__Original Research Article__

Assessment of Irrigation Requirements for Summer Paddy Cultivation on *Vertisols* in Raipur, Chhattisgarh

ABSTRACT

Water scarcity is a critical issue in agriculture, especially for summer crop cultivation in central India. The long-term sustainability of the summer crop is contingent upon the effective management of available water resources through optimal irrigation. This requires accurate data on evapotranspiration, crop water requirements, and irrigation scheduling. The study emphasizes ascertaining the water needs for summer paddy cultivation on *vertisols* soil in Raipur district of Chhattisgarh. During the summer seasons of 2023 and 2024, field experiments were conducted at the Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, to collect information on cumulative irrigation, crop management techniques, and other pertinent data. The FAO-CROPWAT 8.0 model was employed for the study, utilizing the FAO Penman-Monteith technique to analyses meteorological data and evaluate reference evapotranspiration (ET_0). Crop evapotranspiration (ETc) was computed using crop coefficient (Kc) values associated with specific developmental stages. A comprehensive water balance model for summer paddy was developed, containing soil, climate, and phenological variables. The findings indicated that the crop evapotranspiration (ETc) and irrigation water requirement (Irr Req) for both seasons were 714 mm and 723 mm, and 772 mm and 793 mm, respectively. Upon adjusting for field losses, the total net irrigation (TNI) for both the years was assessed at 988 mm and 1009 mm, whereas combining 70% of the irrigation system efficiency, the total gross irrigation (TGI) was evaluated at 1411 mm and 1443 mm, respectively. This study offers essential insights for effective irrigation management for summer paddy, fostering sustainable agriculture, and resource distribution. Utilizing CROPWAT 8.0 to optimize irrigation schedules and enhance water consumption efficiency facilitates comprehensive decision-making in water resource management, highlighting the necessity for customized methods to meet distinct agricultural water requirements.

Keywords: Summer paddy, Crop water requirement (CWR), Irrigation requirements, irrigation scheduling, CROPWAT 8.0.

1. INTRODUCTION

Despite the fact that India is abode to 18% of the global population, it only has 4% of the world's renewable water resources (Shiklomanov, 2000). The significant use of freshwater for irrigation, notably in agriculture, highlights a critical water management challenge (Sharma *et al.*, 2018). Global water scarcity is exacerbated by ineffective water management in agriculture, which has an impact on sustainable water use (Madani *et al*., 2016). Agriculture, which is the largest consumer of freshwater, frequently encounters challenges in optimizing water use efficacy in comparison to other sectors (Taheripour*et al*., 2015).

The agricultural practicesof India aresignificantly influenced by paddy cultivation, which occupies a quarter of the cultivated land and provides a primary food source for half of the population (FAO, 2020). Chhattisgarh, indicated as the "Rice Bowl" of Central India, is distinguished for its significant rice cultivation (Ram *et al*., 2023). Despite government recommendations to priorities other crops like oilseeds and pulses during the rabi season, farmers increasingly opt for summer paddy due to its higher yields attributed to favorable weather conditions and lower pest incidence (Mongabay, India, 2020).Nevertheless, the recent increase in cultivation of summer paddy has prompted disquiets about the sustainability of water management.

The water resources of Chhattisgarh are being strained by the intensification of irrigation for summer paddy cultivation. The state's basin is 85% covered by rivers such as the Ganga, Mahanadi, Narmada, and Godavari, which are essential water sources (CGWB, 2021). Nevertheless, the increasing irrigation needs are not adequately addressed by the 18,249 million cubic meters of available surface water (CGWB, 2021).

In regions with erratic rainfall patterns, such as in the summer season, the effective administration of irrigation is essential for guaranteeing food security. To optimize irrigation scheduling and water use efficiency in agriculture, it is essential to comprehend crop water requirement (CWR) and evapotranspiration (ET) (Doorenbos and Pruitt, 1977). Allen *et al*., (1998); Smith *et al*., (2009) underscored the significance of precise CWR estimation in the context of sustainable irrigation management. The CROPWAT 8.0 model is employed in this study to achieve the primary objective of the research to evaluate the irrigation water requirement and irrigation scheduling for summer paddy in Raipur District, Chhattisgarh, for available *vertisols* soil, thereby promoting sustainable water management in agriculture.

The FAO-CROPWAT 8.0 model facilitates the estimate of crop water requirements (CWR) by including environmental factors with the specific needs of the crop; hence, it helps to develop customized water resource management strategies and irrigation planning (FAO, 2012). Attributed to sustainable water resources management in agriculture by the integration of precise CWR estimation into irrigation scheduling, which can minimize water wastage and maximize agricultural productivity (Allen *et al*., 1998; Smith *et al*., 2009).

In summary, the critical importance of effective water management is emphasized by the challenges of water scarcity and intensified agriculture, particularly in summer paddy cultivation. In regions like Chhattisgarh, where irrigation is essential for agricultural productivity, utilizing tools such as CROPWAT 8.0 for crop water requirement estimation and irrigation scheduling can significantly enhance sustainable water use and contribute to food security amidst increasing water stress.

2. MATERIALS AND METHODS

2.1 Description of study area

On November 1, 2000, Chhattisgarh was embraced as the 26th state of India,situated between 17°46' and 24°5' North Latitude and 80°15' and 84°20' East Longitude. The Bastar Plateau, Chhattisgarh Plain, and Northern Hill are three distinct agroclimatic zones of Chhattisgarh. The Raipur district is located between 21°08' and 21°41' North Latitude and 81°14' and 81°51' East Longitude, inside the Chhattisgarh Plain Zone (Fig. 1). The typical rainfall in Chhattisgarh is approximately 1200 mm. The state has net cultivated area about 4.67 million hectares, which accounts for 34% of its total geographical spreadof 13.78 million hectares. *Vertisols*, which are locally referred to as *Kanhar*or clayey soil, comprise approximately 26.4% of the cultivated land in Chhattisgarh (Singh *et al.* 2006). The medium-to-light texture, high fertility, and exceptional water-holding capacity of *vertisols* soil render it suitable for the cultivation of a variety of crops, including paddy, wheat, maize, sugarcane, and pulses, during both the kharif and rabi seasons.

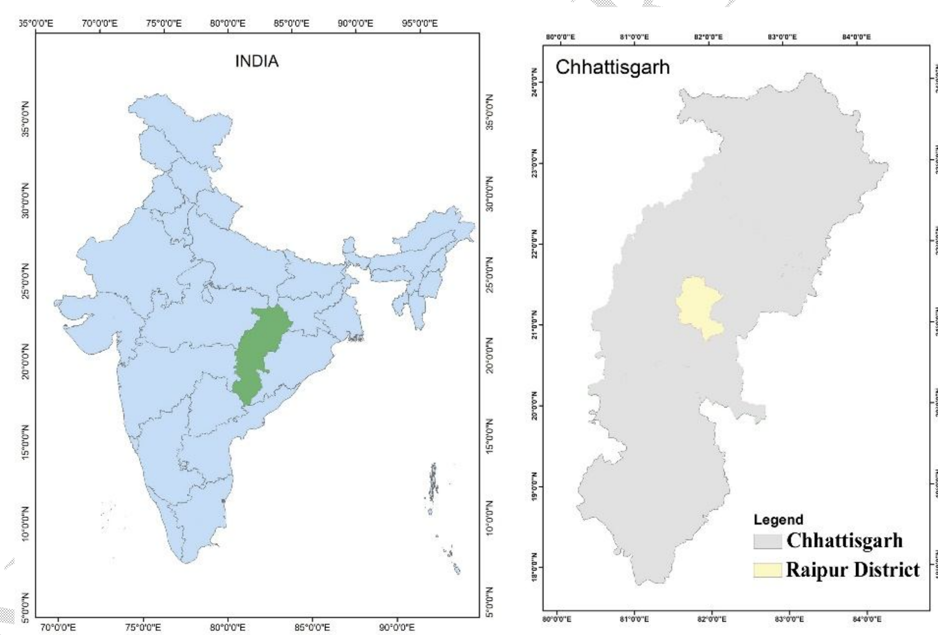

Fig. 1. Location map of the study area

2.2. Model description and input data

CROPWAT 8.0 is a freeware tool created by FAO that utilizes soil, climate, and agricultural management datasets to evaluate crop water requirements and irrigation demands. The program also facilitates the creation of irrigation schedules and is compatible with several crop management practices. The CROPWAT program uses FAO methods and the Penman-Monteith equation to compute reference crop evapotranspiration (ET_0). Crop evapotranspiration

(ETc) is then calculated by taking into account the crop coefficient (Kc). Following accounting for the losses, the net irrigation and gross irrigation water requirements are calculated.

2.3 Climate data

To calculate reference evapotranspiration with CROPWAT 8.0, agro-meteorological data is sourced from the meteorological observatory at Indira Gandhi Krishi Vishwavidyalaya in Raipur, Chhattisgarh. Model accuracy is assured by employing daily datafor the years 2023 and 2024. The data necessary for ET_0 computation include geographical characteristics like altitude, latitude, and longitude, as well as daily minimum and maximum temperatures (°C), wind speeds (km/day), humidity (%), daylight hours (h/day), and precipitation. The model employs climatic data from the daily dataset corresponding to the crop period of the designated years.

2.4Field experiment and sampling details

During the summer seasons of 2023 and 2024, paddy trials were conducted at the Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, where meticulous observations were collected with the support of the field supervisor and the scientific team of the department. The recorded data included summer paddy management practices, irrigation practices during several growth phases, and many other yields forecast metrics, etc. Moreover, comprehensive crop attributes, including field preparation strategies, length of crop growth phases, rooting depth, panicle initiation, maturation time, and other relevant details, were recorded throughout the experiments. The soil sampling was also performed from the experimental field, which was analyzed for various relevant parameters. Technical information on data needed was obtained from the help section of the CROPWAT 8.0 model, which clarifies the essential inputs. Additionally, extensive datasets from credible sources, such as FAO publications and other research projects, were considered for further insights and verification.

2.5 Crop details

The study selected MTU 1010 crop variety, a 120-day crop known for its short duration and an average rooting depth of 50 cm. This quality makes it well-suited for summer cultivation. In summer, MTU 1010 verity is frequently cultivated in *vertisols* soil in low-lying areas, where the soil shows exceptional water retention capacity.The summer paddy nursery is typically sown in mid-January and transplanted during the first week of February. The mature crop is usually harvested by mid-May after the full crop cycle has been completed.

2.6 Soil data

The soil sample that was collected from the field experiment was gone through the laboratory analysis at the Department of Soil Science and Agricultural Chemistry, IGKV, Raipur, Chhattisgarh. The results show, soil type in the field was identified as *vertisols*. The CROPWAT 8.0 program necessitates specific soil-related parameters, such as total available soil moisture, maximum rooting depthand initial available soil moisture. These parameters were determined based on correlated variables outlined in the FAO 56 manual.

2.7 Rainfall data

Rainfall data for 2023 and 2024 was collected from the agrometeorological station at IGKV Raipur which is located very near to the experimental field. The data were arranged and averaged as required for these years using MS Excel software and used as input in CROPWAT program. An established percentage approach was used to ascertain effective rainfall, defined as 70% of the total rainfall. Effective rainfall is the segment of total yearly or seasonal precipitation that directly or indirectly aids in crop production. The effectiveness of rainfall is affected by several elements, including the physical and chemical features of field and soil, meteorological conditions, and the characteristics of the rainfall itself.

2.8 Reference evapotranspiration (ET_0)

Reference crop evapotranspiration (ET□) represents the water demand of anideal grass crop, characterized by specific attributes and an ample water supply. Its primary aim is to assess atmospheric evapotranspiration demand, independent of variables such as crop type, soil properties, growth stages, and management practices. The relationship between the crop coefficient and the reference evapotranspiration enables the calculation of actual evapotranspiration for experimental conditions, as outlined in FAO 56. The Penman-Monteith equation, implemented in CROPWAT 8.0, serves as the standard method for estimating ET_0 using diverse meteorological data. For this analysis, daily average meteorological data from 2023 and 2024 were utilized, encompassing parameters such as minimum and maximum temperatures (°C), wind speed (km/day), relative humidity (%), sunlight duration, and topographical features including elevation, latitude, and longitude. This comprehensive approach facilitates accurate irrigation management and water resource planning.

2.9 Crop water requirement (CWR)

Crop water requirement (CWR) refers to the volume of water needed to offset evapotranspiration losses from a crop. It is calculated by multiplying the crop coefficient (Kc) by the reference evapotranspiration (ET_0). This relationship can be expressed mathematically as $CWR = Kc \times ET_0$. CWR is typically quantified in terms of evapotranspiration rate, measured in millimeters per day. This metric is essential for effective irrigation management and optimizing water usage in agricultural practices (Pereira *et al.*, 2015). Understanding CWR is crucial for ensuring crop health and maximizing agricultural productivity.

2.10 Irrigation Terminologies

Evapotranspiration (ET) is the integrated process of water vaporization from surfaces and transpiration from plant leaves. The ET has various relatable parameters; ET_0 denotes the reference evapotranspiration of a sufficiently irrigated reference crop, serving as a standard for estimating evapotranspiration in other crops. The FAO Penman-Monteith equation computes ET_0 using characteristics such as radiation, temperature, humidity, and wind speed data. Thereafter, crop evapotranspiration (ETc), or crop water demand, is calculated using the equation $ETc = ET_0 * Kc$, where Kc is the crop coefficient that reflects the water requirements unique to various phases of crop development. The irrigation water requirement (IR) is the volume of water necessary to meet crop evapotranspiration, taking into account effective rainfall and the water supplied by precipitation. Net irrigation water requirement (NIWR) includes all water necessary for crop development, including for losses such as percolation, leaching, application, and other losses. Furthermore, including irrigation efficiency in NIWR results in the Gross Irrigation Water Requirement (GIWR) (Michael, 2008).Figure 2 illustrates a flowchart depicting the methodology for estimating crop water requirements, irrigation needs, and the subsequent irrigation scheduling used in the research.

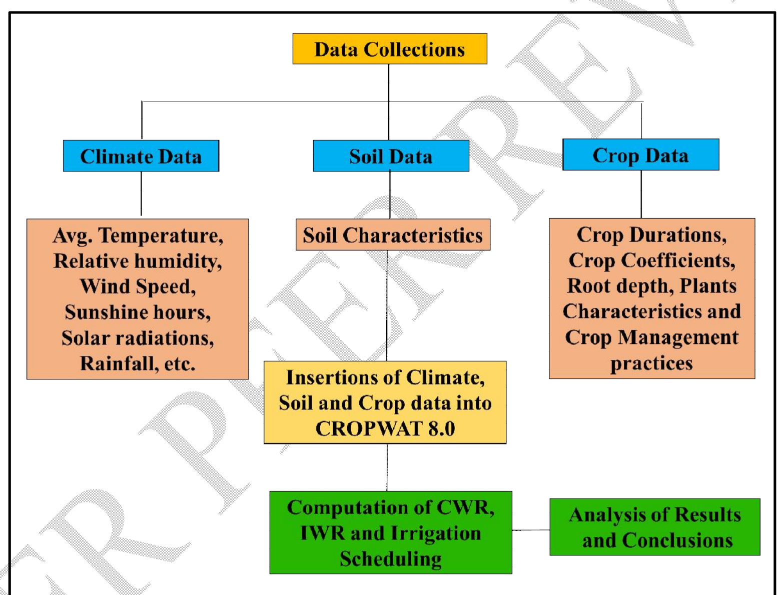

Fig. 2. Flow chart for estimation of irrigation water requirement and irrigation scheduling in CROPWAT 8.0

2.11 Scheduling the irrigation water needs

Optimal conditions for rice production need continual irrigation to satisfy varying water requirements throughout distinct development stages and seasons. After transplantation, it is essential to maintain a water depth of roughly 3 cm. As the paddy plants mature, water levels should progressively rise to a range of 5–10 cm, which must be maintained until the field is emptied 7–10 days before harvest to dry out the field to support the harvesting operation. Paddy exhibits significant sensitivity to water shortage (Kumari *et al.*, 2021).

The field experiment and irrigation scheduling also employ a standardized irrigation method predicated on particular thresholds: irrigation commences when the water depth attains 10 cm and is uniformly applied throughout all phases of the crop's life cycle. Following the irrigation discontinued when the water depth attains 4 cm in the early stages, 5 cm throughout development and midway stages, and 2 cm in the late-season stage. Irrigation is derived from a proximate borewell, with an estimated efficiency of 70%.

Results and discussions

3.1 Rainfall

The rainfall records from the years of 2023 and 2024 were used for rainfall analysis in the experimental region, providing a thorough comprehension of the precipitation patterns, with an average annual rainfall of 1720.9 mm in 2023 and 1273.3 mm in 2024. The substantial rainfall recorded in 2023 was a considerable divergence from the average, in contrast to the lesser amounts measured in 2024, highlighting the variability of rainfall distribution. This fluctuation underscores the need for adaptive techniques in agricultural planning and water resource management to address uncertain rainfall patterns and maintain sustainable practices despite changing environmental circumstances. July had the maximum rainfall for both years, followed by August and September, while February, January, and November saw the lowest precipitation. The effective rainfall is considered as at 70% of total precipitation, with the corresponding statistics shown in Table 1 and the figure 3 below.

Table 1. Monthly rainfall pattern for the year of 2023 and 2024

Month	2023		2024	
	Rainfall (mm)	Eff rainfall (mm)	Rainfall (mm)	Eff rainfall (mm)
Jan	1.8	1.3	8.6	6
Feb	0.0	0.0	5.8	4.1
Mar	21.8	15.3	28.9	20.2
Apr	34.8	24.4	62.2	43.5
May	71.4	50	13.2	9.2
Jun	226.4	158.5	188.2	131.7
Jul	501.8	351.3	361.9	253.3
Aug	348.6	244	323	226.1
Sep	479.6	335.7	217.9	152.5
Oct	11.9	8.3	44.6	31.2
Nov	5.0	3.5	8.4	5.9
Dec	17.8	12.5	10.6	7.4
Total	1720.9	1204.6	1273.3	891.3

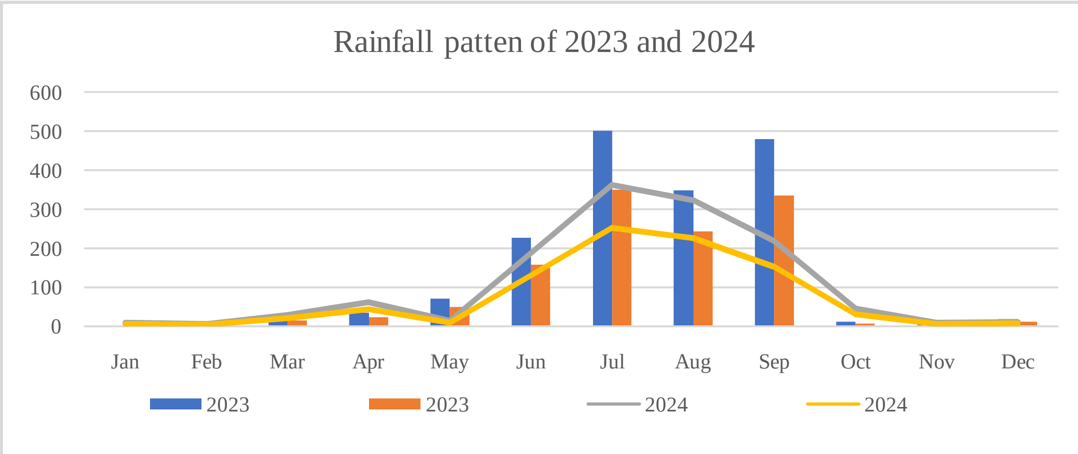

Fig. 3. Rainfall pattern for year 2023 and 2024

3.2 Reference evapotranspiration (ET_0)

A thorough assessment of the meteorological variables influencing reference evapotranspiration (ET_0) was conducted to estimate the ET_0 for the years 2023 and 2024. The model employs the Penman-Monteith equation to compute reference evapotranspiration (ET_0) using meteorological data as daily averages for minimum and maximum temperatures (°C), wind speed (km/day), relative humidity (%), sunshine duration, and topographical data, including elevation, latitude, and longitude. The result of monthly ET_0 values indicates peak measurements in May for both years, as 6.81 and 7.05 mm/day, while the lowest values were seen in December as 2.42 and 2.45 mm/day, respectively. The dataset provides significant insights into the monthly fluctuation of meteorological factors and their influence on ET_0, crucial for guiding agricultural practices, water management methods, and climate adaptation measures in the research region.

3.3 Crop water requirement

Table 2illustrates the crop water requirements for the summer paddy experiment of rice variety MTU 1010, respective to different periods of crop development. The CWR was estimated by multiplication of crop coefficient (Kc) and reference evapotranspiration (ET_0).The results indicate similar reference evapotranspiration (ET_0) for both years, as the Kc values exhibit a consistent trend. The result shows in January, the crop is in nursery phase with a Kc of 0.3, leading to negligible evapotranspiration. February marks the initial (init) stage characterized by fluctuating Kc values, signifying heightened water requirements as the crop develops, leading to elevated ETc values. March signifies the development stage, during which Kc values continue to rise as the crop grows, resulting in heightened ETc levels. The mid-season period in March and April has a peak in Kc and ETc values, signifying the highest water need during this growth phase. As the crop advances into the late-season phase in April and May, Kc levels begin to diminish, indicating decreased water demands as the crop cycle concludes. The table shows the crop water requirement for the years 2023 and 2024.

The crop coefficient (Kc) quantifies the ratio of actual evapotranspiration (ETa) to reference evapotranspiration (ET_0) for a specific crop, hence assessing its water consumption. During the cropping period of paddy, Kc values often display a trapezoidal pattern with notable variations. During the initial growth phase, the crop coefficient (Kc) stays comparatively low, referred to as Kci. As the crop progresses, Kc incrementally increases, reaching its zenith during the mid-season growth period (designated as Kcmid), indicative of the peak water need. In the late-season growth phase, Kc progressively decreases (termed Kcend), signifying fewer water requirements as the crop nears maturity (Kumari *et al*., 2022).

The model's findings correspond with those presented by Kumari *et al*. (2022), demonstrating the temporal variations in Kc and ETc values during different development stages of rice crops. The crop water requirement for the year 2023 was estimated as 714 mm, whereas for the year 2024 it was calculated at 771.6 mm, with the highest crop water demand in the mid- and late-season stages because at this time there is high water consumption that is needed by plants. It seems to be as equitable as the study conducted by Jangre*et al*., (2022), who calculated crop evapotranspiration (ETc) during the kharif season as the average CWR was determined to be 575.64 mm.This comprehensive research underscores the variable water needs over the several development phases of summer paddy (MTU1010), offering critical insights for improving irrigation strategies to enhance water management and increase crop yield.

3.4 Irrigation water requirement

Table 2 provides detailed information on the irrigation water requirements for summer paddy, computed by taking effective rainfall into account. The irrigation water requirements were determined to be 771.6 mm for 2023 and 793.1 mm for 2024. Similarresults were reported by Mohanty *et al*. (2020), who calculated a summer paddy water requirement of 844.95 mm in Orisha, India. Additionally, it was noted that during the first weeks of February, a total of 164.4 mm and 149.1 mm of water were consumed in the years 2023 and 2024, respectively for the field preparation operations. This resulted in a heightened need for irrigation water throughout the first crop phase and transplanting.

Table 2. Estimation of Crop water requirement and Irrigation water requirement

Month, dec	Stage	CWR (mm/dec)		IWR (mm/dec)	
		2023	2024	2023	2024
Jan 2	Nurs	0.3		0.3	
Jan 3	Nurs	1	0.8	1	0
Feb 1	Init	17.2	1.9	164.4	149.1
Feb 2	Init	42.6	42.7	42.6	38.6
Feb 3	Deve	38.9	37.1	38.9	37.1
Mar 1	Deve	54	52.6	53.1	52.6
Mar 2	Deve	56.9	58.7	49.2	41
Mar 3	Mid	74.2	77.3	67.5	74.8
Apr 1	Mid	72.9	75	72.2	54.4

Apr 2	Mid	88.1	74.9	88.1	61.6
Apr 3	Late	80.9	87.5	57.2	77.8
May 1	Late	74.5	91	25.1	85.9
May 2	Late	81.4	78.5	80.8	75.5
May 3	Late	31.2	45.3	31.2	44.7
Total		**714**	**723.1**	**771.6**	**793.1**

3.5 irrigation scheduling plan for summer paddy

A detailed irrigation schedule for summer paddy cultivation for the years 2023 and 2024 is shown in figures 4 and 5, respectively, highlighting the different developmental stages and irrigation needs in relation to certain days after transplanting. The data covers the period from early February, specifically a transplant date of February 7, 2023, to mid-May, culminating in a harvest date of May 24, 2023, and also includes pre-puddling to the end of the crop cycle. In 2024, the transplanting date was February 11th, while the harvesting date was May 26th. It emphasizes the precise control of irrigation operations, including puddling and irrigation application. During the various stages as puddling, initial, development, mid-season, and late season, then harvest, the irrigation scheduling efficiently sustains ideal soil moisture levels essential for crop growth and development. In the first weeks of February, a land preparation operation was conducted, requiring a substantial volume of water for puddling, as shown by the higher water demand during this time and the significant percolation observed. The findings indicate that the summer paddy net irrigation requirement (TNI), including crop water needs, land preparation, and field percolation demand, amounted to 988 mm for 2023 and 1009 mm for 2024. Considering the irrigation source efficiency as 70%, the total gross irrigation (TGI) was determined to be 1411 mm in 2023 and 1443 mm in 2024. This complete irrigation scheduling method is a key tool for optimizing water management in summer paddy farming, leading to improved crop yields and sustainable agricultural management.

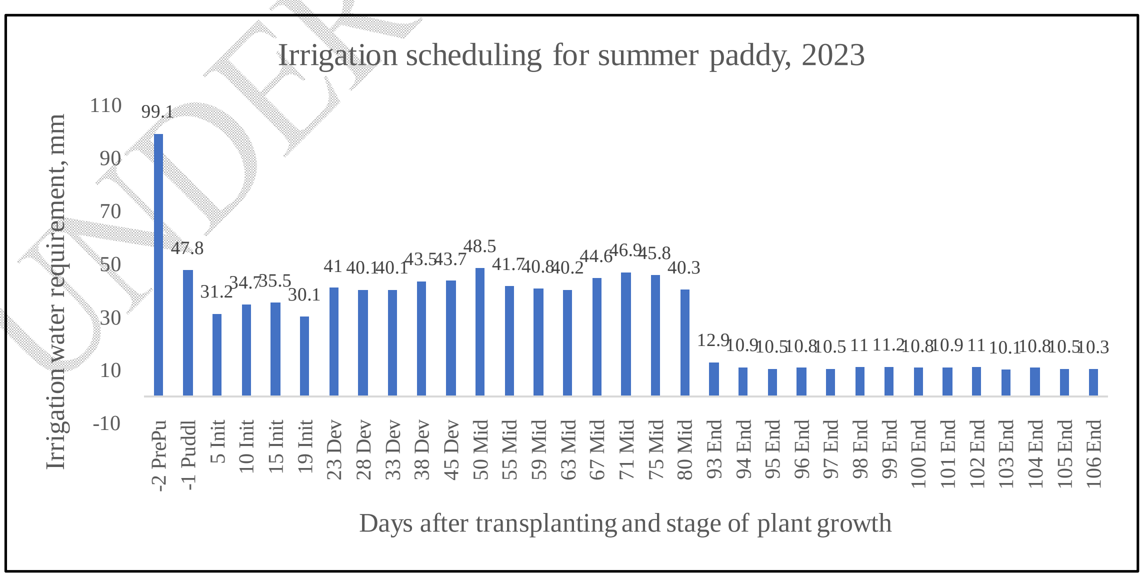

Fig. 4. Irrigation scheduling plan for summer paddy, 2023

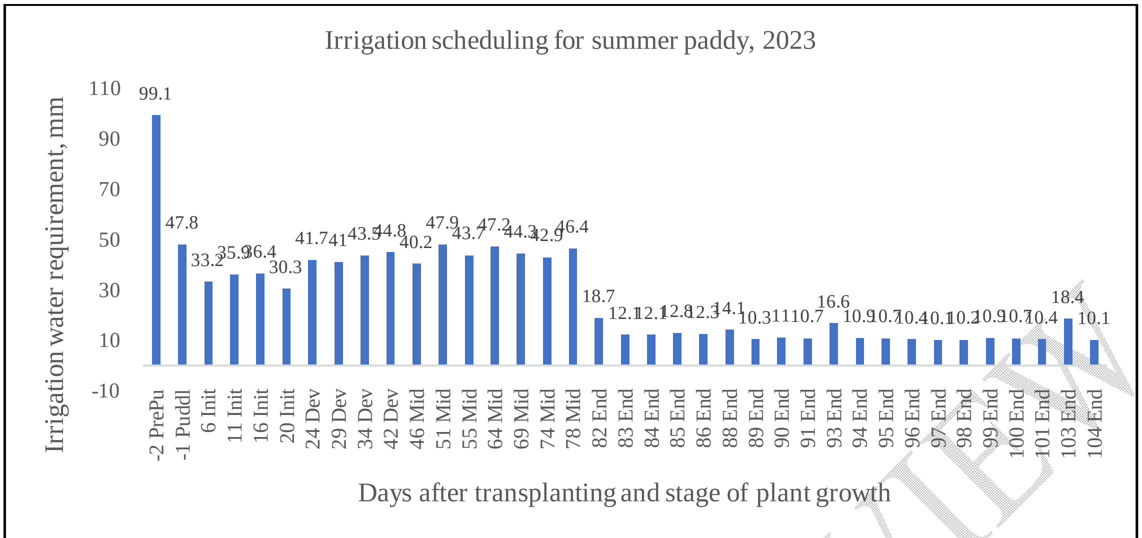

Fig.5. Irrigation scheduling plan for summer paddy, 2024

3. Conclusion

Analyzing rainfall variability, climatic influences on evapotranspiration, and fluctuating water demands throughout crop development phases enhances comprehension of paddy crop water management. As shown in the study, irrigation water requirements were assessed for *vertisols* in Raipur District, Chhattisgarh. The findings suggest that accurately assessing the water needs of summer paddy can enhance water resource management and crop production. Scientific tools such as CROPWAT 8.0 can evaluate the crop water requirement (CWR) with considerable precision, enhancing optimized irrigation scheduling and sustainable water resource management. The results highlight the need for customized strategies to meet irrigation water requirements, guaranteeing the prudent use of water resources in light of changing agricultural practices. The findings of this research may assist agriculturists and water resource planners in future strategies, facilitating water conservation while adhering to crop water requirements for productive crop growth with appropriate quantity and frequency of crop irrigation.

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