INTRODUCTION

The most important two scarce natural resources for agricultural development and economic advancement for any country are land and water (Shrivastava and Kumar, 2015). With the gradual decline in per capita availability of land and water, augmenting agricultural productivity has become more important factor in meeting the demand of agricultural produce to fast growing population of the country. The availability of irrigation water for crop production needs to be judiciously utilized. Land degradation due to soil salinity and water-logging is threatening the sustainable use of land resources in India. Globally, salt affected soils increased from 45 million hectare in 1990 to 62 million hectares in 2013 (Qadir et al., 2014). According to Qadir et al. (2014; 2015), salt-induced land degradation has been on the rise and every day, the world is losing about 2000 hectares of land due to salinity.

Cotton is one of the most important fibre-producing plant. India is the second largest producer of cotton in the world after China. In India, the total area under cotton cultivation was 12.43 million hectare and total cotton production in the country was 34.89 million tonnes in 2017-18. The per hectare yield of cotton in the country was 477 kg during 2017-18. The major cotton producing Indian states are Gujarat, Maharashtra, Telangana, Andhra Pradesh, Rajasthan, Madhya Pradesh,
Haryana, Punjab and Karnataka. Among the Indian states, Gujarat is the highest cotton producing state. The total area under cotton cultivation in Gujarat was 2.38 million hectares accounting for 22 per cent of India’s total area in 2016-17. Total cotton production in Gujarat was 8.58 million tonnes, accounting for 26.32 per cent of the country’s total cotton production during 2016-17. Per hectare, the average cotton yield in Gujarat was 612 kg higher than the national average of cotton yield. The total irrigated area under cotton production in Gujarat was 58.70 per cent during 2014-15. In 2015-16, per hectare cost of cultivation of cotton in Gujarat was estimated to be Rs 55081.77. The average cotton yield in Gujarat was 18.25 quintal per hectare during 2015-16 (Government of India, 2019).

The irrigation water demand management becomes the key to the overall strategy for managing scarce water resources. Since agriculture is the major competitive user of diverted water in India (Singh, 2017; Surendran et al., 2013), demand management in agriculture in water-scarce and water-stressed regions would be central to reducing the aggregate demand for water to match the available future supplies (Singh, 2017; de Fraiture and Wichelns, 2010). With the growing concern about the exploitation of scarce water resources, there is a renewed interest in increasing the water use efficiency in agriculture (Kumar, et al. 2014). One of the important parameter for comparing water use efficiency is water productivity (Kumar, et al. 2014; Hozayn et al., 2013; El-Habbasha et al., 2014).

Three dimensions of water productivity include physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net return per unit of water consumed; and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kumar et al., 2013). Water productivity is an important driver in projecting future water demands (Kumar et al., 2013). Efficient irrigation technologies help to establish greater control over water delivery (water control) to the crop root zone, reduce non-beneficial evaporation and non-recoverable percolation from the field, and return flows into “sinks” and often increases beneficial ET, though the first component could be very low for field crops (Singh et al., 2013). Water productivity improves with a reduction in depleted fraction and yield enhancement. Since at the theoretical level, water productivity improvements in irrigated agriculture can save water used for crop production, any technological interventions, which improve crop yields, are also, in effect, water saving technologies. Hence, water saving technologies in agriculture can be broadly classified into three: water saving crop technologies, water saving and yield enhancing irrigation technologies; and, yield improving crop technologies (Singh et al., 2013; Kumar and Palanisami, 2011; Palanisami et al., 2011; El-Habbasha et al. 2014; Zafar et al., 2020).

Many past researchers have reported high water use efficiency and crop yield under drip method of irrigation as compared to conventional irrigation throughout the globe (Singh, et al., 2013; Kumar and Palanisami, 2011; Narayananmoorthy, 2012; Abdelraouf et al., 2020; Barkunan et al., 2019; Uddian and Dhar, 2020; Zafar et al., 2020; Mehriya et al., 2020). In drip irrigation, the volume of wetted soil at a particular water application is controlled by the volume of water added, dripper discharge rate and the water content in the soil. Drip method of irrigation is highly suited to semi-arid and arid areas where water is scarce, and low water-consuming and high-value crops can be grown. In India, drip method of irrigation for cotton crop is being practised by some farmers in Gujarat, Madhya Pradesh and Maharashtra in heavy textured soil viz., black cotton soil. But in light texture and brackish underground water, drip irrigation to cotton crop is at the experimental stage. The overall objective of the present study was to estimate and compare the irrigation water use and physical water productivity of cotton crop under alternate furrow and drip method of irrigation in Bhavnagar district of Gujarat.

MATERIALS AND METHODS

Methodology

Present study was based on primary data and it was collected on different parameters for normal rainfall and drought year through personal interview using pre-tested schedule. These parameters were related to: (a) size of land holding; (b) cotton crop (area under cotton, date of sowing, data of harvesting, plant and row spacing, fertiliser application and crop yield); (c) irrigation (source of irrigation, method of irrigation, number of irrigations and duration per irrigation); (d) well/tube-well (number of wells/tube-wells, depth of well, depth to water level, type of pump, pump capacity and age of pump); and (e) drip (number of drip line per row, spacing between dripper in each line, spacing between laterals, discharge of first dripper on first line, discharge of last dripper on last line and discharge of middle dripper on middle line). The Bhavnagar district of Gujarat was purposively selected for the present study because the district was ranked fourth largest cotton growing district in the Gujarat State. The district consists of nine talukas viz., Ballabhipur, Bhavnagar, Gariyadhar, Ghogha, Mahuva, Palitana, Shihor, Talaja and Umrala (Fig. 1). To represent the district, all the talukas of the district were considered for primary data collection. Sample farmers of these talukas were using groundwater for irrigating the cotton crop. The irrigation methods used by the sample farmers for the cotton crop was a
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For the present study, 40 farmers were selected for primary data collection. The important criterion for the selection of sampled farmers was growing cotton and using drip and furrow method of irrigation.

**Estimation of irrigation water requirement**

The crop evapotranspiration (ETc), effective rainfall and irrigation water requirement were estimated using CropWat model developed by the Food and Agriculture Organisation (Allen et al., 1998; Bouraima et al., 2015; Amarasinghe et al., 2010; Laghari et al., 2014; Kumari et al., 2017; Kumari et al., 2017a). In the model, the whole cotton crop period was divided into four stages of crop periods i.e. initial (1-30 days after sowing), development (31-50 days after sowing), mid-season (51-60 days after sowing) and late season (61-95 days after sowing) and crop coefficients were 0.35, 0.35, 1.20 and 0.60 respectively. The irrigation water requirements for the crop was estimated by subtracting the effective rainfall from the calculated crop evapotranspiration on a daily basis using the relationship:

\[
IR = ET_0 \times Kc - Re 
\]

Where, 
- \( IR \) is the net depth of irrigation (mm per day),
- \( ET_0 \) is reference potential evapotranspiration (mm per day),
- \( Kc \) is crop coefficient and
- \( Re \) is the effective rainfall. 

The Penman-Monteith equation integrated into the CropWat programme (Bouraima et al. 2015) is expressed by equation 2.

\[
ET_0 = \frac{0.408A(Rn - G) + \frac{37}{\Delta + \gamma} (T_{hr} - T_{at}) - u_2 \gamma}{\Delta + \gamma} 
\]

Where:
- \( ET_0 \) = reference evapotranspiration (mm/hour)
- \( Rn \) = net radiation at the grass surface (MJ/m²/hour)
- \( G \) = soil heat flux density (MJ/m²/hour)
- \( \Delta \) = mean hourly air temperature (°C)
- \( \gamma \) = saturation slope vapour pressure curve at \( T_{hr} \) (kPa/°C)
- \( e(0) \) = saturation vapour pressure at air temperature \( T_{hr} \) (kPa)
- \( u_2 \) = average hourly actual vapour pressure (kPa)
- \( T_{hr} \) = mean hourly air temperature (°C)
- \( \Delta \) = saturation slope vapour pressure curve at \( T_{hr} \) (kPa/°C)

**Irrigation water applied**

The estimation of irrigation water applied to cotton crop during crop period was estimated by using the following method (Singh and Singh, 2020):

\[
IWA_{m^3} = NI \times Hrs \times Pd 
\]

Where: \( IWA_{m^3} \) is irrigation water applied to cotton (m³/ha), \( NI \) is number of irrigations given to cotton crop; \( Hrs \) is hours required for providing one irrigation to cotton crop (Hrs.) and \( Pd \) is pump discharge (m³/Hrs).

The farmers of the study area were using groundwater for irrigating cotton crop. For the quantification of pump discharge rate, following formula was used (Singh, 2017a):

Fig. 1. Location map of Bhavnagar district, Gujarat.
If a region becomes dry, groundwater was being used for irrigated crop production. Out of this, nearly 92.98 per cent of groundwater extraction in the Bhavnagar district was estimated to be 778.63 MCM in 2017. Total annual groundwater extraction was 4.6352 MCM. The study area, the groundwater recharge was from other sources during monsoon season and the remaining 8.20 per cent recharge comes from other sources during the non-monsoon season (Priya et al., 2019a). The total natural discharge was 40.98 MCM during the non-monsoon season (June to September) and the remaining 8.20 per cent recharge comes from other sources during monsoon season (October to May) was 819.61 MCM. Out of total groundwater recharge, 73.98 per cent recharge comes from rainfall, 14.77 per cent recharge from other sources during monsoon season and the remaining 8.20 per cent groundwater recharge was from other sources during the non-monsoon season (Government of India, 2019a). The total natural discharge was 40.98 MCM (Table 1).

The annual extractable groundwater resources were estimated to be 778.63 MCM in 2017. Total annual groundwater extraction in the Bhavnagar district was 463.52 MCM. Out of this, nearly 92.98 per cent of groundwater was being used for irrigated crop production. The share of groundwater use for industrial and domestic uses were 1.05 and 5.97 per cent, respectively. The stage of groundwater development in the district was 59.53 per cent. All the talukas of the districts were falls under the safe zone.

**Land holding size and soil type**

The average size of landholding of the sample farmers in the study area was found to be 1.76 hectares. The average size of landholding for alternate furrow method for cotton irrigated farmers was 1.49 hectare, whereas, in the case of drip irrigated cotton growers, the average size of landholding was 2.06 hectare. The soil available in the study area was heavy textured soil viz. black cotton soil.

**Crop evapotranspiration, effective rainfall and irrigation water requirement**

During the normal rainfall year, the cotton crop duration ranged between 150 days to 250 days (Fig. 2). The crop evapotranspiration ($ET_c$) for the entire period of the cotton crop was increasing with an increase in crop duration. Crop evapotranspiration was 583.4 mm for 150 days crop duration and it was increased to the level of 917.4 mm for 250 days cotton crop. For the short duration of the cotton crop (150 to 212 days), most of the $ET_c$ requirement was met out from the effective rainfall and after that (222 to 250 days), the share of effective rainfall was showing a declining trend. The gap between $ET_c$ and effective rainfall was met out by supplying irrigation water to crop. The irrigation water requirement was also increasing with an increase in crop duration. The effective rainfall ranging between 452.7 to 507.2 mm and irrigation water requirement ranged between 179.3 to 598.3 mm. The crop duration during the drought year in the study area ranged between 122 days to 252 days (Fig. 3). During the drought year, the $ET_c$ for the entire cotton period in the study area ranged between 481.2 to 925.4 mm. During the short duration of the cotton crop (122 to 145 days) most of the $ET_c$ requirement was met out from the effective rainfall after that (145 to 252 days) larger part of $ET_c$ requirement was met out from the irrigation water. The effective rainfall ranging between 324.5 to 323.9 mm and irrigation water requirement ranged between 230.3 to 743.8 mm.

The evapotranspiration demand depends on temperature, solar radiation, humidity, wind speed and plant characteristics like stomatal conductance and leaf area index (Priya et al., 2014). If a region becomes warmer, there will be increased evaporative demand and more irrigation water will be required to maintain crop yields (Priya et al. 2014). In the study area, the evapotranspiration was higher during drought year
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as compared to normal rainfall year. As a result, irrigation water requirement was more and effective rainfall was less during drought year as compared to normal rainfall year.

**Fertilizer application**

Fig. 4 represents the fertilizer applied by the sample farmers in the cotton crop during normal rainfall and drought year. During the normal rainfall, the average quantity of chemical fertilizer applied by the sample farmers in the study area was 329 kg per hectare and it was ranging between 137 to 561 per hectares. During a drought year, the average quantity of fertilizer applied by the sample farmers was 244 kg per hectare and it was ranging between 124 to 521 kg per hectare. It is clear from the above discussion that during the drought year, fertilizer application to the cotton crop was reduced by 25.82 per cent as compared to normal rainfall year. Past researchers reported that there is positive and significant relationship between irrigation water use and intensity of fertilizer application (Yan et al., 2019; Zafar et. al., 2020; Feng et al., 2020; Lian et al., 2017). Similar results were also observed in the study area. The doses of fertilizer application in cotton crop was higher during the normal rainfall year as compared to drought year in the study area.

**Crop yield**

Agricultural production largely depends upon natural calamities. Despite the fact that Indian government and farmers were creating/developing irrigation facility for providing irrigation water to the crop. Fig. 5 represents the cotton yield during normal rainfall and drought year for the sample farmers. During the normal rainfall year, the average per hectare cotton yield for sample farmers was estimated to be 2386 kg and it was ranging between 1333 to 3875 kg. During the drought year, the average cotton yield in the study area was estimated to be 1499 kg per hectare. The cotton yield of the sample farmers during drought year was ranging between 172 to 2500 kg per hectare. The cotton yield during drought year was nearly 37.18 per cent, which was lower than the normal rainfall year.

The past researchers reported that there is a linear relationship between crop yield and irrigation water

| Particulars                                      | Million Cubic Meter (MCM) |
|-------------------------------------------------|---------------------------|
| 1. Total groundwater recharge (monsoon & non-monsoon season) | 819.61                    |
| 2. Total natural discharge                       | 40.98                     |
| 3. Annual Extractable Ground Water Resources     | 778.63                    |
| 4. Current annual groundwater extraction:        |                           |
| a. Irrigation                                   | 463.52                    |
| b. Industrial                                   | 430.98                    |
| c. Domestic                                     | 4.88                      |
| 5. Net Ground Water Availability for future use | 27.66                     |
| 6. Stage of Ground Water Extraction (%)         | 296.18                    |
| 7. Net Ground Water Availability for future use | 59.53                     |

Table 1. Dynamic ground water resources of Bhavnagar District, 2017.

Fig. 2. ETc, effective rainfall and irrigation requirement during normal rainfall year.

Fig. 3. ETc, effective rainfall and irrigation requirement during drought year.

Fig. 4. Fertilizer application in cotton during normal rainfall and drought year.

Fig. 5. Cotton yield during normal rainfall and drought year.
supply less than optimum (deficit) irrigation (Li et al., 2017; Montoya et al., 2017; Fucang et al., 2015; Zafar et al., 2020). Massive output return of agricultural production can be achieved by maintaining environmental quality and efficiently managing inputs practising like irrigation scheduling and efficient use of fertilizer (Macintosh et al., 2019; Willy et al., 2019). Similar results were also observed in the study area. During normal rainfall year, the cotton yield was higher than the drought year.

Irrigation water use and water productivity
Table 2 represents the cotton yield, irrigation water applied for growing irrigated cotton and physical irrigation water productivity of sample farmers during normal rainfall and drought year under alternate furrow and drip method of irrigation. It is clear that during the normal rainfall year, farmers were getting higher cotton yield as compared to drought year under both methods of irrigation viz., alternate furrow and drip. During the normal rainfall year, farmers were applying less irrigation water under both irrigation methods compared to drought year. The physical water productivity for applied water was higher for both the irrigation method during normal rainfall year compared to drought year. The crop yield and physical water productivity for the drip irrigation method were higher during normal rainfall year and drought year than the alternate furrow irrigation method. The sample farmers applied less volume of irrigation water under drip method of irrigation compared to alternate furrow method of irrigation during normal rainfall and drought year.

During the normal rainfall year, the per hectare cotton yield of the sample farmers in the study area was found to be 2313 and 3389 kg for alternate furrow and drip irrigation method, respectively (Table 2). The irrigation water applied for cotton production under alternate furrow and drip irrigation was found to be 6521.82 and 5086.44 m³ per hectare, respectively. The applied physical water productivity was found to be 0.33 and 0.40 kg per m³ for alternate furrow and drip method of irrigation, respectively. Many past researchers reported that after the adoption of water saving technology, i.e. Drip, crop yield under drip method of irrigation was higher than conventional/alternate furrow method of irrigation (Fucang et al., 2015; Parthasarathi et al., 2018; Assefa et al., 2019; Abdelraouf et al. 2020; Barkunan et al., 2019; Uddian and Dhar, 2020; Mehriya et al., 2020)

Total water use and water productivity
Per hectare cotton yield, total water use (effective rainfall + irrigation water) and physical water productivity for cotton crop under alternate furrow and drip irrigation methods are presented in Table 3. Here, it is assumed that there is no return flow from the cotton field in the study area under both irrigation methods, i.e. alternate furrow and drip irrigation. It is clear from Table 3 that the per hectare cotton yield, total water use and physical water productivity was higher under drip irrigation for both conditions viz., normal rainfall year and drought year as compared to alternate furrow method of irrigation.

During the normal rainfall year, the sample farmers’ per hectare average cotton yield was 2313 and 3389 kg for alternate furrow and drip method of irrigation, respectively. Total water (effective rainfall + irrigation water) used for cotton production in the study area was 7931.37 and 5612.21 m³ per hectare under alternate furrow and drip irrigation. The physical water productivity was found to be 0.29 and 0.40 kg per m³ for alternate furrow and drip method of irrigation, respectively (Table 3).

During the drought year, per hectare, the average cotton yield in the study area was estimated to be 1593 and 1985 kg under alternate furrow and drip irrigation, respectively (Table 2). The irrigation water applied by the sample farmers for irrigated cotton production under alternate furrow and drip method of irrigation was found to be 6521.82 and 5086.44 m³ per hectare, respectively. The applied physical water productivity was found to be 0.33 and 0.40 kg per m³ for alternate furrow and drip method of irrigation, respectively. Many past researchers reported that after the adoption of water saving technology, i.e. Drip, crop yield under drip method of irrigation was higher than conventional/alternate furrow method of irrigation (Fucang et al., 2015; Parthasarathi et al., 2018; Assefa et al., 2019; Abdelraouf et al. 2020; Barkunan et al., 2019; Uddian and Dhar, 2020; Mehriya et al., 2020)

Table 2. Cotton yield, irrigation water use and physical water productivity.

| Particulars                          | Method of Irrigation |
|-------------------------------------|----------------------|
|                                     | Alternate furrow     | Drip               |
|                                     | Normal Rainfall Year |                    |
| Crop Yield (Kg/Ha)                  | 2313                 | 3389               |
| Irrigation water applied (m³/Ha)    | 4486.09              | 2994.97            |
| Physical irrigation water productivity (Kg/m³) | 0.79                | 0.97               |
| Drought Year                        |                      |                    |
| Crop Yield (Kg/Ha)                  | 1593                 | 1985               |
| Irrigation water applied (m³/Ha)    | 6521.82              | 5086.44            |
| Physical irrigation water productivity (Kg/m³) | 0.33                | 0.40               |
Table 3. Cotton yield, total water use and physical water productivity.

| Particulars                     | Method of Irrigation                  | Normal Rainfall Year | Drought Year |
|---------------------------------|---------------------------------------|----------------------|--------------|
|                                 | Alternate furrow | Drip | Alternate furrow | Drip |
| Crop yield (Kg/ha)              | 2313 | 3389 | 1577 | 1638 |
| Total water use [effective rainfall + irrigation water] (m$^3$/Ha) | 7931.37 | 5612.21 | 6006.22 | 5163.04 |
| Physical water productivity (Kg/m$^3$) | 0.29 | 0.60 | 0.26 | 0.32 |

Conflict of interest
The authors declare that they have no conflict of interest.

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