Sensitivity of Crop Water Requirements to Elevated Temperatures in Arid Rajasthan

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Abstract: The impacts of elevated temperatures of 1 to 4°C on crop water requirements of major crops of arid Rajasthan have been studied. The seasonal crop water requirements were estimated by multiplying daily potential evapotranspiration (PET) with crop coefficients obtained from long-term lysimetric experiments conducted in the region. The daily PET was computed using modified Penman-Monteith equation with daily normal meteorological parameters. The spatial variation in daily PET in the region ranged from 2 mm in winter to 12 mm in summer and the annual PET varied between 1502 mm at Nagaur to 2221 mm at Jaisalmer. Water requirement of different crops in the region varied from 308 to 411 mm for pearl millet, 244 to 332 mm for clusterbean, 217 to 296 mm for green gram, 189 to 260 mm for moth bean, 173 to 288 mm for wheat and 209 to 343 mm for mustard. Further, a rise of 4°C in air temperature owing to global warming, increases ET requirement of arid zone crops over that of present level by 12-13% for kharif and 17-19% for rabi crops.

Key words: Evapotranspiration, elevated air temperatures, Indian arid region

Weather variability and climate change continue to influence fragile arid regions of India, which has a high human/livestock population and the people largely depend on climate sensitive sectors like agriculture and animal husbandry. Further, the adaptive capacity of desert dwellers of this region is low due to poor socio-economic conditions. The arid phase of north-west India has a history of about 3000 years (Pant and Maliekel, 1987). The studies conducted on secular changes in rainfall and air temperatures of Sri Ganganagar region showed favorable increase in rainfall and a reduction in air temperatures particularly during the past three decades (Rao, 1996). The studies on climate change over Jodhpur region showed that inspite of rainfall and air temperature being favorable, the increase in human population (by 400%) and livestock (by 127%) during 12th century had resulted in a major shift in land use pattern exerting tremendous pressure on land and groundwater resources leading to increased desertification in the region (Rao and Miyazaki, 1997).

The Inter-Governmental Panel on Climate Change (IPCC, 2001) has projected increase between 0.15 and 0.3°C per decade for 1990 to 2005 in global average temperature. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections (Iglesias, 2005). Continued greenhouse gas emissions at or above current rate would cause further warming by 21st century. The IPCC (2007) report projected globally averaged surface warming, the best estimate for the low emission scenario (B_1) is 1.8°C (likely range is 1.1°C to 2.9°C), and the best estimate for the high emission scenario (A_1F_1) is 4.0°C (likely range is 2.4°C to 6.4°C). The IPCC analysis on climate change impact estimates a general reduction of potential crop yields and a decrease in water availability for agriculture particularly sensitive to climatic hazards in Africa, South and Central America and Asia (Parry *et al.*, 1999 and 2004).

PRECIS (Providing Regional Climates for Impact Studies) model for India (Rupa Kumar *et al.*, 2006) predicted 10-15% increase in annual rainfall in the eastern fringe and by 20-40% in the south, but the north-west will experience up to 30% reduction in rainfall. The model also showed 3 to 5°C increase in annual mean surface temperature under A_2 scenario and 2.5 to 4°C under B_2 scenario, with warming being more pronounced in the northern parts of India by the end of century. Warming is more in winter (December-February) and post-monsoon (October-November) seasons compared to south-west monsoon (June-September) season (Rupa Kumar *et al.*, 2006). Though, the long term rainfall trend of arid Rajasthan showed an insignificant rise @ 0.56 mm year^{-1}, the monsoon rainfall declined at 37 out of 65 locations in the region (Rao and Purohit, 2009). The bio-physical resources of Indian arid region are already in a delicate balance with prevalent climate, pressure
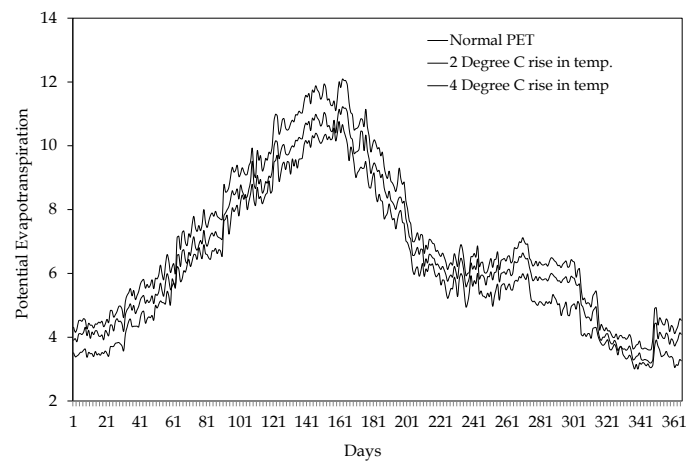
*E-mail: ashivrao@gmail.com

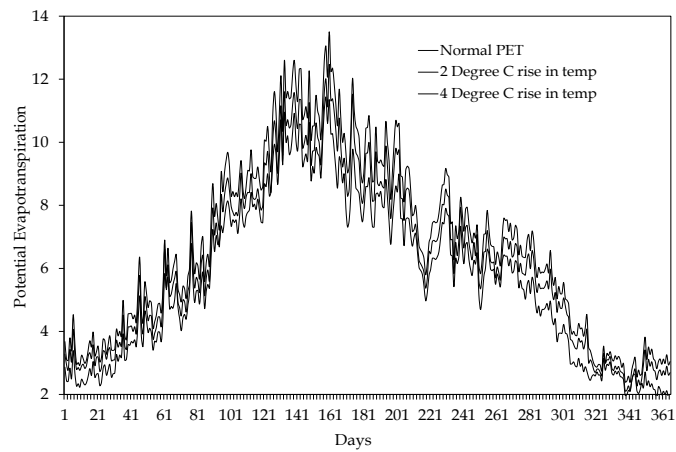*Fig. 1. Daily potential evapotranspiration at Jodhpur.*

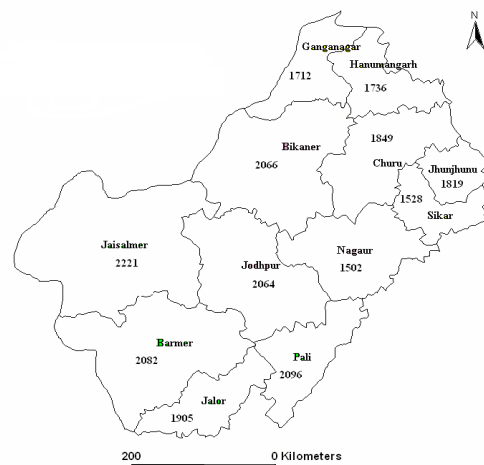*Fig. 2. Daily potential evapotranspiration at Jaisalmer.*

Fig. 3. Annual potential evapotranspiration (mm) of arid Rajasthan.

due to accelerated growth of human and livestock population and poor socio-economic conditions. In this paper, we are presenting an analysis of impact of projected elevated temperatures due to climate change on seasonal crop water requirement for crops of arid Rajasthan and identifying the hotspots in the region for focusing on adaptive and mitigation planning of the region.

Table 1. Daily potential evapotranspiration (mm) of arid Rajasthan during monsoon (JJAS)

District	Normal	PET at elevated air temperatures by				Increase in PET at 4°C (%)
		1°C	2°C	3°C	4°C	
Barmer	5.3-8.9	5.5-9.2	5.6-9.5	5.8-9.8	5.9-10.2	11-15
Bikaner	6.1-10.3	6.4-10.7	6.6-11.1	6.8-11.3	7.0-11.5	12-15
Churu	5.3-8.1	5.5-8.3	5.6-8.6	5.8-8.9	6.0-9.2	13-14
Sri Ganganagar	5.3-7.5	5.5-7.7	5.7-8.0	5.9-8.2	6.1-8.4	12-15
Hanumangarh	5.4-7.6	5.6-7.8	5.7-8.1	5.9-8.3	6.1-8.5	12-13
Jaisalmer	4.7-11.4	5.0-11.9	5.3-12.5	5.5-13.0	5.8-13.5	18-23
Jalore	4.8-8.5	5.0-8.8	5.1-9.1	5.2-9.4	5.4-9.7	13-14
Jhunjhunu	4.9-8.0	5.1-8.3	5.2-8.5	5.3-8.8	5.4-9.0	10-13
Jodhpur	5.0-10.8	5.3-11.0	5.5-11.2	5.7-11.6	5.8-12.1	12-16
Nagaur	3.8-7.8	3.9-8.0	4.1-8.2	4.2-8.5	4.4-8.7	12-16
Pali	4.6-10.1	4.7-10.5	4.8-10.9	5.1-11.3	5.2-11.7	13-16
Sikar	4.6-6.1	4.7-6.2	4.8-6.4	4.9-6.6	5.0-6.7	09-10

Table 2. Daily potential evapotranspiration (mm) of arid Rajasthan during winter (DJF)

District	Normal	PET at elevated air temperatures by				Increase in PET at 4°C (%)
		1°C	2°C	3°C	4°C	
Barmer	3.0-5.1	3.1-5.3	3.2-5.6	3.3-5.8	3.4-6.1	13-20
Bikaner	2.0-4.1	2.1-4.3	2.2-4.5	2.3-4.7	2.4-4.9	19-20
Churu	1.8-3.8	1.9-3.9	2.0-4.1	2.1-4.2	2.2-4.3	13-22
Sri Ganganagar	1.5-3.2	1.6-3.3	1.7-3.4	1.8-3.5	1.9-3.6	13-27
Hanumangarh	1.6-3.2	1.7-3.3	1.8-3.4	1.9-3.6	2.0-3.7	16-25
Jaisalmer	1.9-5.1	2.2-5.5	2.4-5.8	2.6-6.0	2.8-6.3	24-47
Jalore	2.5-4.8	2.6-5.0	2.8-5.2	2.9-5.4	3.0-5.6	17-20
Jhunjhunu	2.1-3.7	2.2-3.8	2.3-4.0	2.4-4.2	2.5-4.4	18-19
Jodhpur	3.0-5.4	3.1-5.7	3.3-6.0	3.4-6.3	3.5-6.6	17-22
Nagaur	1.0-3.6	1.1-3.8	1.3-4.0	1.4-4.3	1.5-4.5	25-50
Pali	3.0-5.5	3.1-5.8	3.2-6.1	3.3-6.4	3.4-6.7	13-22
Sikar	1.9-3.2	2.0-3.3	2.1-3.4	2.2-3.5	2.3-3.6	12-21

Materials and Methods

The daily potential evapotranspiration (PET) for 12 arid districts of Rajasthan were calculated by modified Penman-Monteith equation (Doorenbos and Pruit, 1977) using daily meteorological data (1971-2000) recorded in the respective district by India Meteorological Department (IMD, 2008). The reference evapotranspiration (ET_0) was estimated using the Penman-Monteith method (Allen *et al.*, 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + (1 + 0.34u_2)}$$

where, ET_0, is the reference evapotranspiration (mm day^{-1}); R_n, net radiation at the crop surface (MJ m^{-2} day^{-1}); G, soil heat flux density (MJ m^{-2} day^{-1}); T, mean daily air temperature (°C) at 2 m height; u_2, wind speed (m s^{-1}) at 2 m height; e_s, saturation vapour pressure (kPa); e_a, actual vapour pressure (kPa); e_s - e_a, saturation vapour pressure deficit (kPa); Δ, slope of the vapour pressure curve (kPa

Table 3. Seasonal crop water requirements (mm) for crops of arid Rajasthan

Districts	Pearl millet	Clusterbean	Green gram	Moth bean	Wheat	Mustard
Barmer	351	284	253	221	287	343
Bikaner	410	332	296	260	207	252
Churu	365	295	263	230	186	227
Sri Ganganagar	375	305	272	238	169	209
Hanumangarh	379	308	275	241	173	214
Jaisalmer	411	325	292	255	207	246
Jalore	315	258	229	200	248	293
Jhunjhunu	336	271	242	211	228	273
Jodhpur	372	289	258	225	288	340
Nagaur	384	296	267	235	230	244
Pali	308	244	217	189	252	318
Sikar	311	254	226	198	195	228
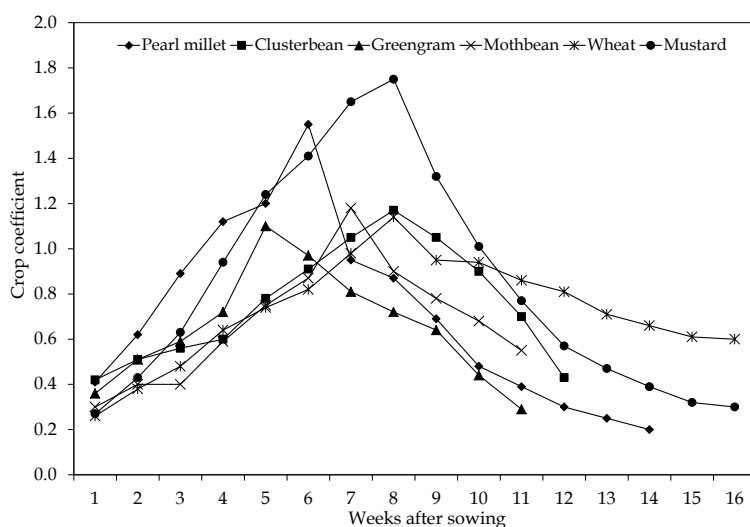
Fig. 4. Crop coefficients for principal crops of arid Rajasthan.

°C⁻¹); γ, psychrometric constant (kPa °C⁻¹). From daily potential evapotranspiration, the crop water requirement (CWR) at different stages of six crops was calculated by multiplying with crop coefficients available from previous lysimetric experiments for rainfed crops viz., pearl millet, clusterbean, green gram and moth bean and for irrigated winter crops viz., wheat and mustard (Bandyopadhyay and Mallik, 2003; Rao *et al.*, 2000; Rao and Singh, 2003 and 2007; Singh *et al.*, 2000; Singh and Rao, 2007).
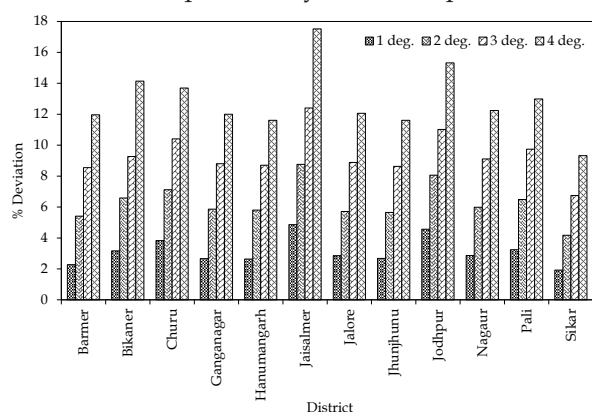
Fig. 5. Evapotranspiration requirement of pearl millet in arid Rajasthan.
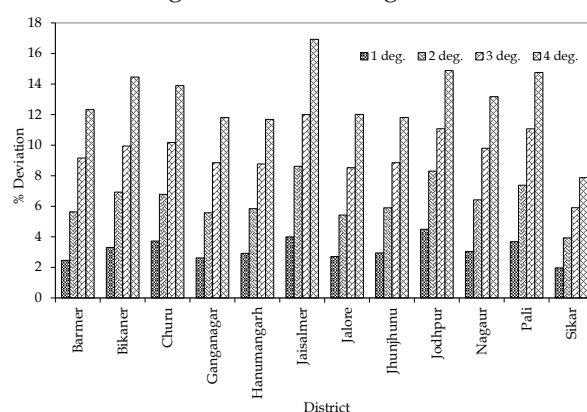

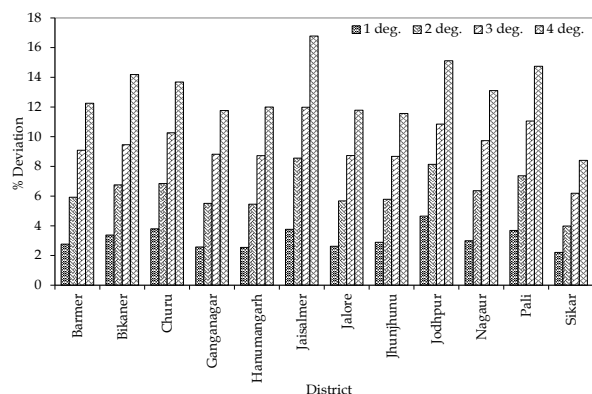Fig. 6. Evapotranspiration requirements of clusterbean in arid Rajasthan.

Fig. 7. Evapotranspiration requirements of green gram in arid Rajasthan.
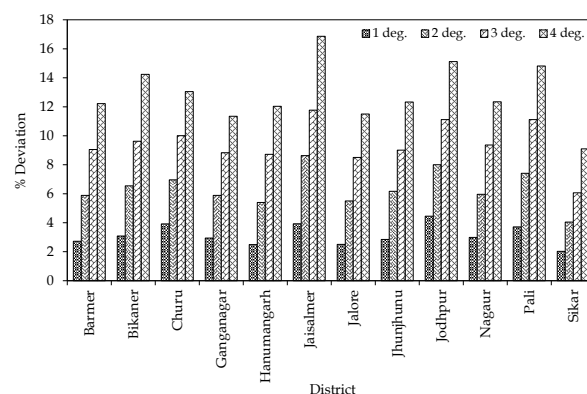

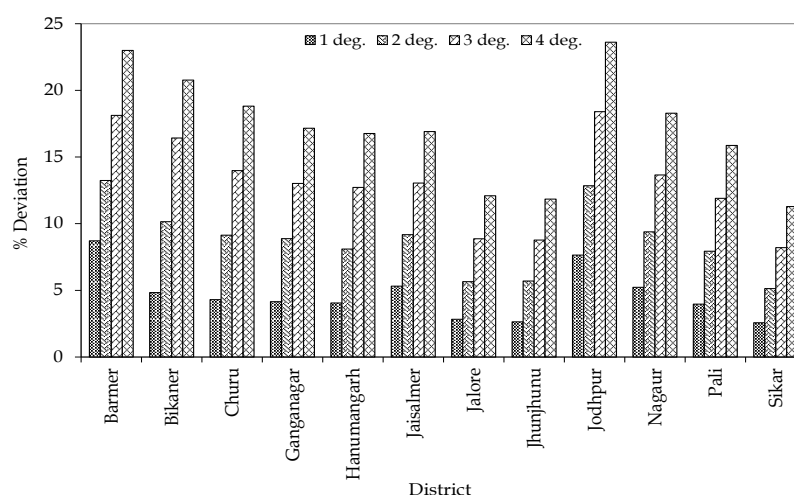Fig. 8. Evapotranspiration requirements of moth bean in arid Rajasthan.

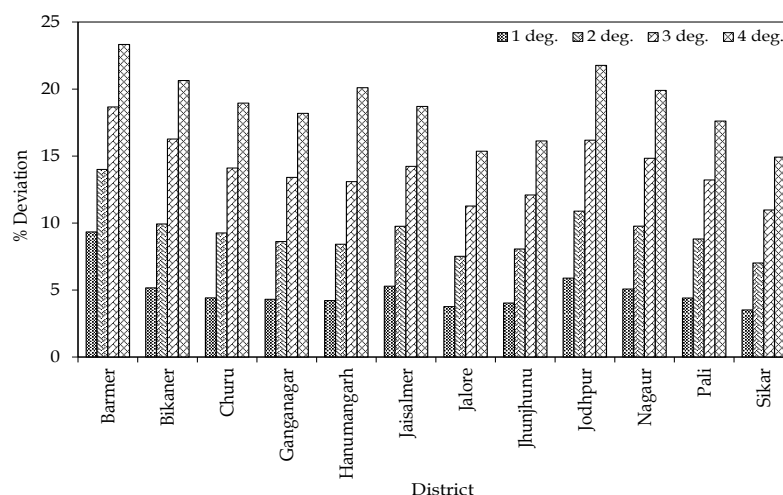*Fig. 9. Evapotranspiration requirements of wheat in arid Rajasthan.*

Fig. 10. Evapotranspiration requirements of mustard in arid Rajasthan.

The seasonal CWR was calculated by summation of daily CWR from emergence to harvest for each crop. The available climate change scenarios for arid Rajasthan due to global warming were taken from the PRECIS model generated at Hadley Centre, IPCC (2007) and Indian Institute of Tropical Meteorology, Pune (Rupa Kumar *et al.*, 2006). The sensitivity of seasonal CWR for each degree rise in temperature upto 4°C is studied using the Penman-Monteith equation adjusting with crop coefficients and resulting water scenario by 21st century and its likely impact on crop production in arid Rajasthan are also presented.

Results and Discussion

Sensitivity of daily and seasonal potential evapotranspiration to elevated temperatures

The sensitivity of daily PET, at normal and elevated air temperatures at Jaisalmer and Jodhpur are shown in Figs. 1 and 2. The normal daily PET at these locations varied from 1.9 to 11.4 mm at Jaisalmer and from 3.0 to 10.8 mm at Jodhpur. Low ET in arid Rajasthan is confined to winter season and during this period irrigated crops like mustard and wheat are grown, whereas the ET rates are at peak during May and June. The spatial variability in annual PET over arid Rajasthan (Fig. 3) shows that high PET prevails in the extreme western districts of Bikaner (2066 mm) and Jaisalmer (2221 mm) and low PET in northern districts of Sri Ganganagar (1712 mm) and Hanumangarh (1736 mm). The northern districts are fed with canal irrigation from Beas and Sutlej rivers and find lower impact due to raising crop water requirements. However, the western districts of Jaisalmer and Bikaner are often prone to drought on an average every alternate year thus causing frequent crop failures. PET isolines follow reverse trend to the rainfall isohytes in the arid Rajasthan.
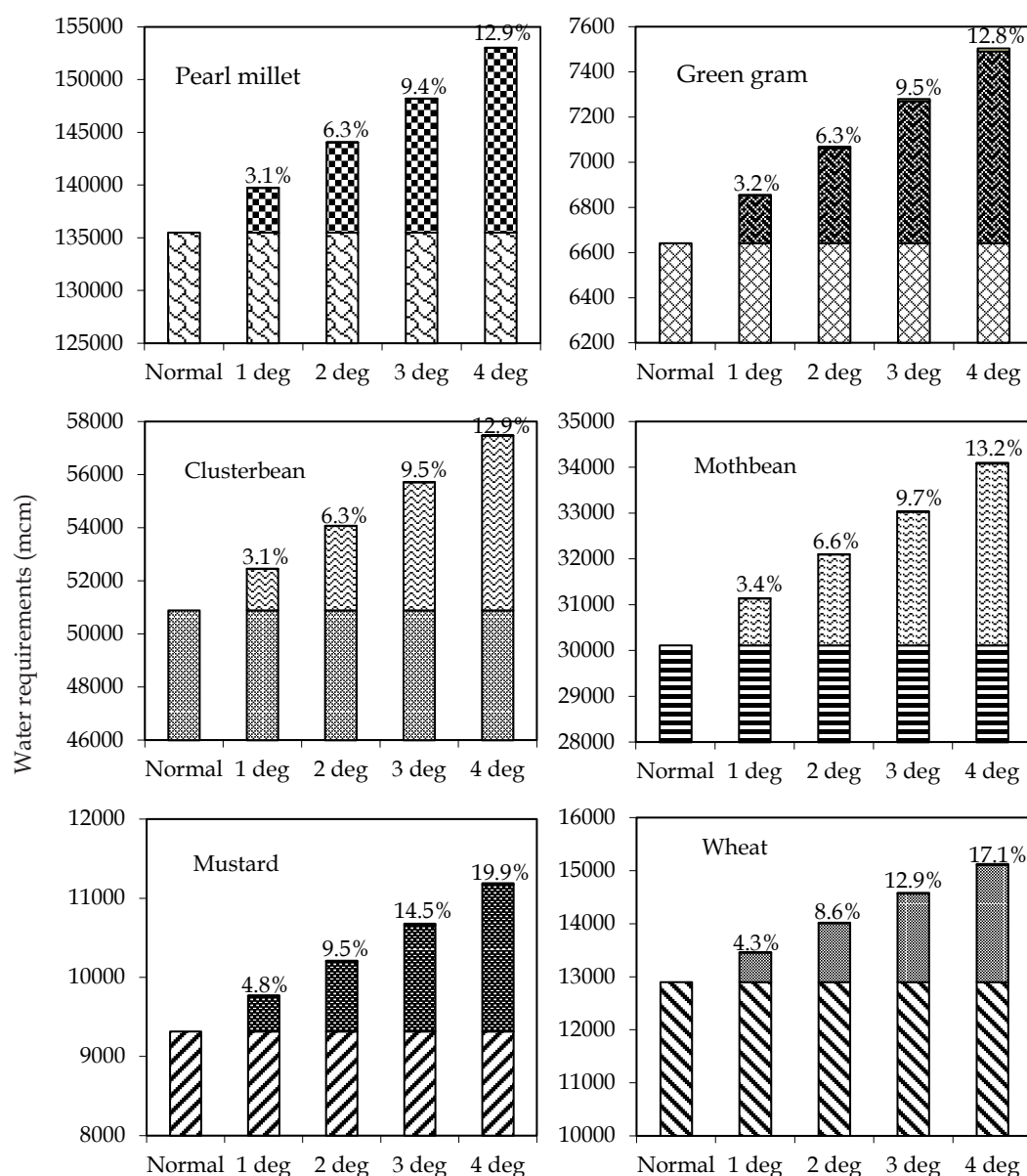
Fig. 11. Seasonal crop water requirements of kharif and rabi crops at elevated temperatures.

During major cropping season of monsoon period (July to September), the impact of elevated temperatures on PET shows that there was an increase in PET by 0.1 to 0.5 mm day^{-1} for 1°C rise, 0.3 to 1.1 mm day^{-1} for 2°C rise, 0.4 to 1.6 mm day^{-1} for 3°C rise and 0.6 to 2.1 mm day^{-1} for a 4°C rise in temperature (Table 1). Thus, by the end of 21st century, the PET during monsoon period may increase by 9 to 23% from its current level.

During winter (December to January), the elevated temperatures are likely to increase PET by 0.3 to 0.5 mm day^{-1} for 1°C rise, 0.3 to 1.1 mm day^{-1} for 2°C rise, 0.4 to 1.6 mm day^{-1} for 3°C rise and 0.6 to 2.1 mm day^{-1} for a 4°C rise (Table 2).

Impact of elevated temperatures on crop water requirements

The crop coefficients for crops of arid Rajasthan used for multiplying with PET to obtain the crop water requirements are shown in Fig. 4. Crop coefficients varied from 0.2 to 1.1 for monsoonal rainfed crops, and from 0.2 to 1.7 for winter irrigated crops. Irrigation to monsoon crops is restricted to drought years, but winter crops, are irrigated by farmers in the region.

The CWRs in the region were 308 to 411 mm for pearl millet, 244 to 332 mm for clusterbean, 217 to 296 mm for green gram, 189 to 260 mm for

moth bean, 173 to 288 mm for wheat and 209 to 343 mm for mustard (Table 3). Crop production in arid Rajasthan is likely to decrease with increased CWR owing to projected increase in temperatures by 21st century.

Pearl millet, which is grown in 3.78 M ha, requires 1,35,500 mcm of water to meet the ET requirement of the crop at normal weather conditions prevailing now. As such, the ET demand is likely to increase by 2 to 5% for a rise of 1°C, 4 to 9% for a rise of 2°C, 7 to 12% for a rise of 3°C and 9 to 18% for a rise of 4°C temperature over the present requirement (Fig. 5). Similarly, clusterbean which is grown in 1.74 M ha require 50,896 mcm of water to meet its crop water needs, but likely to increase its ET by 2 to 4% for a rise of 1°C , 4 to 9% for a rise of 2°C, 6 to 12% for a rise of 3°C and 8 to 17% for a rise of 4°C temperature over the present requirement (Fig. 6). Green gram is grown in 0.27 M ha and the crop requires 6,641 mcm of water to meet its ET requirement. From this level, the ET demand increases by 2 to 5% for a rise of 1°C, 4 to 9% for a rise of 2°C, 6 to 12% for a rise of 3°C and 8 to 17% for a rise of 4°C.

Wheat is grown in 0.670 M ha and the crop requires 13,229 mcm of water to meet its ET requirement at prevailing normal weather conditions. From this level, the ET demand increases by 3 to 9% for a rise of 1°C , 5 to 13% for a rise of 2°C , 8 to 18% for a rise of 3°C and 11 to 24% for a rise of 4°C temperature (Fig. 9). Mustard is grown in 0.38 M ha and forms a major oil seed crop of *rabi* season in the region. The crop requires 9,906 mcm of water to meet its ET requirement. From this level, the ET demand increases by 4 to 9% for a rise of 1°C, 7 to 19% for a rise of 2°C, 11 to 29% for a rise of 3°C and 15 to 39% for a rise of 4°C temperature (Fig. 10).

The western districts of Barmer, Bikaner and Jaisalmer, which are already in low rainfall zone form hot-spots due to impact of projected rise in temperature leading to higher crop water demand, whereas, the districts Sri Ganganagar and Hanumangarh having canal water facility for irrigation, the impact due to climate change in these areas are likely to be less.

Acknowledgements

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