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Study on crop water requirement of field crops under different climatic conditions of Madhya Pradesh

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ABSTRACT

Improved and efficient irrigation water management through precise estimation of crop water requirement has a vital role to play in ensuring food security. However, the crop water requirement data of field crops are not locally available. In view of this, present investigation was aimed at quantifying the crop water requirement of *rabi* and *kharif* season crops grown under paired row planting in different agro climatic conditions of Madhya Pradesh. The crop water requirement was calculated based on the already developed crop coefficient and reference evapotranspiration. Daily weather data of 35 years (1979 to 2013) for twenty districts of Madhya Pradesh was collected to determine the reference evapotranspiration using Aquacrop model. The study revealed that the daily ET_o increased continuously from 1st SMW to its maximum values during 21st-22nd SMW, thereafter decreased sharply and remains low from 30th to 34th SMW in all selected districts. The highest value of ETo (11.0 mm day^{-1}) was found in Datia at 21st SMW and lowest in Betul i.e. 2.2 mm day^{-1} at 32nd SMW. The daily water requirement estimates showed that the water requirement of chickpea, wheat and lentil i.e. 1.73 lpd, 0.70 lpd and 0.49 lpd respectively is highest in Jabalpur. Sugarcane has the highest water requirement 13.56 lpd in Narsinghpur during mid season. In all *kharif* crops cotton has highest water requirement 6.53 lpd in Harda followed by sesame and groundnut i.e. 2.75 lpd and 2.46 lpd respectively in Datia. These results can be used in efficient management of irrigation water under drip irrigation system in selected district of Madhya Pradesh.

Key words: Aquacrop model, Crop coefficient (K_c), Crop water requirement, *kharif* crops, *Rabi* crops, Reference evapotranspiration (ET_o).

INTRODUCTION

Irrigation plays a paramount role not only in improving the agriculture but overall economy and development of the region. With increasing scarcity and growing competition for water, judicious use of water in agricultural sector is necessary. Drip irrigation has great potential to improve the water use efficiency due to its numerous advantages. Optimization and minimization of water to be applied to the crops is essential in drip irrigation system. Yields of the crops are adversely affected with excess or inadequate water supply. Yields can be considerably increased by adopting proper irrigation management. Many times even with favourable climatic conditions, the crop production is very low due to absence of proper water resource planning and scientific management.

According to Tan and Lanye (1981) for proper irrigation management the challenge is to estimate crops water requirement in the context of growth stages and climate. The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field (USDA Soil Conservation Service 1993). Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration (ET_c) refers to the amount of water that is lost through evapotranspiration (Allen *et al*., 1998), so evapotranspiration is the dominant variable for irrigation scheduling. The evapotranspiration for different *rabi* and *kharif* season crops were studied e.g. cotton by Khatri and Suryanarayana (2008), sesame by Rao and Sondge (1995), corn by Suneethadevi and Rao (2002), groundnut noted by Palanisami and Chandrasekaran (2004), sugarcane by Selvaraj and Palanisami, (2003), wheat and soybean by Singh *et al*. (2014) under different climatic and local conditions. These studies show that there was variation in the evapotranspiration due to the climatic and local conditions, which reflects the change in the water requirement. There was less work done for estimation of water requirement for field crops in semi-arid region. So an attempt has been made for estimation of crop water requirement of *rabi* and *kharif* season crops for different agro climatic conditions of Madhya Pradesh.

MATERIALS AND METHODS

Study area: This research was conducted for different agro-climatic conditions of Madhya Pradesh which are

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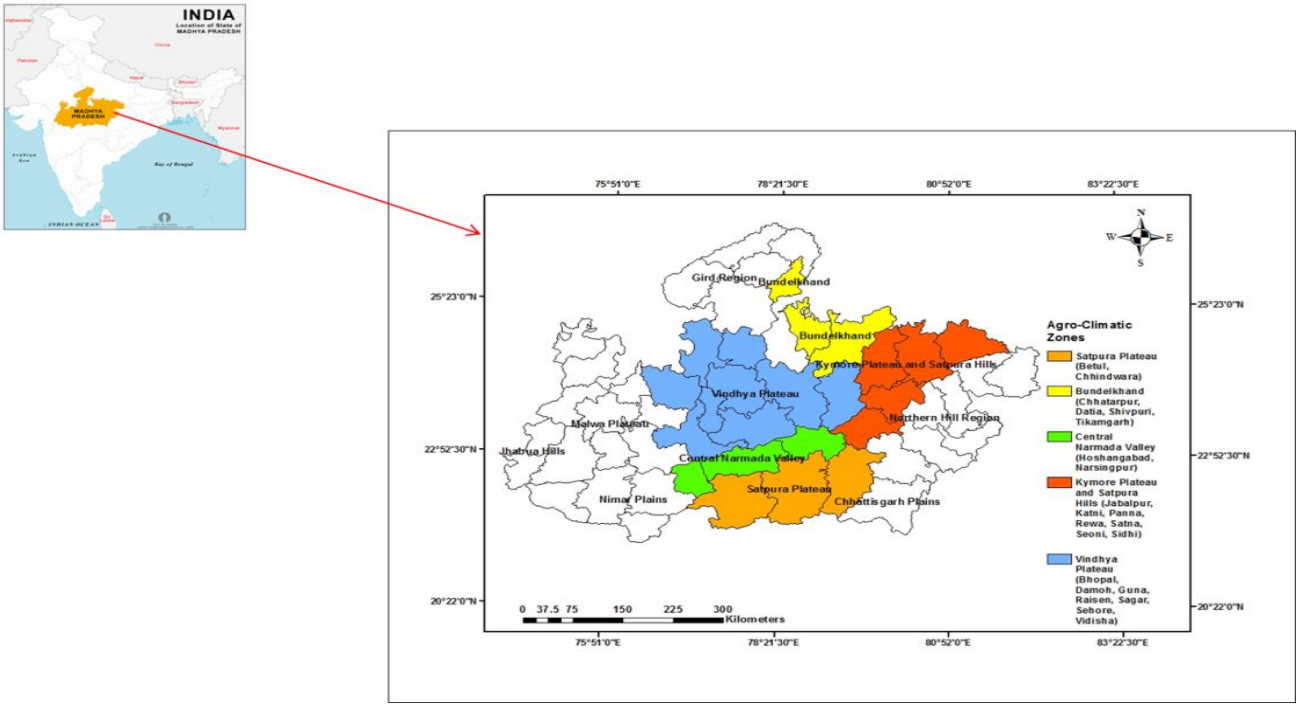

Fig 1: Location map of study area

geographically located between 21°6'N to 26°30'N latitude and 74°9'E to 82°48'E longitude with an area of 1,38,923 km^2. The region comprises of five agro-climatic zones of Madhya Pradesh namely Kymore Plateau and Satpura Hills, Central Narmada Valley, Bundelkhand Region, Satpura Plateau and Vindhya Plateau, which covers twenty districts; Rewa, Panna, Jabalpur, Seoni, Sidhi, Katni, Harda, Hoshangabad, Narsinghpur, Sagar, Damoh, Bhopal, Raisen, Sehore, Vidisha, Datia, Chhatarpur, Tikamgarh , Betul and Chhindwara of the state as shown in (Fig 1). Madhya Pradesh state has great variability in the rainfall and the climate ranges from sub-humid area of central part to semi-arid in the northern Madhya Pradesh. Hot dry summer extends from April to June followed by monsoon from July to September and winter months (November to February) are cool and relatively dry. Summer temperature ranges from 33°C to 44°C and winter temperature ranges from 10°C to 27°C. Various crops have also been identified for different agro-climatic zones.

Data collection: The daily weather data (maximum temperature, minimum temperature, mean relative humidity, wind speed and solar radiation) of 35 years period (1979 to 2013) for different districts were obtained from global weather data site and was used for estimation of reference crop evapotranspiration. The major field crops of each district were taken for estimation of water requirement for drip irrigation system under paired row planting. The information regarding time of sowing, harvesting, length of crops development stages and crop coefficient values for *rabi* and *kharif* season crops were collected from the report published by FAO.

Estimation of reference evapotranspiration (ET_o): The daily reference evapotranspiration ET_o at the respective weather station was estimated by Aquacrop model developed by Food and Agriculture Organization, Italy using daily weather data set. Aquacrop uses the FAO Penman Monteith method to calculate the reference crop evapotranspiration. The FAO Penman Monteith method is a physically based analytical approach, a combination of the energy balance and mass transfer method, specifying the resistance factors of the reference surface. The mathematical expression of FAO Penman Monteith method to estimate ET_o is presented below:

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

Where, ET_o is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), Δ is slope of vapour pressure curve (kPa °C^{-1}), γ is psychometric constant (kPa °C^{-1}).

Crop water requirement: The amount of water need to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Crop water requirement has been calculated for each plant based on its crop coefficient for different developmental stages (Table 1)

and estimated reference evapotranspiration rate. The water requirement or volume of water to be applied for a period through drip irrigation under paired row planting can be calculated by the following relationship with the addition of emission uniformity.

Water requirement (litre/day),

$$WR = \frac{S_1 \times S_d \times ET_o \times K_C \times W_P}{E_u}$$

Where,

A = Area of the crop (m^2) = row to row (m) × plant to plant spacing (m);

ET_o = Reference evapotranspiration, mm/day

K_c = Crop coefficient;

S_l = Lateral spacing along the sub main, m

S_d = Dripper spacing along the lateral, m

W_p = Percentage wetted area, decimal

E_u = Emission uniformity of drip system, decimal

The water requirement of crop was determined based on crop area covered, lateral and dripper spacing and percentage wetted area of different crops presented in Table 2.

Table 1: Crop coefficient (Kc) values of some selected rabi and *kharif* season field crops.

Crops	Initial stage (K_{cini})	Development Stage (K_{cdev})	Mid-stage (K_{cmid})	Late stage (K_{clet})
wheat	0.40	0.78	1.15	0.78
Chickpea	0.40	0.70	1.00	0.68
Groundnut	0.40	0.78	1.15	0.88
Lentil	0.40	0.75	1.10	0.70
Soybean	0.40	0.78	1.15	0.83
Cotton	0.35	0.75	1.15	0.83
Mustard	0.35	0.75	1.15	0.75
Sesame	0.40	0.83	1.25	1.00
Maize	0.30	0.75	1.20	0.78
Sugarcane	0.40	0.83	1.25	1.00
Pigeon pea	0.30	0.65	1.00	0.65

Table 2: Spacing and percent wetted area for different field crops under paired row planting.

Crops	Crop spacing (cm)	Lateral × Dripper Spacing (cm)	% Wetted Area
Sugarcane	75-150 × 60	225 × 75	60
Cotton	75-150 × 75	225 × 75	50
Maize	75 × 30	150 × 30	80
Chickpea	45 × 10	90 × 60	70
Pigeon pea	60 × 20	120 × 20	70
Groundnut	45 × 10	90 × 60	70
Soybean	45 × 5	90 × 30	70
Sesame	45 × 15	90 × 60	70
Mustard	30 × 15	60 × 20	70
Lentil	30 × 5	60 × 20	70
Sorghum	45 × 15	90 × 60	70
Wheat	22	60 × 30	70

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following sub heads;

Reference evapotranspiration (ET_o): The daily values of reference evapotranspiration (ET_o) calculated by Aquacrop model used to calculate average weekly (as per standard meteorological week) ET_o. The pattern of average weekly ET_o variation during the year across the location for different agro climatic zones presented in (Fig- 2) and observed that the ET_o increased continuously from 1st SMW to and reached to its maximum during 21st-22nd SMW at all districts. It is sharply decreased after 23rd SMW and remains low from 30th to 34th SMW. The result indicated that ET_o highest (11.0 mm day^{-1}) at 21st SMW in Datia and lowest (2.2 mm day^{-1}) at 32nd SMW in Betul. May is the month of highest rate of ETo for all the twenty districts which in descending order are 11.0 mm day^{-1} in Datia, 10.5 mm day^{-1} in Panna, 10.4 mm day^{-1} in Chhatarpur and Tikamgarh, 10.2 mm day^{-1} in Vidisha, 10.0 mm day^{-1} in Sehore, 9.9 mm day^{-1} in Bhopal, 9.7 mm day^{-1} in Narsinghpur, 9.6 mm day^{-1} in Harda, 9.4 mm day^{-1} in Sagar, Hoshangabad and Betul, 9.3 mm day^{-1} in Damoh, 9.2 mm day^{-1} in Chindwara, 8.62 mm day^{-1} in Seoni during 21st SMW and 10.32 mm day^{-1} in Raisen at 22nd SMW. The rate of evapotranspiration is obtained to be highest in the months of April to June (14th to 25th SMW) in Madhya Pradesh.

Thus it was found that as one moves northward, the reference evapotranspiration (ET_o) increases. Beside latitudinal variation, the daily variation in wind speed, temperature, mean relative humidity (RH_{min}) and solar radiation is attributed to the variation in reference evapotranspiration (ET_o). Since the climatic parameters vary with locations therefore ETo also varies with the locations (Mehta and Pandey, 2015).

Crop water requirement: The water requirement of major *rabi* and *kharif* season crops of each district were worked out on daily basis by using estimated reference crop evapotranspiration (ET_o) and crop coefficient (K_c) values of respective growth stages given in (Table 1). The meteorological week wise variation in CWR under various stages for rabi and Kharif season crops for different districts presented in (Fig- 3,4) respectively along with mean variation.

CWR of *rabi* season crops: During rabi season, mean crop water requirement of wheat is found to be 0.25 lpd at the time of planting in 44th SMW. The mean water requirement of wheat varies between 0.24 lpd to 0.65 lpd. Among different location the highest (0.70 lpd) water requirement was observed in Raisen and lowest (0.58 lpd) in Jabalpur during its mid season at 4th SMW. The water requirement of chickpea increases continuously with small fluctuation from initial stage (42nd SMW) and reaches to its peak value 1.62 lpd at 47th SMW during mid season stage. The highest CWR is found to be 1.73 lpd in Raisen at 47th SMW. The water requirement of lentil is almost constant during its initial stage

(40th to 42nd SMW) and its mean value is 0.17 lpd. The peak value of CWR 0.49 lpd observed in Raisen druing 9th SMW at the time of harvesting due high evapotranspiration in month of March. In case of mustard CWR determined for Datia and Tikamgarh and almost same pattern of water requirement has been observed in both. The mean CWR of mustard crop ranges from 0.22 lpd to 0.41 lpd. For sugarcane mean water requirement increases continuously from 1st SMW at the time of planting and reaches to its peak value 13.33 lpd at 21st SMW during mid season than decreases afterword. The maximum value of CWR of sugarcane is found to be in Narsinghpur.

CWR of *kharif* season crops: The mean crop water requirement of pigeon pea ranges from 0.25 lpd to 0.87 lpd. The highest value (0.89 lpd) occurred in 41st SMW at Sidhi. For maize, water requirement is found to be 0.56 lpd during 27th SMW at the time of planting. The water requirement goes on increasing during the successive meteorological

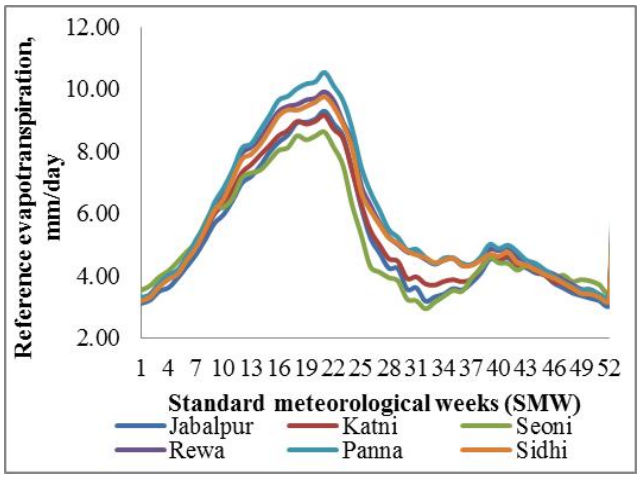

Fig. 2(a): Weekly pattern of ET_o at different districts of Kymore Plateau and Satpura Hills

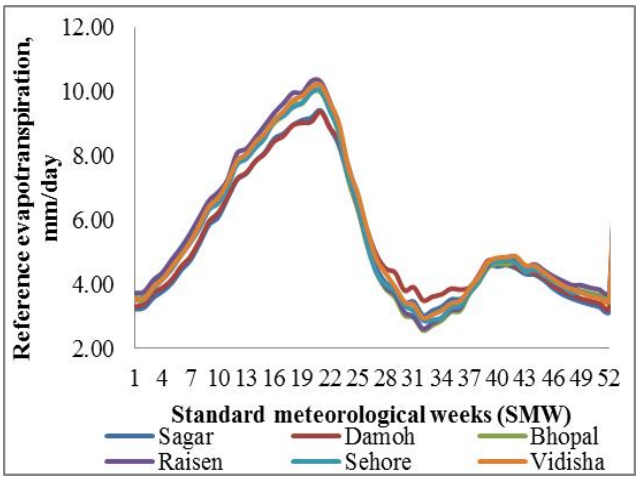

Fig. 2(b): Weekly pattern of ET_o at different districts of Vindhya Plateau

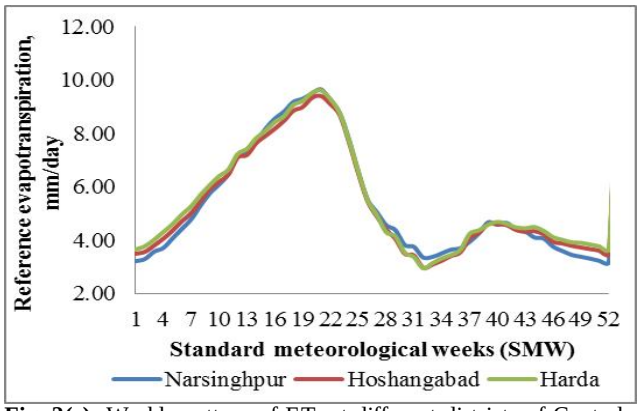

Fig. 2(c): Weekly pattern of ET_o at different districts of Central Narmada Valley

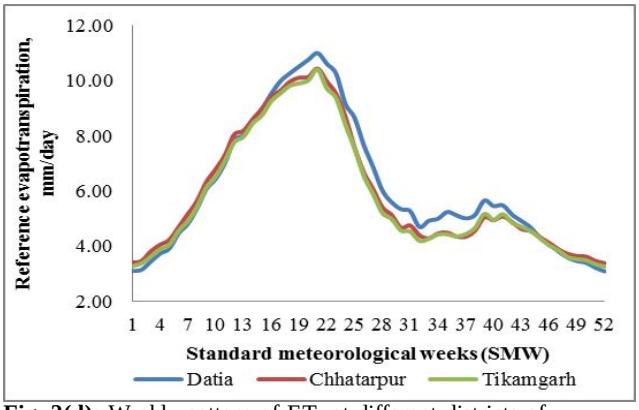

Fig. 2(d): Weekly pattern of ET_o at different districts of Bundelkhand Region

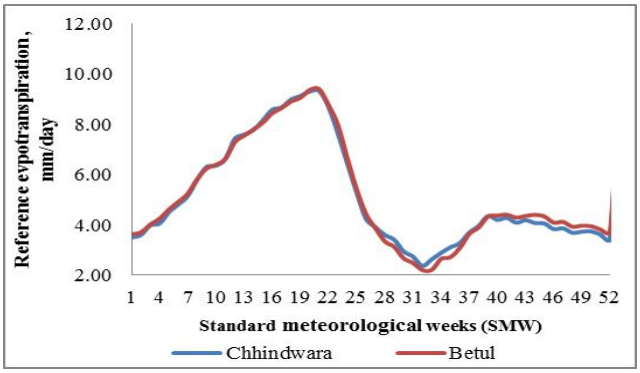

Fig. 2(e): Weekly pattern of ET_o at different districts of Satpura Hills

Fig. 2: Weekly pattern of reference evapotranspiration (ET_o) variation in different districts of Madhya Pradesh

weeks, reaching a maximum of 2.19 lpd at 39th SMW and reduced to 1.32 lpd in the 44th SMW. The highest water requirement is found in Sidhi. While for cotton, it is the highest (6.53 lpd) in Harda during 22nd SMW at developmental stage. The mean water requirement of cotton varies between 2.96 lpd to 6.32 lpd. In case of soybean large fluctuation in CWR occurred from 23rd to 31st SMW, during this period mean CWR varies between 0.54 lpd to 0.88 lpd. The highest water requirement observed in Panna and Damoh i.e. 1.21 lpd and 1.15 lpd respectively during 39th SMW. Groundnut required 1.07 lpd water during its initial stage. The peak value of 2.35 lpd is observed during 38th SMW at the end of mid season, with 1.85 lpd at the end of season. The sesame had mean crop water requirement 1.66 lpd at 23rd SMW at the time of planting. The highest water requirement occurred in 35th SMW i.e. 2.55 lpd. The maximum water requirement of sesame is observed in Datia.

From the analysis it was found that in all field crops except wheat and lentil maximum amount of water required

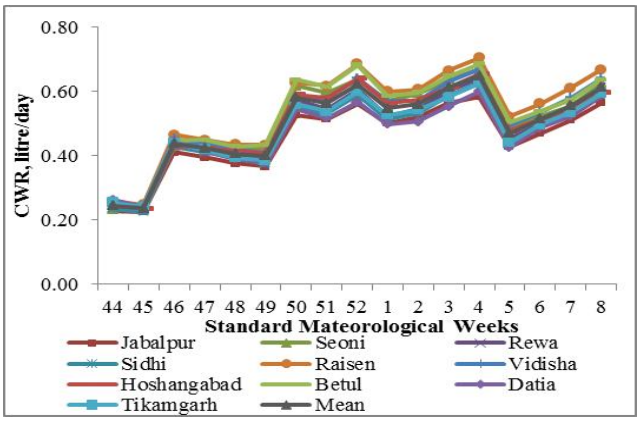

Fig.3(a): Stage wise variation in CWR of Wheat at different districts of Madhya Pradesh

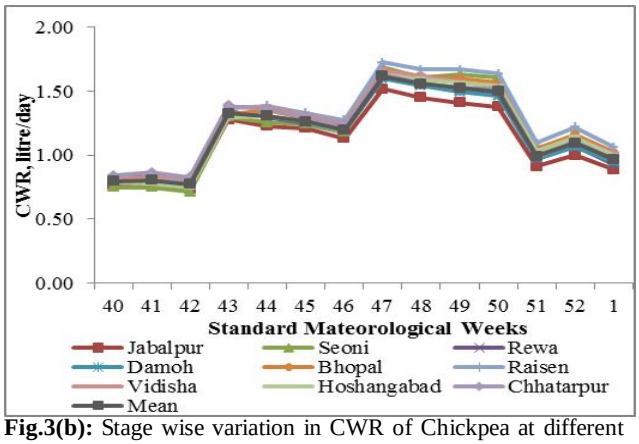

Fig.3(b): Stage wise variation in CWR of Chickpea at different districts of Madhya Pradesh

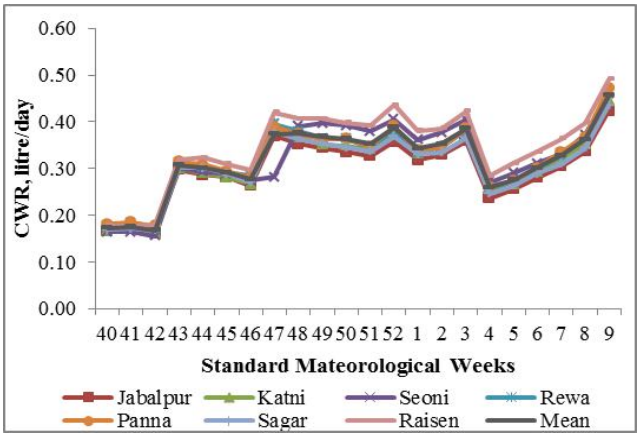

Fig.3(c): Stage wise variation in CWR of Lentil at different districts of Madhya Pradesh

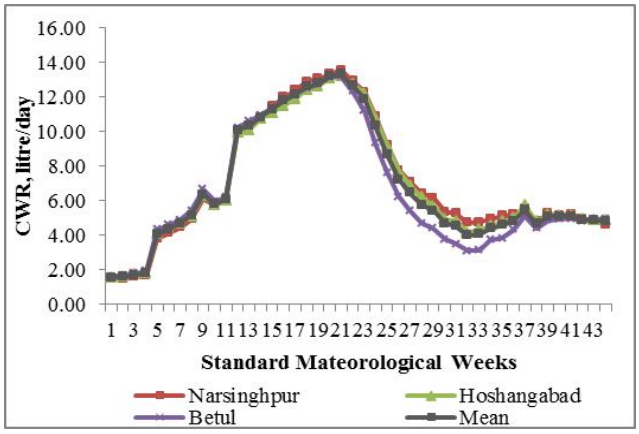

Fig.3 (d): Stage wise variation in CWR of Sugarcane at different districts of Madhya Pradesh

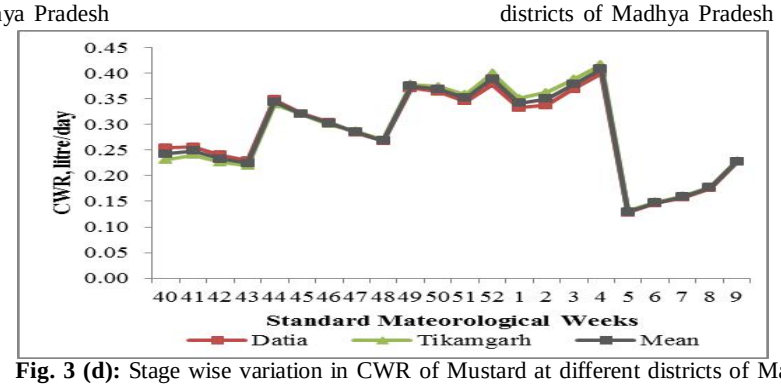

Fig. 3 (d): Stage wise variation in CWR of Mustard at different districts of Madhya Pradesh

Fig. 3: Stage wise variation in crop water requirement of major *rabi* season crops of different districts in different meteorological weeks

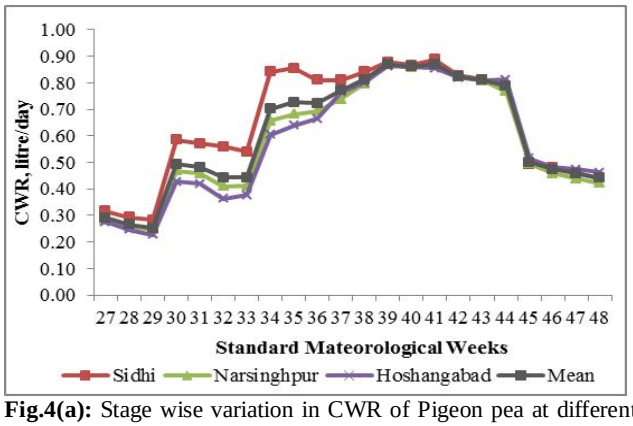

Fig.4(a): Stage wise variation in CWR of Pigeon pea at different districts of Madhya Pradesh

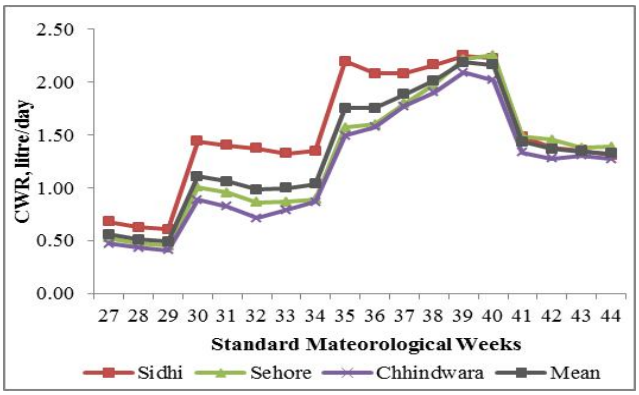

Fig. 4(b): Stage wise variation in CWR of Maize at different districts of Madhya Pradesh

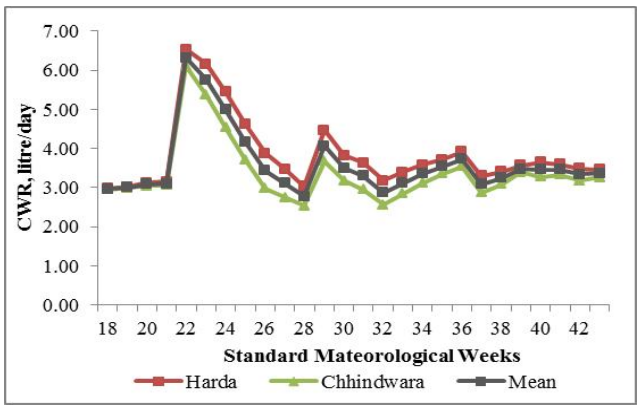

Fig. 4(c): Stage wise variation in CWR of Cotton at different districts of Madhya Pradesh

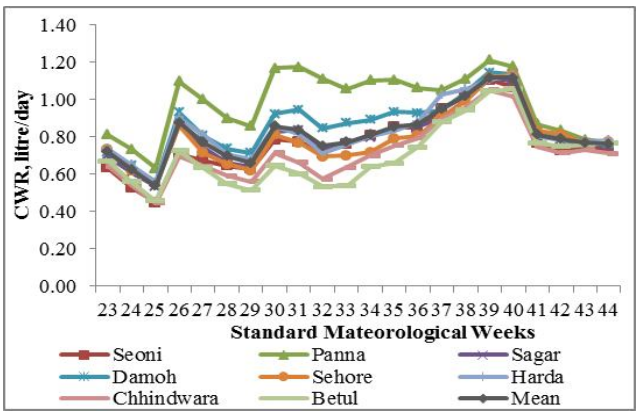

Fig. 4(d): Stage wise variation in CWR of Soybean at different districts of Madhya Pradesh

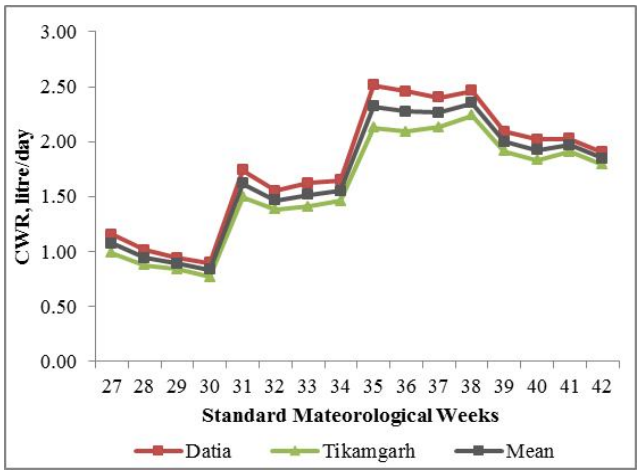

Fig 4(e): Stage wise variation in CWR of Groundnut at different districts of Madhya Pradesh

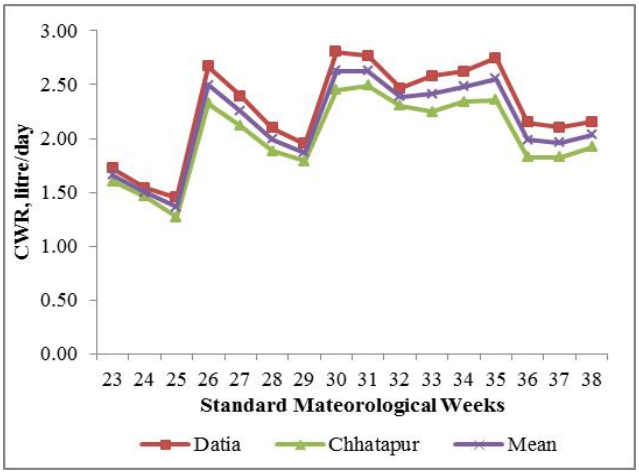

Fig. 4(f): Stage wise variation in CWR of Sesame at different districts of Madhya Pradesh

Fig 4: Stage wise variation in crop water requirement of major *kharif* season crops of different districts in different meteorological weeks

during mid season and developmental stage as compared to initial and late season stage. The CWR of chickpea, wheat and lentil is higher in Raisen whereas lower in Jabalpur. Among all kharif crops cotton had highest CWR in Harda district. Sugarcane required maximum amount of water for irrigation as compared to all field crops and its CWR is highest in Narsinghpur.

CONCLUSION

The study reveals that the ET_o increases continuously from 1st SMW and reaches to maximum during

21st-22nd meteorological week in all districts. The highest ET_o value 11.0 mm day^{-1} was found at Datia in month of May (21st SMW) and lowest 2.2 mm day^{-1}at Betul in August (32nd SMW). The result indicated that the water requirement of seasonal field crops increasing from plantation up to the end of mid season and reduces at the end of season. It was also found that water requirement was affected by crop coefficient at different development stages and evapotranspiration rate. The water requirement of chickpea, Wheat and lentil i.e. 1.73 lpd, 0.70 lpd and 0.49 lpd respectively is highest in Raisen. Sugarcane has highest water requirement 13.56 lpd in Narsinghpur during mid season. In all *kharif* crops cotton has highest water requirement 6.53 lpd in Harda followed by sesame and groundnut i.e. 2.75 lpd and 2.46 lpd respectively in Datia. These peak water requirement values for different crops can be utilized for optimum use of water as well as planning and design of drip irrigation system.

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