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Climate change impact on crop water requirements in arid Rajasthan

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ABSTRACT

The impact of projected climate change by 21st century on water requirements of rainfed monsoon and irrigated winter crops of arid Rajasthan has been studied. Crop water requirements were estimated from daily potential evapotranspiration at ambient and projected air temperature by 2020, 2050, 2080 and 2100 using modified Penman-Monteith equation and then by multiplying with crop coefficients. Crop water requirements 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, due to global warming, if the projected temperatures rises by 4°C, by the end of 21st century, water requirement in arid Rajasthan increases from the current level, by 12.9% for pearl millet and clusterbean, 12.8% for green gram, 13.2% for moth bean, 17.1% for wheat and 19.9% for mustard. The increased crop water requirements in the region, resulted in reduction in crop growing period by 5 days for long duration crops, but the crop acreage where rainfall satisfies crop water requirements, reduced by 23.3% in pearl millet, 15.2% in clusterbean, 6.7% in green gram, 13% in moth bean. The study reveals that the impact will be more severe on *rabi* crops than *kharif* crops, the *rabi* crops being dependent on depleting ground water resources in the region.

Key words: Climate change, elevated air temperatures, crop water requirement, Indian arid region

Weather variability and climate change continue to influence fragile eco-regions like Indian hot arid zone which has a high density human or livestock population and 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 northwest India has a history of about 3000 years (Pant and Maliekel, 1987). The studies conducted on secular changes in rainfall and air temperatures of northwest India covering the meteorological sub-divisions of Punjab, Haryana, west Rajasthan and west Madhya Pradesh showed that there was a marginal increase in the rainfall by 141 mm in the past 100 years (Pant and Hingane 1988) and particularly in irrigated belts of Sri Ganganagar region (Rao, 1996). The studies on climatic change over Jodhpur region showed that the rainfall and air temperature were favourable, but the increase in human population (by 400%) and livestock (by 127%) during the twentieth century, resulted a major shift in land use pattern with tremendous pressure on surface and groundwater resources, resulting in as main causative factor for desertification conditions in the region (Rao and Miyazaki, 1997).

The Inter-Governmental Panel on Climate Change (IPCC, 2001) projected an increase in global average temperature between 0.15 and 0.3°C per decade for 1990 to 2005. This can be now 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) projected globally averaged surface warming, for the low scenario (B_1) 1.8°C (*likely* range is 1.1°C to 2.9°C), and for the high scenario (A_1F_1) 4.0°C (*likely* range is 2.4°C to 6.4°C) with a general reduction of potential crop yields and a decrease in water availability for agriculture particularly in countries such as Africa, South and Central America and Asia (Parry *et al.*, 1999 and 2004). Such impacts are more likely on fragile eco-systems like arid Rajasthan, where hot environment, low and erratic rainfall conditions prevail, where crops like pearl millet are sensitive to soil water (Rao and Saxton, 1995).

The PRECIS (Providing Regional Climates for Impact Studies) model for the Indian arid region predicted for an increase in annual rainfall by 10-15% in the eastern fringe and 20-40% in the south, but the northwest will experience upto 30% reduction in rainfall. Analyses of long term rainfall trend of arid Rajasthan also showed a reduction in the monsoon rainfall at 37 out of 65 locations in the region (Rao and Purohit, 2009). The PRECIS model for India also showed an increase in an annual mean surface temperature by 3 to 5°C under A_2 scenario and 2.5 to 4°C under B_2 scenario, with warming 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 southwest monsoon (June-September) season (Rupa Kumar *et al.*, 2006). In this paper, an analysis on the impact of projected increase in temperatures on seasonal crop water requirement for crops of arid Rajasthan has been made

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

S.No.	District	Normal	At elevated air temperatures by				Increase in PET at 2100 (%)
			2020	2050	2080	2100	
1	Barmer	7.1	7.4	7.6	7.8	8.1	14
2	Bikaner	8.2	8.6	8.9	9.1	9.3	13
3	Churu	6.7	6.9	7.1	7.4	7.6	13
4	Ganganagar	6.4	6.6	6.9	7.1	7.3	14
5	Hanumangarh	6.5	6.7	6.9	7.1	7.3	12
6	Jaisalmer	8.1	8.5	8.9	9.3	9.7	20
7	Jalore	6.7	6.9	7.1	7.3	7.6	13
8	Jhunjhunu	6.5	6.7	6.9	7.1	7.2	11
9	Jodhpur	7.9	8.2	8.4	8.7	9.0	14
10	Nagaur	5.8	6.0	6.2	6.4	6.6	14
11	Pali	7.4	7.6	7.9	8.2	8.5	15
12	Sikar	5.4	5.5	5.6	5.8	5.9	09

focusing on adaptive strategies in the region.

MATERIALS AND METHODS

Twelve western districts of Rajasthan constitutes 61% area of the Indian hot arid zone, where the annual rainfall varies from 100 mm in the extreme west to 400 mm towards eastern part of the region. The coefficient of annual rainfall varies from 40 to 70% causing larger inter-annual variability in rainfall influencing crop production. The daily potential evapotranspiration for 12 arid districts of Rajasthan was calculated using the following modified Penman-Monteith equation (Allen *et al.*, 1998, Doorenbos and Pruit, 1977) with daily normal meteorological data of the respective districts (IMD, 2008).

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

where ET_o 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 at 2 m height (°C), u_2: wind speed at 2 m height (ms^{-1}), 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 °C^{-1}), γ: psychrometric constant (kPa°C^{-1}). From daily potential evapotranspiration, the crop water requirements (CWR) at different stages of six crops were calculated by multiplying with crop coefficients available from previous lysimetric experiments for rainfed crops viz., pearl millet, clusterbean, green gram and mothbean 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). From daily to seasonal CWR was calculated by summation of daily CWR from sowing to harvesting period for each of these crops.

Based on projected increase in air temperatures of about 1^0C by 2020, 2^0C by 2050, 3^0C by 2080 and 4^0C by 2100 (Lal *et al.*, 2001; Rupa Kumar *et al.*, 2006), the increase in crop water requirements by respective periods were calculated to find out water scenario of arid Rajasthan. The *kharif* crop growing period is determined by comparison of rainfall with at least meeting at 50% of crop water requirement at normal and enhanced temperatures up to 2080. The likely reduction in crop growing area due to increase in crop water requirements with projected change in rainfall was used for estimation of the impacts on crop production in the region.

RESULTS AND DISCUSSION

Daily and seasonal potential evapotranspiration to projected temperatures

The sensitivity of daily potential evapotranspiration (PET, mm) at normal and projected air temperatures in different arid districts of Rajasthan are given in Tables 1 and 2. The spatial variability in annual potential evapotranspiration (PET) over arid Rajasthan shows that high PET prevails in the extreme arid Rajasthan in Bikaner (2066 mm) and Jaisalmer (2221 mm) and low PET in northern arid districts of Ganganagar (1712 mm), Hanumangarh (1736 mm). These northern districts are fed with canal irrigation from Beas and Sutlez rivers and find lower impact due to high crop water requirements. 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 in trend to rainfall isohytes of the arid Rajasthan.

During major cropping season of monsoon period (JJAS), the impact of projected temperatures on (PET) shows that there was an increase in PET by 0.1 to 0.4 mm day^{-1}

Table 2: Daily potential evapotranspiration (mm) of arid Rajasthan (Winter Season, DJF)

S.No.	District	Normal	At elevated air temperatures by				Increase in PET at 2100 (%)
			2020	2050	2080	2100	
1	Barmer	4.1	4.2	4.4	4.6	4.8	17
2	Bikaner	3.1	3.2	3.4	3.5	3.7	19
3	Churu	2.8	2.9	3.1	3.2	3.3	18
4	Ganganagar	2.4	2.5	2.6	2.7	2.8	17
5	Hanumangarh	2.4	2.5	2.6	2.8	2.9	21
6	Jaisalmer	3.5	3.9	4.1	4.3	4.6	31
7	Jalore	3.7	3.8	4.0	4.2	4.3	16
8	Jhunjhunu	2.9	3.0	3.2	3.3	3.5	21
9	Jodhpur	4.2	4.4	4.7	4.9	5.1	21
10	Nagaur	2.3	2.5	2.7	2.9	3.0	30
11	Pali	4.3	4.5	4.7	4.9	5.1	19
12	Sikar	2.6	2.7	2.8	2.9	3.0	15

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
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

by 2020, 0.2 to 0.8 mm day^{-1} by 2050, 0.4 to 1.2 mm day^{-1} by 2080 and 0.5 to 1.6 by 2100 (Table 1). Thus by end of 21st century, the PET requirements during monsoon period increases by 9 to 20% from the current levels of PET.

During winter (DJF), passing western disturbances from northern latitudes bring cold winds to lower the PET rates particularly in northern districts of Ganganagar and Hanumangarh. The projected temperatures on PET during winter shows that there was an increase in PET by 0.1 to 0.4 mm/day by 2020, 0.2 to 0.6 mm day^{-1} by 2050, 0.3 to 0.8 by 2080 and 0.4 to 1.1 mm/day by 2100 (Table 2). Thus by end of 21st century, though the quantum of increase in the PET requirements during winter are comparable to that in monsoon period, but the rates of increase were much higher and are up to 15 to 31% from the current levels of normal PET.

Seasonal crop water requirements

The crop coefficients (ratio of actual evapotranspiration to class A pan evaporation) of different crops of arid Rajasthan used for multiplying with daily PET to obtain crop water requirements are shown in Fig.1. 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 dry periods, but for winter crops irrigation levels practiced by farmers in the region are at par with crop water requirements estimated using coefficients.

The seasonal crop water requirements (CWR) 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. Western districts of Barmer, Bikaner and Jaisalmer which fall bellow 250 mm rainfall isohyets demand for higher crop water requirements (Table 3).

Impact of climatic change on crops

The impact of enhanced crop water requirement on *kharif* crop growing period shows that the growing period reduces by 5 days by 2080 in case of pearl millet and clusterbean. In case of short duration crops, namely green gram and moth bean, there was no significant reduction in the growing period. In case *rabi* wheat and mustard which are irrigated, the growing period much depends on irrigated

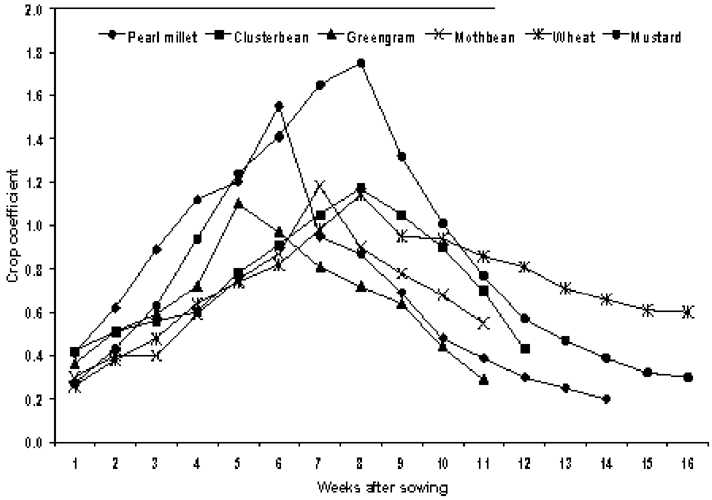

Fig.1 : Crop coefficients for principal crops of arid Rajasthan

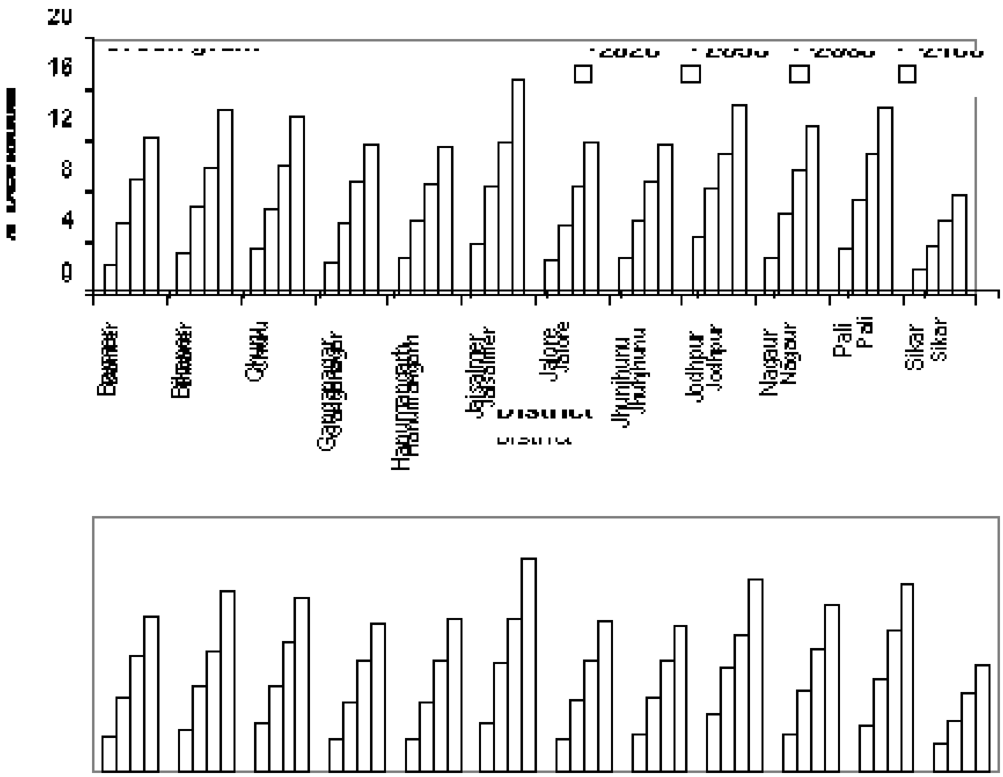

Fig. 2(a) : Evapotranspiration requirements for crops in arid Rajasthan

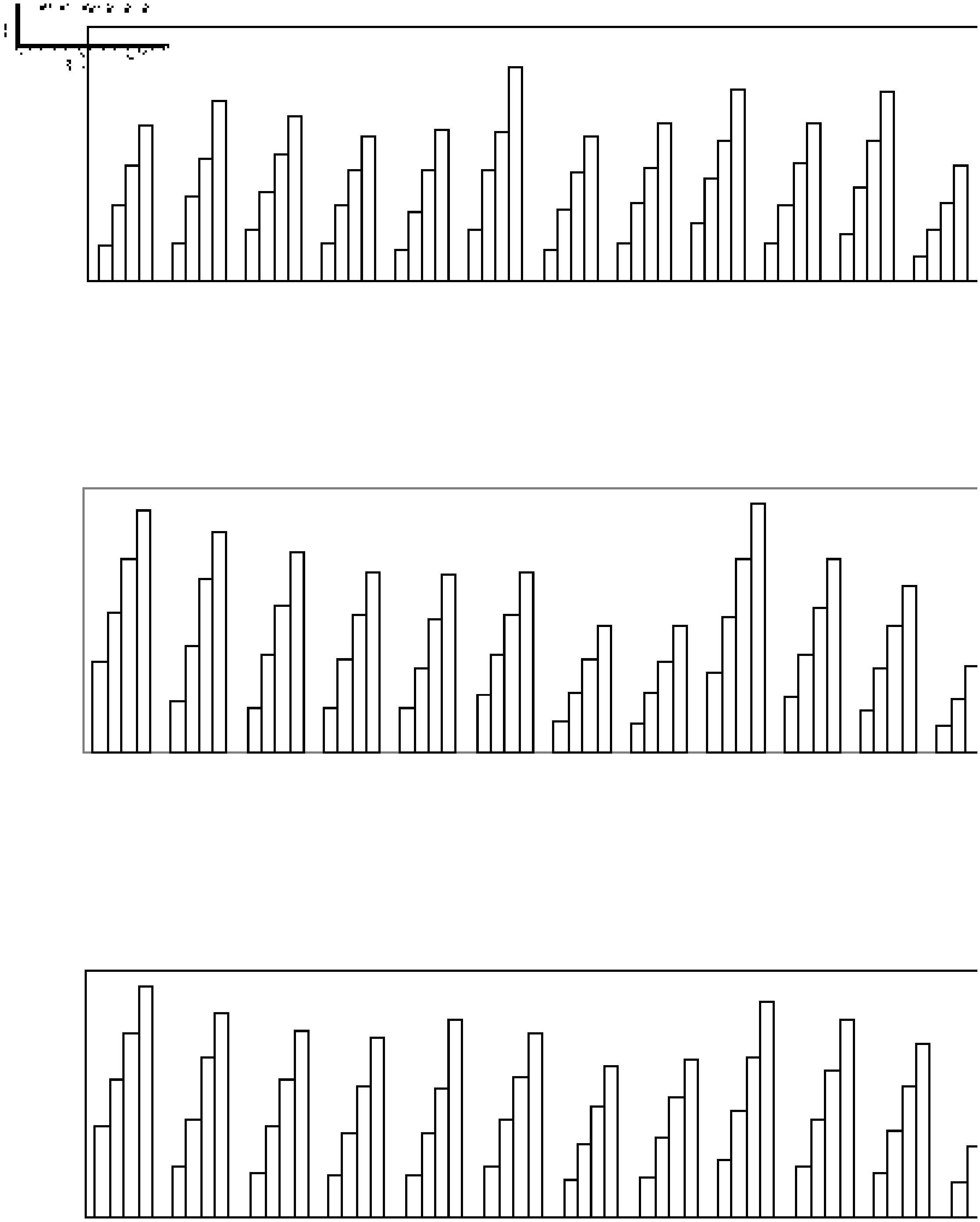

Fig. 2(b) : Evapotranspiration requirements for crops in arid Rajasthan

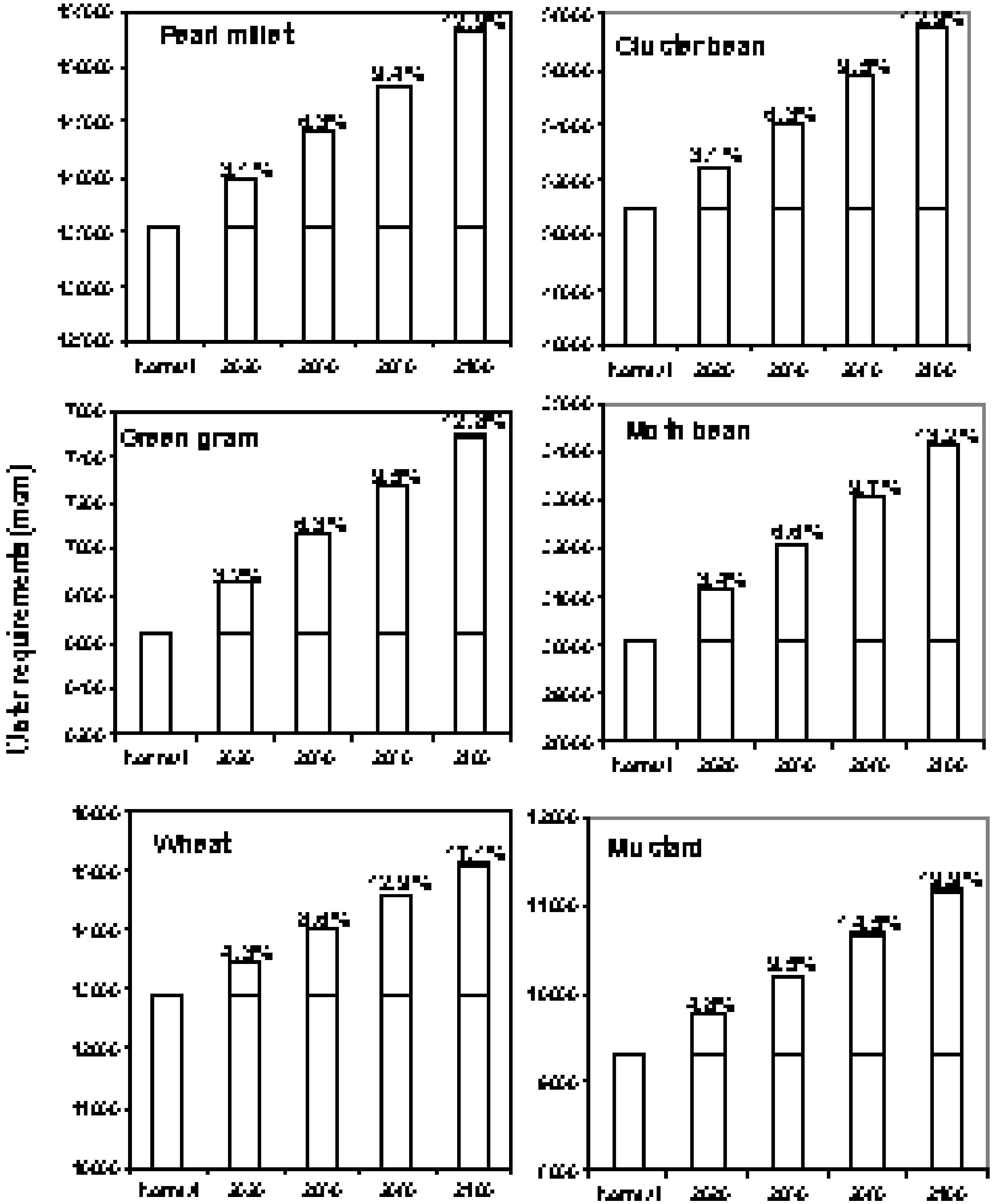

Fig. 3 : Seasonal crop water requirements of *kharif* and *rabi* crops at elevated temperatures

potential in the region. The rains at the time of onset of monsoon are much higher than the enhanced crop water requirement at initial crop stages, but the reduction in growing period is observed in long duration crops of pearl millet and clusterbean at maturity stage.

Comparison of rainfall with enhanced crop water requirements for pearl millet, clusterbean, green gram and moth bean and for irrigated winter wheat and mustard for 12 arid districts of Rajasthan showed reduction in crop acreage and production in arid Rajasthan. Pearl millet is presently grown in 3.78 million ha and the crop requires 1,35,500 mcm of water to meet its evapotranspiration requirement at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 2 to 5% by 2020, 4 to 9% by 2050, 7 to 12% by 2080 and 9 to 18% by 2100 (Fig. 2a). Clusterbean is grown in 1.74 million ha and the crop requires 50,896 mcm of water to meet its CWR at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 2 to 4% by 2020, 4 to 9% by 2050, 6 to 12% by 2080 and 8 to 17% by 2100 (Fig. 2a).

Green gram and moth bean are important pulse crops of arid Rajasthan suiting to its rainfall patterns because of its short duration in nature. Green gram is grown in 0.27 million ha and the crop requires 6,641 mcm of water to meet its evapotranspiration requirement at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 2 to 5% by 2020, 4 to 9% by 2050, 6 to 12% by 2080 and 8 to 17% by 2100 (Fig.2a). Moth bean is grown in 1.28 million ha and the crop requires 30,115 mcm of water to meet its evapotranspiration requirement at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 2 to 4% for a rise of 2020, 4 to 9% by 2050, 6 to 12% by 2080 and 9 to 17% by 2100 (Fig. 2b).

Wheat is grown in 0.67 million ha and the crop requires 13,229 mcm of water to meet its evapotranspiration requirement at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 3 to 9% by 2020, 5 to 13% by 2050, 8 to 18% by 2080 and 11 to 24% by 2100 (Fig. 2b). Mustard is grown in 0.38 million 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 evapotranspiration requirement at prevailing normal weather conditions. From this level, the evapotranspiration demand increases by 4 to 9% by 2020, 7 to 19% by 2050, 11 to 29% by 2080 and 15 to 39% by 2100 (Fig. 2b).

The total impact of projected increase in air temperatures of about 4^0C by 21st century on evapotranspiration requirements for crops of all 12 arid districts of Rajasthan showed that resulting decrease in cropped area leads to reduction in crop yield from the current level by 12.9% for pearl millet, and clusterbean, 12.8% for green gram, 13.2% for moth bean, 17.1% for wheat and 19.9% for mustard (Fig.3). The study also shows that the likely impact on crop evapotranspiration is lower on monsoon rainfed crops of pearl millet, clusterbean, green gram and moth bean compared to winter irrigated crops of wheat and mustard. In a scenario of depleting ground water resources in arid Rajasthan, the winter crops may face multiple effects in crop production.

CONCLUSIONS

PRECIS-Hadley and IPCC (2007) projections for Indian arid region indicate an increase in annual temperature and reduction in annual rainfall by the end of 21st century, except in the fringes of eastern and southern parts of arid Rajasthan. The spatial variability in crop water requirements of crops ranged 308-411 mm for pearl millet, 244-332 mm for clusterbean, 217-296 mm for green gram, 189-260 mm for moth bean, 173-288 mm for wheat and 209-343 mm for mustard. Further, the impact of rising air temperatures upto 4^0C by 21st century on crop water requirements of arid Rajasthan showed that the water requirement increases from the current level by 13%, during *kharif* and 17-20% during *rabi* season. The study revealed that the climate change impact is more pronounced on irrigated winter crops than rainfed monsoon seasonal crops.

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