm)		Crop Coefficient: Priestley-Taylor (mm)		Crop Coefficient: FAO-56 (mm)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
$D_1I_1M_1$	548.9	482.3	596.9	582.7	458.3	452.1	502.7	500.6	542.1	525.4	602.4	423	1.2	1.1	1.1	1.0	1.0	0.9	0.9	1.1
$D_1I_1M_2$	566.7	526.6	596.9	582.7	458.3	452.1	502.7	500.6	542.1	525.4	602.4	423	1.2	1.2	1.1	1.1	1.0	1.0	0.9	1.2
$D_1I_2M_1$	510.7	445.6	596.9	582.7	458.3	452.1	502.7	500.6	542.1	525.4	602.4	423	1.1	1.0	1.0	0.9	0.9	0.8	0.8	1.1
$D_1I_2M_2$	535.8	455.6	596.9	582.7	458.3	452.1	502.7	500.6	542.1	525.4	602.4	423	1.2	1.0	1.1	0.9	1.0	0.9	0.9	1.1
$D_2I_1M_1$	499.8	410.3	431.9	450.4	354.0	357.5	395.3	425.1	432.7	394.9	419.3	358.1	1.4	1.1	1.3	1.0	1.2	1.0	1.2	1.1
$D_2I_1M_2$	527.9	431.8	431.9	450.4	354.0	357.5	395.3	425.1	432.7	394.9	419.3	358.1	1.5	1.2	1.3	1.0	1.2	1.1	1.3	1.2
$D_2I_2M_1$	474.6	368.0	431.9	450.4	354.0	357.5	395.3	425.1	432.7	394.9	419.3	358.1	1.3	1.0	1.2	0.9	1.1	0.9	1.1	1.0
$D_2I_2M_2$	470.8	385.8	431.9	450.4	354.0	357.5	395.3	425.1	432.7	394.9	419.3	358.1	1.3	1.1	1.2	0.9	1.1	1.0	1.1	1.1
$D_3I_1M_1$	434.4	320.8	361.1	369.1	309.1	315.4	339.0	315.4	414.4	354.9	414.6	312.2	1.4	1.0	1.3	1.0	1.0	0.9	1.0	1.0
$D_3I_1M_2$	450.8	338.0	361.1	369.1	309.1	315.4	339.0	315.4	414.4	354.9	414.6	312.2	1.5	1.1	1.3	1.1	1.1	1.0	1.1	1.1
$D_3I_2M_1$	369.5	295.6	361.1	369.1	309.1	315.4	339.0	315.4	414.4	354.9	414.6	312.2	1.2	0.9	1.1	0.9	0.9	0.8	0.9	0.9
$D_3I_2M_2$	405.7	310.7	361.1	369.1	309.1	315.4	339.0	315.4	414.4	354.9	414.6	312.2	1.3	1.0	1.2	1.0	1.0	0.9	1.0	1.0

depletion estimated from soil moisture retention measured at successive time intervals. As more than 99% of the water used by the crop is expended in the process of evapotranspiration, the moisture depletion by the crop was taken equivalent to crop evapotranspiration (ET_c), which was used for the computation of crop coefficient.

2.5. *Computation of crop coefficient*

Crop coefficient was computed by using the following formula:

$$K_c = \frac{ET_c}{ET_o}$$

where,

ET_c = Crop evapotranspiration (mm/day)

ET_0 = Reference crop evapotranspiration (mm/day)

K_c = Crop coefficient

2.6. *Computation of Water Use Efficiency*

The water use efficiency (WUE) is the yield of marketable crop produced per unit of water used in evapotranspiration. It was calculated by using the following formula:

$$WUE = Y/ET_c$$

where,

WUE = Water use efficiency (kg/ha mm of water)

Y = the marketable yield (kg/ha)

ET_c = Crop evapotranspiration

2.7. *Sensitivity analysis*

Sensitivity analysis was conducted by increasing temperature by +1, +2 and +3°C as well as CO_2 by +200 ppm and +400 ppm to simulate the effect of climate change on water productivity of wheat by using DSSAT-CSM-Ceres-wheat.

TABLE 2

Water use efficiency of maize under different date of sowing, irrigation and mulch levels w.r.t. straw yield and grain yield during *kharif* 2016 and 2017

Treatments	Water use (mm)		Straw yield (kg/ha)		Grain yield (kg/ha)		Water use efficiency (kg/ha-mm)			
							Straw		Grain	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Dates of Sowing										
D_1 (Third week of May)	540.5	477.5	15250.0	10294	5239.7	5086.6	28.21	21.56	9.69	10.65
D_2 (Second week of June)	493.3	399.0	15440.0	12472	5435.1	5357.1	31.30	31.26	11.02	13.43
D_3 (First week of July)	415.1	316.3	13798.0	10586	4448.0	4103.7	33.24	33.47	10.72	12.97
Irrigation										
I_1 (IW/CPE=1.00)	504.8	418.3	14727.0	10326	5006.0	4705.0	29.17	24.69	9.92	11.25
I_2 (IW/CPE=0.75)	461.2	376.9	14798.0	11909	5075.0	4979.0	32.09	31.60	11.00	13.21
Mulch										
M_1 (with straw mulch @ 5t/ha)	473.0	387.1	15027.0	11156	5192.0	5071.0	31.77	28.82	10.98	13.10
M_2 (without mulch)	493.0	408.1	14499.0	10979	4889.0	4614.0	29.41	26.90	9.92	11.31

3. Results and discussion

3.1 *Moisture extraction by the crop*

Among the dates of sowing, moisture extraction was observed to be highest under D_1 (540.5 and 477.5 mm) followed by D_2 (493.3 and 399.0 mm) and was lowest in D_3 (415.1 and 316.3 mm) during *kharif* 2016 and 2017. Among the irrigation and mulch levels, it was lower under IW/CPE = 0.75 (461.2 and 376.9 mm) and mulch application @ 5t/ha (473.0 and 387.1 mm) during both the seasons. Mulch application leads to reduction in evaporation, stabilization of temperature and improvement in the moisture status of the soil (Kingra and Kaur, 2017). Dhaliwal *et al.* (2019) also observed higher moisture availability under mulch application.

3.2. *Computation of ET_0 by different methods*

During 2016, open pan recorded a cumulative ET_0 of 596.9 mm, 431.9 mm and 361.1 mm under the crop sown on third week of May, second week of June and first week of July, respectively, whereas for the corresponding values of ET_0 were 582.7 mm, 450.4 mm and 369.1 mm, respectively, indicating highest open pan evaporation in the crop sown in third week of May followed by that sown in second week of June and lowest for first week of July (Table 1). During 2016, Papadakis method computed a cumulative ET_0 of 458.3 mm, 354.0 mm and 309.1 mm under the crop sown on third week of May, second week of June and first week of July, respectively, which was observed to be 452.1 mm, 357.5 mm and 315.4 mm during 2017. During 2016, CROPWAT model computed cumulative ET_0 of 502.7 mm, 395.3 mm and 339.0 mm under the crop sown on third week of May, second week of June and first week of July, respectively, which was 500.6 mm, 425.1 mm and 363.9 mm during 2017. On an average, it computed higher ET_0 for the crop season of 2017. From the data, it can be concluded that CROPWAT model computed higher ET_0 than the Papdakis method.

During 2016, Priestley-Taylor method computed a cumulative ET_0 of 542.1 mm, 432.7 mm and 414.4 mm and FAO-56 computed a cumulative ET_0 of 602.4 mm, 419.3 mm and 414.6 mm under the crop sown on third week of May, second week of June and first week of July, respectively, whereas during 2017, these values were 525.4 mm, 394.9 mm and 354.9 mm for Priestley-Taylor method and 423.0 mm, 358.1 mm and 312.2 mm for FAO-56. FAO-56 method estimated higher amount of ET_0 as compared to Priestley-Taylor method in 2016, whereas it was higher for Priestley-Taylor model during 2017. In general all the methods computed highest ET_0 for earlier sown and lowest for later sown crop. On an average it was higher during 2016 as compared to 2017.

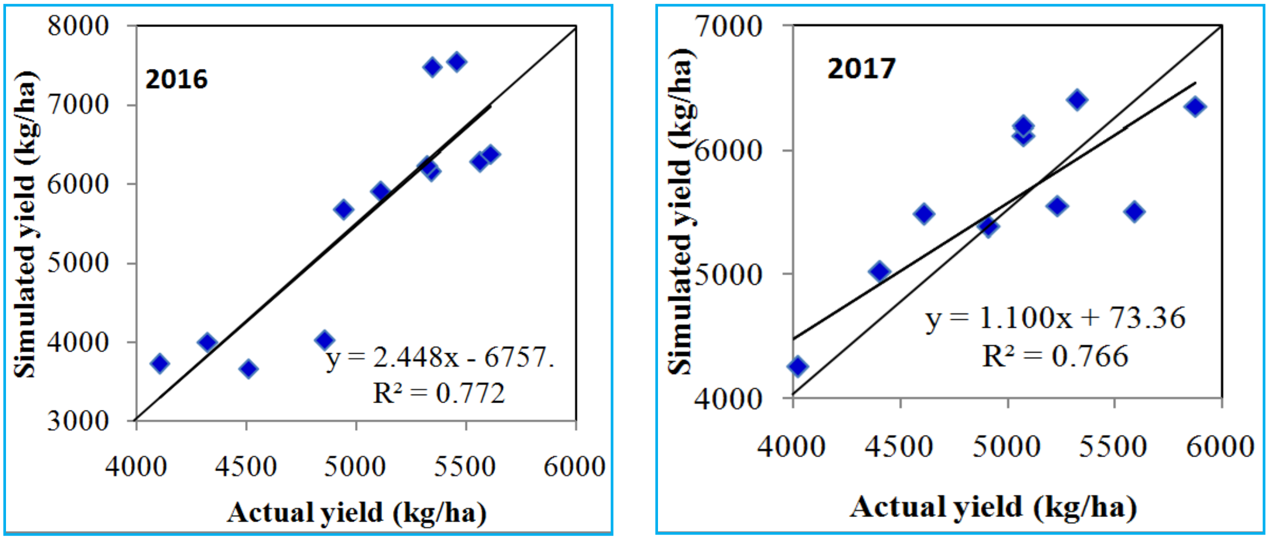

Fig. 1. Actual and simulated maize yield (kg/ha) during year 2016 and 2017

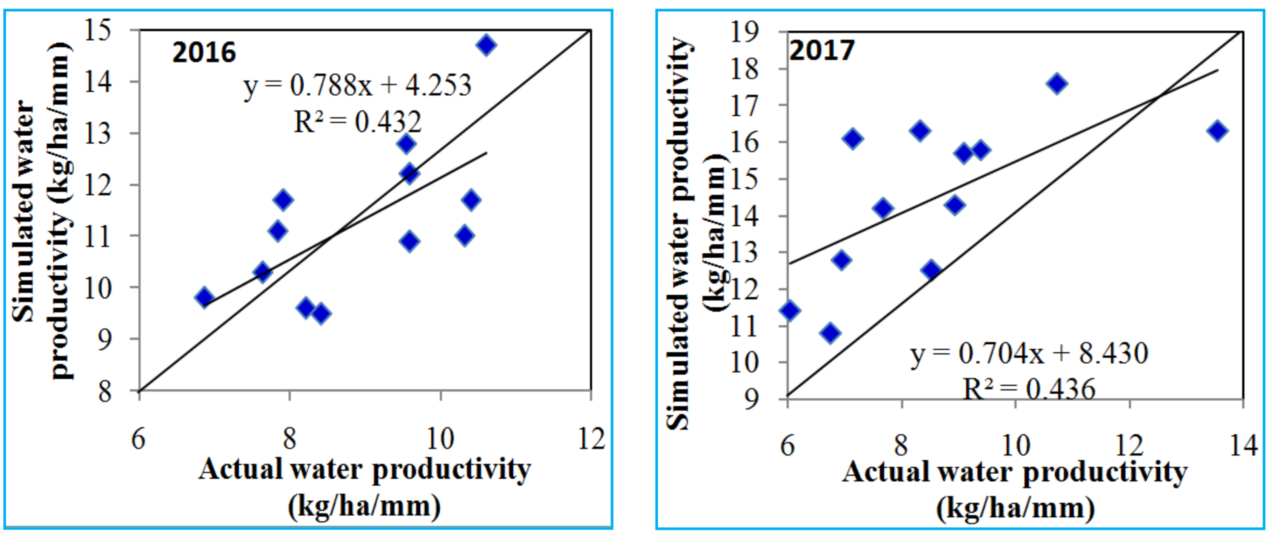

Fig. 2. Actual and simulated maize water productivity (kg/ha/mm) during year 2016 and 2017

During 2016, among all the methods the reference evapotranspiration was higher in FAO-56 (602.4 mm, 419.0 mm and 414.4 mm) and Priestley - Taylor (542.1 mm, 432.0 mm and 414.4 mm) as compared to other methods under all the dates of sowing. During 2017, the reference evapotranspiration was higher in open pan evaporation (582.4 mm, 450.4 mm and 369.1 mm) as compared to other methods. Among all the four methods, the Priestley-Taylor method gave higher ET_0 in all three dates of sowing and was closer to open-pan evaporation except in first date of sowing during 2016, in which ET_0 was higher in FAO-56 (602.4 mm).

3.3. *Estimation of crop coefficient*

The values of crop coefficients during 2016 ranged from 1.0 to 1.3 for CROPWAT model, 1.1 to 1.5 for Papadakis method, 0.9-1.2 for Priestley Taylor method of DSSAT model and 0.8-1.3 for FAO-56 method (Table 1). During 2017, the crop coefficient calculated by

TABLE 3

Simulation of effect of increase in mean temperature and CO_2 concentration on water productivity (kg/ha/mm) of maize

Treatment	Water productivity (kg/ha/mm)				
	Increase in temperature			Increase in CO_2	
	+1 °C	+2 °C	+3 °C	+200 pm	+400 ppm
Dates of Sowing					
D_1 (Third week of May)	-2.2	-3.1	-6.1	+10.1	+14.0
D_2 (Second week of June)	-0.7	-1.4	-4.2	+8.0	+9.4
D_3 (First week of July)	-1.6	-2.7	-5.4	+10.1	+12.4
Irrigation levels					
I_1 (IW/CPE=1.00)	-1.2	-2.0	-5.2	+9.2	+11.1
I_2 (IW/CPE=0.75)	-1.1	-2.3	-5.7	+11.1	+13.0
Mulch levels					
M_1 (With straw mulch @ 5t/ha)	-1.9	-3.3	-4.8	+11.6	+14.0
M_2 (Without mulch)	-2.8	-4.5	-6.9	+9.3	+11.7

CROPWAT model were almost similar to that by Papadakis method which ranged from 0.9 to 1.1 for CROPWAT model and 0.9 to 1.2 for Papadakis method. The values of Crop Coefficient by Priestley-Taylor method of DSSAT model was lower as compared to FAO-56 method which ranged from 0.8 to 1.1 for Priestley-Taylor method and 0.9 to 1.2 for FAO-56 method. Salam and Mazrooe (2007) reported that the crop coefficients (K_c) for maize at initial, development, mid and later stages were 0.30, 1.20, 1.20 and 0.50 respectively.

3.4. *Yield and water use efficiency*

In both the crop seasons, the crop sown in second week of June (D_2) exhibited higher grain yield (5435.1 and 5357.1 kg/ha) and water use efficiency w.r.t. to grain yield (11.02 and 13.43 kg/ha-mm) as compared to the delayed sowing dates, *i.e.*, third week of May (D_1) (9.69 and 10.65 kg/ha/mm) and first week of July (D_3) (10.72 and 12.97 kg/ha-mm). Among the irrigation levels, grain yield (5075.0 and 4979.0 kg/ha) and water use efficiency w.r.t grain yield was higher in I_2 (11.00 and 13.21 kg/ha-mm) as compared to I_1 for both the years (Table 2). Bharti *et al*. (2007) also observed that water use efficiency (WUE) decreased with increase in IW: CPE ratio and was maximum at IW : CPE 0.6. Palled *et al*. (1991) reported that water use efficiency decreased with irrigation applied beyond 0.7 IW:CPE ratio. Similar results were reported by Hussaini *et al*. (2002) and Viswanatha *et al*. (2002).

Among the mulch levels, higher grain yield (5192.0 and 5071.0 kg/ha) and WUE w. r. t grain yield was found in the mulch, *i.e.*, (M_1) (10.98 and 13.10 kg/ha-mm) level as compared to non-mulch in 2016 and 2017, respectively. Tolk *et al*. (1999) observed increase WUE by 14% with mulch application as compared with bare soil treatment in maize crop. Muhammad *et al*. (2003) also found more WUE (18.89 kg $ha^{-1}mm^{-1}$) in mulched soil than that from the non-mulched soil (17.38 kg $ha^{-1}mm^{-1}$). On an average, WUE was found to be higher in the crop season of 2016 as compared to that of 2017.

3.5. *Simulation of maize yield and water productivity*

Good agreement was observed between actual and simulated yield as R^2 was observed to be 0.77 for yield and 0.43 for water productivity for both the years (Figs. 1&2). Sensitivity analysis showed that when the temperature was increased by 1 °C, 2 °C and 3 °C water

TABLE 4

Simulation of effect of elevated mean temperature of +1°C at variable CO_2 concentration on water productivity (kg/ha/mm) of maize

Treatment	Water productivity (kg/ha/mm)					
	+200 ppm	+400 ppm	+200 ppm	+400 ppm	+200 ppm	+400 ppm
	+1 °C		+2 °C		+3 °C	
Dates of sowing						
D_1 (Third week of May)	+6.1	+11.8	+4.4	+8.3	+3.5	+7.5
D_2 (Second week of June)	+4.2	+7.3	+2.1	+4.9	+1.4	+2.1
D_3 (First week of July)	+5.0	+10.5	+2.7	+7.0	+1.9	+2.7
Irrigation levels						
I_1 (IW/CPE=1.00)	+5.3	+8.0	+3.8	+7.3	+1.5	+2.3
I_2 (IW/CPE=0.75)	+5.1	+7.5	+2.8	+5.9	+1.2	+2.0
Mulch levels						
M_1 (With straw mulch @ 5t/ha)	+6.6	+9.3	+4.7	+8.5	+2.3	+3.0
M_2 (Without mulch)	+5.1	+7.4	+6.6	+7.4	+3.9	+4.5

productivity decreased by -2.2, -3.1 and -6.1%, respectively, under D_1, by -0.7, -1.4 and -4.2% under D_2 and by -1.6, -2.7 and -5.4%, respectively, under D_3. Among the irrigation levels, water productivity decreased by -1.2, -2.0 and -5.2% with increase in temperature by 1under I_1 and by -1.1, -2.3 and -5.7%, respectively, in I_2 level of irrigation. Among mulch levels, when mean temperatures were increased by 1 °C, 2 °C and 3 °C there was decrease in water productivity by -1.9 percent, -3.3 percent and -4.8 percent in M_1 (mulch) and in M_2 (non-mulch) water productivity decreased was -2.8 percent, -4.5 percent and -6.9 percent, respectively (Table 3). These results indicated that water productivity is likely to decrease under warming scenarios, hence appropriate microclimatic modifications/management practices need to be adopted. Rey *et al*. (2011) also reported that in the future projections both the yield and water requirements will decrease and maize yield will be lower as it is very much sensitive to high temperatures, however, with the use of traditional varieties and adjusting the sowing dates the reduction in ET, water needs and yields may be reduced.

By increasing CO_2 concentration by 200 ppm and 400 ppm the water productivity increased by 10.1 and 14.0%, respectively in D_1, 8.0 and 9.4% in D_2 and 10.1 and 12.4% in D_3, respectively. Among the irrigation levels the water productivity increased by 9.2 and 11.1% in I_1 and 11.1 and 13.0% in I_2, Among the mulch treatments, the water productivity was increased by 11.6 and 14.0% in M_1 and 9.3 and 11.7% in M_2 (Table 3). Prior *et al*. (2010) reported that elevated CO_2 significantly increased WUE and concluded that soil moisture could be better conserved at elevated CO_2 during reproductive growth. This increase in WUE at elevated CO_2 is largely due to decrease in stomatal conductance and transpiration.

When the mean temperature was elevated by 1°C at different values of CO_2, *i.e*., +200 and +400 ppm the water productivity was increased by 6.1 and 11.8% in D_1, 4.2 and 7.3% D_2 and 5.0 and 10.5% in D_3. Among the irrigation levels the water productivity was increased by 5.3 and 8.0% in I_1 and 5.1 and 7.5% in I_2. Among the mulch treatments, the water productivity was increased by 6.6 and 9.3%in M_1 and by 5.1 and 7.4% in M_2 (Table 4). When the mean temperature was elevated by 2°C at different values of CO_2, *i.e*., 200 ppm and 400 ppm the water productivity was increased by 4.4 and 8.3% in D_1, 2.1 and 4.9% in D_2 and by 2.7 and 7.0% in D_3. Among the irrigation levels the water productivity increased by 3.8

and 7.3% in I_1 and by 2.8 and and 5.9% in I_2. Among the mulch treatments, the water productivity increased by 4.7 and 8.5% in M_1 and by 6.6 and 7.4% in M_2. When the mean temperature was elevated by 3 °C at different values of CO_2, *i.e*., 200 ppm and 400 ppm the water productivity was increased by 3.5 and 7.5% in D_1, 1.4 and 2.1% in D_2 and by 1.9 and 2.7% in D_3. Among the irrigation levels, the water productivity increased by 1.5 and 2.3% in I_1 and by 1.2 and 2.0% in I_2. Among the mulch treatments, the water productivity increased by 2.3 and 3.0% in M_1 and by 3.9 and 4.5% in M_2. Bunce (2000) also showed that higher ambient CO_2 reduced the transpiration rate through decreased stomatal conductance especially at higher temperature, resulting in improved water use efficiency and decreased probability of water stress. Trnka *et al*. (2004) also reported that increased CO_2 contributed to the intensified photosynthesis and improved water use efficiency.

4. Conclusions

The study concluded that warming scenarios in future can have severe effect of water productivity of maize, however increased concentration of CO_2 is likely to have positive effect. The study also highlighted that microclimatic modifications such as appropriate sowing date, mulch application and irrigation management etc. can act as important adaptation strategies.

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