*International Journal of Plant & Soil Science*

***Volume 37, Issue 3, Page 407-414, 2025; Article no.IJPSS.133770***
***ISSN: 2320-7035***

# Estimation of Water Requirement of Different Field Crops Grown in Tons Pump Canal Command Area of Eastern Uttar Pradesh, India

**Sachchida Nand Singh [a*], Mohd. Aftab Alam [a], Bharti Tiwari [a], Alka Kumari [b] and Surendra Kumar Pali [a]**

*[a] Department of Irrigation and Drainage Engineering, Sam Higginbottom University of Agriculture Technology and Science, Prayagraj, Uttar Pradesh, India.*
*[b] Department of Soil and Water Conservation Engineering, Banaras Hindu University, Varanasi, Uttar Pradesh, India.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI: https://doi.org/10.9734/ijpss/2025/v37i35377

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/133770

***Original Research Article***

***Received: 29/01/2025***
***Accepted: 02/04/2025***
***Published: 03/04/2025***

## ABSTRACT

The estimation of water requirements for different field crops was conducted in the Tons Pump Canal Command Area of Eastern Uttar Pradesh, utilizing twenty-five years of meteorological data. The study aimed to determine the reference evapotranspiration (ETo) and crop water requirements for major crops cultivated in the region, including wheat, paddy, barley, millet, pea, potato, sugarcane, mustard, til, Arhar, and gram. The Penman-Monteith equation was employed to

**Corresponding author: E-mail: snsingh181992@gmail.com;*

***Cite as:*** *Singh , Sachchida Nand, Mohd. Aftab Alam, Bharti Tiwari, Alka Kumari, and Surendra Kumar Pali. 2025. "Estimation of Water Requirement of Different Field Crops Grown in Tons Pump Canal Command Area of Eastern Uttar Pradesh, India". International Journal of Plant & Soil Science 37 (3):407-14. https://doi.org/10.9734/ijpss/2025/v37i35377.*

calculate ETo, which ranged from 2.27 mm to 6.80 mm per day. The estimated crop water requirements were found to be 53.84 cm for wheat, 16.43 cm for paddy, 32.88 cm for barley, 6.38 cm for pea, 25.39 cm for potato, 70.02 cm for sugarcane, 33.31 cm for mustard, 150.23 cm for til, 38.38 cm for Arhar, 3.57 cm for gram, and 4.98 cm for another crop. Notably, millet required no additional irrigation. These findings provide valuable insights into the water management needs of field crops in the Tons Pump Canal Command Area, assisting in efficient irrigation planning and sustainable water resource utilization. The study underscores the importance of crop-specific water management strategies to optimize agricultural productivity in the region.

*Keywords: Crop water requirement; estimation; evapotranspiration; tons pump canal.*

## 1. INTRODUCTION

The water and land are two most critical requirements for human life in which water is depleting at an alarming rate due to rapid urbanization and intensive irrigation systems. India has of 328 million hectares area, accounting for 2.5 percent of the world's area. After the United States, India has the world's second-largest arable land area of 159.7 million hectares (394.6 million acres). It has the world's highest gross irrigated crop area of 82.6 million hectares (215.6 million acres). Irrigation uses two-thirds of the world's fresh water, with groundwater supplies contributing significantly. Agricultural water needs cannot depend alone on surface water due to irregular rainfall and insufficient access to water from rivers. Groundwater is a reasonable option for meeting agricultural needs but overexploitation should be avoided, as the decrease in groundwater levels in India as well as many other parts of the world, has been critical issue.

Surface water (such as rivers, canals, fresh water lakes and streams) and ground water (such as well and borewell water) are the two major sources of water (Khan and Rehman, 2017). Large-scale canal irrigation was introduced by the British and people continued in independence India and it were the most commonly used irrigation system at that time. Currently net area irrigated by canals in India is approximately 15.8 million hectares. The major canal irrigated areas of India are in the northern plains, with Uttar Pradesh, Haryana, Punjab, Rajasthan, and Bihar accounting for nearly 60% of the country's canal irrigated area. Andhra Pradesh, Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Orissa, and Tamil Nadu are important canal irrigation states in south and central India. It is necessary to forecast irrigation needs and give crops the right amount of water for maximum productivity in order to preserve remaining groundwater and avoid overexploitation. Sufficient moisture is essential for proper crop establishment, growth, yield, and quality. The amount of water required throughout a growing season varies according to the crop, targeted yield, soil, temperature, solar radiation, and other cultural factors. The area of Prayagraj district, selected in the present study, lacks reliable information on the changes in rainfall. This study will immensely benefit in agricultural applications such as water project planning and management.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The *Tons* pump canal command area of Eastern Uttar Pradesh is located in Karchhana Tehsil of Prayagraj district as shown in Fig. 1. There are total three blocks comes under the Karchhana tehsil namely - Chaka, Karchhana, Kondhiyaar. Prayagraj district lies between 24˚47' and 25˚43' N latitude and 81˚31' and 82˚21' E longitude. The total geographical area of Prayagraj district is 5482.00 km$^2$. The *Tons* pump canal command area of Karchhana Tehsil lies between 25˚09'15" and 25˚25'02" N latitude and 81˚48'25" and 82˚04'45" E longitude. The total geographical area of the study area is 546.03 km$^2$.

### 2.2 Climate

Prayagraj district has a humid subtropical climate which is characterized by three seasons: a hot dry summer, a cool dry winter and a hot humid monsoon. The winter usually extends from mid-November to last week of February and is followed by the summer which continues till about the middle of June. The normal rainfall of Prayagraj district is 1027 mm (40.43 inch) and approximately 88% of the annual rainfall received during the monsoon season but the variation from year to year is appreciable. There are approximately 48 rainy days in a year. The yearly

rainfall trend in the study area from 1997 to 2021 is shown in Fig. 2. The annual mean temperature is 26.1 °C (79.0 °F) and monthly mean temperatures are 18–29 °C (64–84 °F). Temperatures begin to rise in March and reach their peak in mid-May to mid-June before gradually declining till they reach their lowest point in mid-December to mid-January (SHUATS Prayagraj). During the monsoon period, the relative humidity in the study area ranges from 70% to 80% while it drops at 15% to 20% during the summer period. During the summer, wind speeds were generally high. From January to December, the wind speed ranged from 2.7 km/hr to 8.7 km/hr with mean yearly speed about 5.7 km/hr.

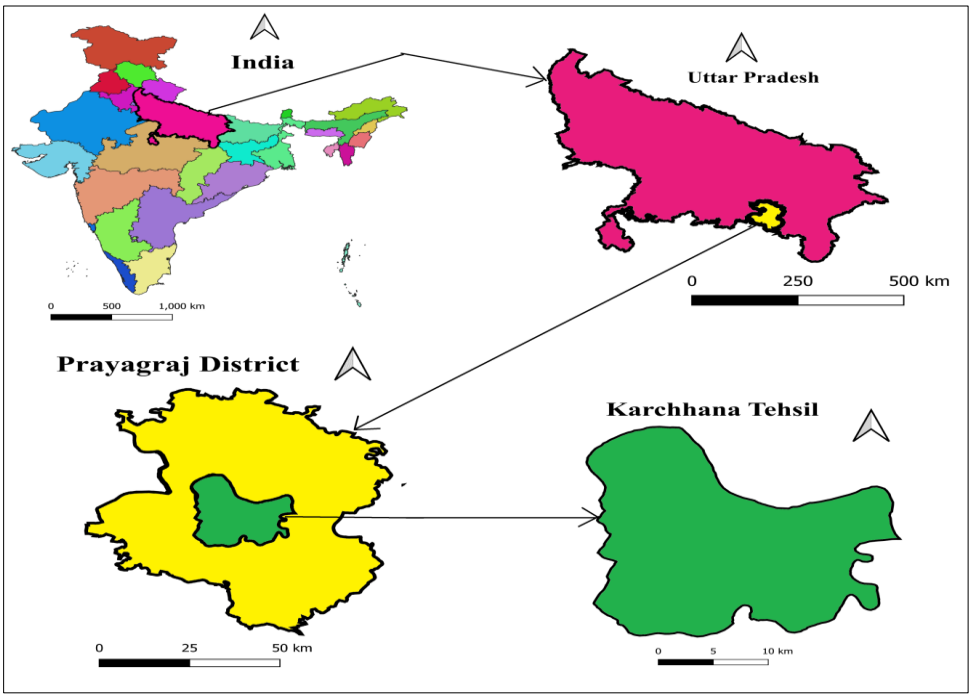


**Fig. 1. Index map of the study area**

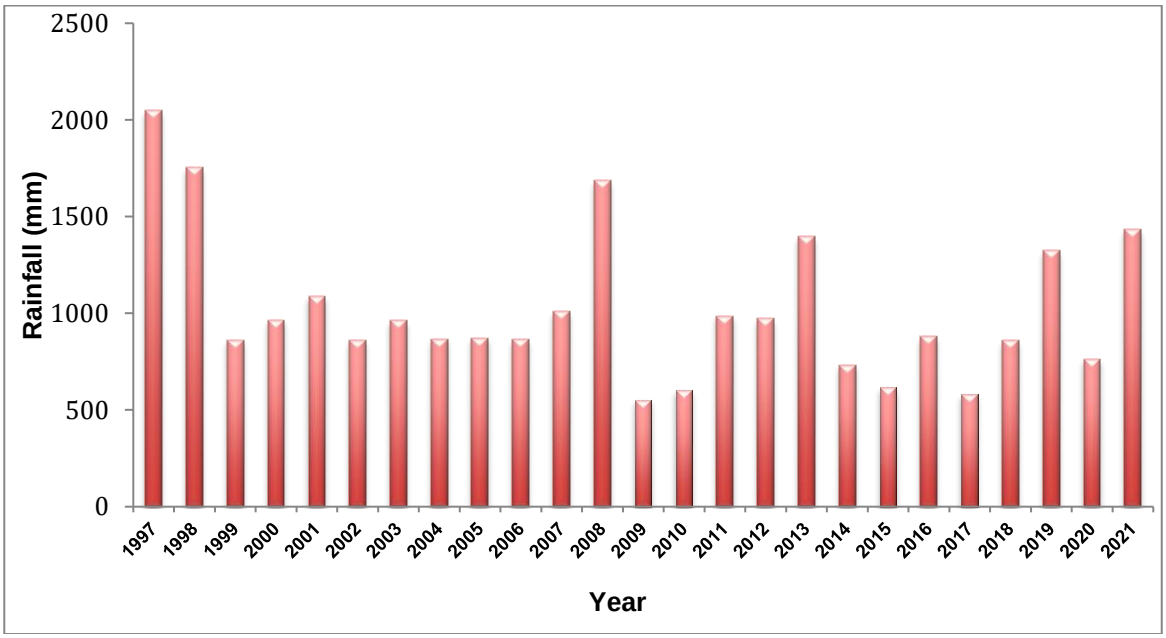


**Fig. 2. Yearly rainfall in the study area**

## 2.3 Land Use

The land of the study area has been divided into four categories *i.e.* gross sown area, fallow land, horticultural land, and grass land. Agriculture covered around 62% of the Prayagraj district and 66% of the study area. The main crops of study area are wheat, rice, and pearl millet.

## 2.4 Data Collection

Meteorological data from 1997 to 2021 (25 years) were collected from the College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) Prayagraj. Data regarding cropping pattern was collected from statistical department of Prayagraj.

## 2.5 Existing Cropping Pattern

In the study area, cropping practices revolve in two main seasons: *Kharif* (October to March) and *Rabi* (July to October). *Rabi* season crop sowing starts towards the end of October or the beginning of November, whereas *Kharif* season crop sowing starts in the middle of June. The main crop grown in *Rabi* and in *Kharif* season is wheat and rice, respectively. Study area existing cropping pattern is given in Table 1.

## 2.6 Estimation of the Irrigation Requirement of Different Crops

Estimation of the irrigation needs of crops of various crops which is grown in the study area calculated by using reference evapotranspiration ($ET_0$), coefficient of crop (Kc), crop evapotranspiration ($ET_{crop}$), effective rainfall, water needed for net irrigation and gross irrigation water requirement.

### 2.6.1 Reference evapotranspiration (ETo)

There are various methods of estimating the reference evapotranspiration. Water requirement for different crops was estimated in this study by utilizing the Penman Monteith Equation.

$$ET_o = \left[\frac{0.408\triangle(Rn-G)+\gamma\left(\frac{900}{T+273}\right)u_2(VPD)}{\Delta+\gamma(1+0.34\,u_2)}\right]$$

Where,

$ET_o$ = reference evapotranspiration [mm $day^{-1}$],

Rn = at crop surface, net radiation [$MJm^{-2}day^{-1}$],

G = heat flux density in soil [$MJm^{-2}day^{-1}$],

T = temperature of air at height of 2 metres [°C],

$u_2$ = speed of wind at height of 2 metres [m $s^{-1}$],

$e_s$ = vapour saturation pressure [kPa],

$e_a$ = vapour actual pressure [kPa],

$e_s$-$e_a$ = deficit vapour saturation pressure [kPa],

Δ = Vapour pressure slope curve [kPa°$C^{-1}$],

Γ = psychrometric constant [kPa°$C^{-1}$].

**Table 1. Existing cropping pattern of the study area**

| S. No. | *Rabi* season | | S. No. | *Kharif* season | |
|---|---|---|---|---|---|
| | **Crop** | **Area (ha)** | | **Crop** | **Area (ha)** |
| 1 | Wheat | 25155 | 1 | Paddy | 15174 |
| 2 | Gram | 2003 | 2 | Millet | 4879 |
| 3 | Potato | 846 | 3 | *Arhar* | 3362 |
| 4 | Barley | 515 | 4 | Sorghum | 543 |
| 5 | Mustard | 488 | 5 | Black Gram (*Urad*) | 104 |
| 6 | Pea | 370 | 6 | *Til* | 11 |
| 7 | Sugarcane | 197 | 7 | Sugarcane | 197 |
| **Cultivated land** | | **29574** | **Cultivated land** | | **24270** |
| **Fallow land** | | **25029** | **Fallow land** | | **30333** |
| **Total land** | | **54603** | **Total land** | | **54603** |

*Source: District statistical Dairy (2021) Prayagraj, Uttar Pradesh*

### 2.6.2 Crop coefficient ($K_c$)

The value of crop coefficient available for every crop growth stage, i.e. initial, crop development, mid-season and late-season stage, were taken from FAO, 56 (Allen et al., 2014). The $K_c$ was estimated by using curve of crop coefficient methods as recommended by FAO 56.

### 2.6.3 Crop evapotranspiration (ETcrop)

Evapotranspiration of each crop was estimated by multiplying reference evapotranspiration ($ET_o$) mm/day to coefficient of crop ($K_c$) (Babu et al., 2016).

$$ET_{crop} = ET_0 \times K_c$$

### 2.6.4 Effective rainfall

Effective rainfall was estimated on the basis of Soil Conservation Service Method (USDA) formula. The formulas utilized in analysis are as following:

$P_{eff} = P_t (125-0.2\ P_t) \times (1/125)$ for $P_t < 250$ mm, and

$P_{eff} = 125 + 0.1 \times P_t$ for $P_t > 250$ mm

Where,

$P_{eff}$ = effective rainfall,

$P_t$ = total rainfall.

### 2.6.5 Net Irrigation Water Requirement (NIWR)

The water needed for net irrigation of each crop was calculated by utilizing field water balance. The formulas utilized in analysis are as following:

$$NIWR = ET\ crop - (P_{eff} + Ge + Wb)$$

Where,

$ET_{crop}$ = crop evapotranspiration,

$P_{eff}$ = effective rainfall,

$G_e$ = groundwater contribution, and

$W_b$ = stored soil water.

## 3. RESULTS AND DISCUSSION

### 3.1 Reference Evapotranspiration ($ET_o$)

The FAO-56 Penman-Monteith method was used to estimate the daily reference evapotranspiration ($ET_o$) values. On the basis of climatological data of 25 years, the computed average daily reference evapotranspiration values are graphically represented in Fig. 3. The estimated daily average reference evapotranspiration ($ET_o$) ranged from 2.27 mm to 6.80 mm.

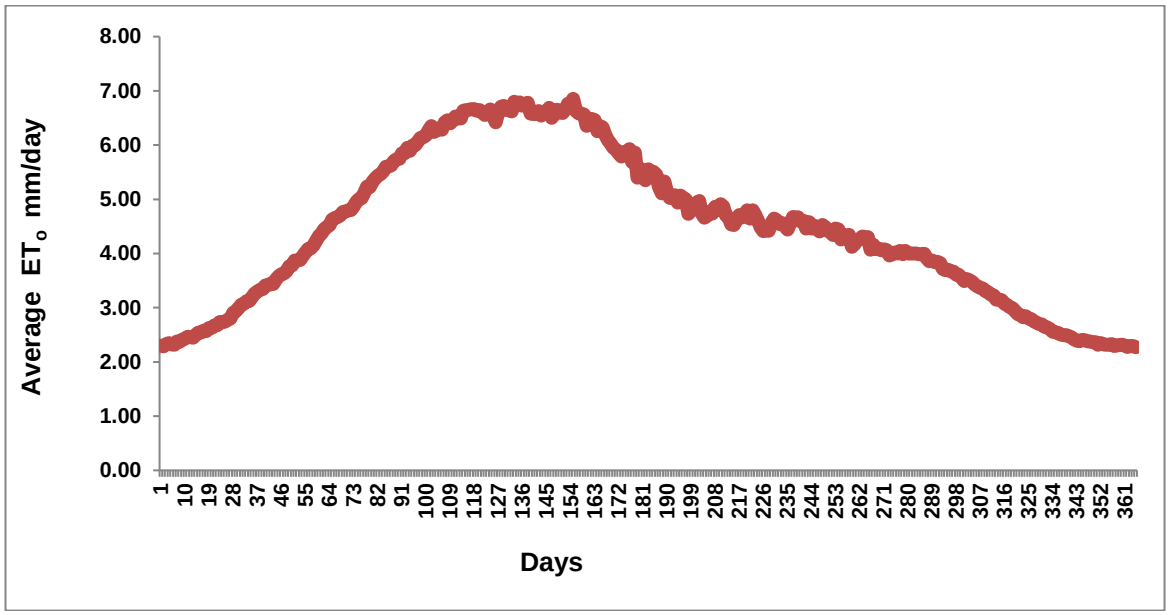


**Fig. 3. Variation of estimated average daily reference evapotranspiration, using FAO-56 Penman-Monteith method**

**Table 2. The number of days for each crop's growth period and each crop's stage-specific KC value**

| Crop | Sowing time | Growth stage period (days) | | | | Total | KC Initial | KC Mid | KC End |
|---|---|---|---|---|---|---|---|---|---|
| | | Initial | Development | Mid | Last | | | | |
| Wheat | November | 20 | 25 | 70 | 30 | 145 | 0.70 | 1.15 | 0.30 |
| Paddy | Mid June | 30 | 30 | 80 | 40 | 180 | 1.05 | 1.20 | 0.90 |
| Millet | Mid June | 15 | 25 | 40 | 25 | 105 | 0.70 | 1.00 | 0.30 |
| Barley | November | 15 | 25 | 50 | 30 | 120 | 0.30 | 1.15 | 0.25 |
| *Urad* | March | 20 | 30 | 30 | 30 | 110 | 0.40 | 1.05 | 0.50 |
| Pea | November | 15 | 25 | 35 | 15 | 90 | 0.50 | 1.15 | 0.30 |
| Gram | Mid October | 20 | 30 | 30 | 30 | 110 | 0.40 | 1.05 | 0.60 |
| Sorghum | April | 20 | 35 | 45 | 30 | 130 | 0.70 | 1.00 | 0.55 |
| Potato | Mid October | 25 | 30 | 30 | 30 | 115 | 0.50 | 1.15 | 0.75 |
| Sugarcane | October | 25 | 70 | 135 | 50 | 280 | 0.40 | 1.25 | 0.75 |
| Mustard | Mid October | 20 | 40 | 60 | 25 | 145 | 0.35 | 1.00 | 0.35 |
| *Arahar* | Mid June | 30 | 25 | 50 | 25 | 130 | 0.50 | 1.00 | 0.60 |
| *Til* | July | 20 | 30 | 40 | 10 | 100 | 0.35 | 1.10 | 0.25 |

**Table 3. Monthly gross irrigation water requirements for different crops grown in study area**

| Month | Gross Irrigation Water Requirement (cm) | | | | | | | | | | | | | Total (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wheat | Paddy | Barley | Millet | *Urad* | Pea | Sorghum | Potato | Sugarcane | Mustard | *Till* | *Arhar* | Gram | |
| Jan | 9.65 | 0.00 | 9.65 | 0.00 | 0.00 | 7.63 | 0.00 | 8.50 | 10.63 | 8.13 | 0.00 | 0.00 | 5.66 | **59.85** |
| Feb | 13.69 | 0.00 | 7.80 | 0.00 | 0.00 | 0.00 | 0.00 | 2.28 | 15.14 | 10.15 | 0.00 | 0.00 | 0.41 | **49.47** |
| Mar | 11.26 | 0.00 | 0.00 | 0.00 | 8.74 | 0.00 | 6.69 | 0.00 | 29.51 | 2.40 | 0.00 | 0.00 | 0.00 | **58.60** |
| Apr | 0.00 | 0.00 | 0.00 | 0.00 | 22.50 | 0.00 | 22.73 | 0.00 | 30.88 | 0.00 | 0.00 | 0.00 | 0.00 | **76.11** |
| May | 0.00 | 0.00 | 0.00 | 0.00 | 23.25 | 0.00 | 26.52 | 0.00 | 28.75 | 0.00 | 0.00 | 0.00 | 0.00 | **78.53** |
| Jun | 0.00 | 1.97 | 0.00 | 0.00 | 5.88 | 0.00 | 14.07 | 0.00 | 14.24 | 0.00 | 0.00 | 0.00 | 0.00 | **36.16** |
| Jul | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |
| Aug | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |
| Sep | 0.00 | 3.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.79 | 0.62 | 0.00 | **5.49** |
| Oct | 0.00 | 11.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.96 | 2.98 | 1.85 | 1.78 | 4.31 | 2.22 | **27.50** |
| Nov | 7.22 | 0.00 | 3.49 | 0.00 | 0.00 | 5.50 | 0.00 | 6.98 | 6.88 | 5.43 | 0.00 | 0.00 | 6.69 | **42.18** |
| Dec | 12.02 | 0.00 | 11.96 | 0.00 | 0.00 | 12.26 | 0.00 | 12.59 | 11.21 | 10.42 | 0.00 | 0.00 | 11.80 | **82.26** |
| **Total** | **53.84** | **16.43** | **32.88** | **0.00** | **60.38** | **25.39** | **70.02** | **33.31** | **150.23** | **38.38** | **3.57** | **4.94** | **26.79** | **516.15** |

### 3.2 Crop evapotranspiration, $ET_{crop}$

The method described in equation 2 was used to estimate the weekly crop evapotranspiration ($ET_c$) values for the various crops grown in the study area. Based on the average $ET_o$ and $K_c$ values for the last 25 years, the $ET_{crop}$ values were calculated. According to FAO-56 approach was used to develop the crop coefficient curves for various crops. The period of crop growth and the related KC values for each stage is given in Table 2.

### 3.3 Crop Water Requirement

The weekly net irrigation requirements of different crops were estimated based on $ET_{crop}$ and average effective rainfall values. Therefore, the monthly gross irrigation requirements (GIR) of different crops in study area are given in Table 3. It may be seen from Table 3 that the maximum monthly water requirement in the month of December was 82.26 cm, while the minimum value was zero in the months of July and August.

## 4. CONCLUSION

This study highlights the variability in crop water requirements in the Tons Pump Canal Command Area of Eastern Uttar Pradesh, emphasizing the importance of efficient irrigation planning. The findings indicate that millets can be grown successfully without supplemental irrigation, making them a suitable crop for water-scarce conditions. In contrast, sugarcane exhibited the highest water requirement, necessitating careful irrigation management. The seasonal analysis revealed that irrigation is not required during the monsoon months of July and August, as natural precipitation is sufficient. However, April and December experience significant water deficits, necessitating intensive irrigation to support crop growth. These insights can aid in the development of water-saving strategies, crop selection, and improved irrigation scheduling, ensuring sustainable agricultural practices in the region.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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