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Modelling Wheat Irrigation Water Requirement Using CRIWAR: A Case Study of Kano River Irrigation Project, Nigeria

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A B S T R A C T :

Understanding and estimating crop water requirements is essential for efficient irrigation water management, especially in arid and semi-arid environments such as Northern Nigeria. This study evaluates the irrigation water requirement (IWR) for wheat (Triticum aestivum L.) using the CRIWAR 3.0 model in the Kano River Irrigation Project (KRIP), located in Kura Local Government Area of Kano State. CRIWAR uses meteorological data, soil properties, crop parameters, and irrigation scheduling inputs to estimate the crop's water needs. Meteorological data were sourced from the Nigerian Meteorological Agency (NiMET) for growing season. The simulation estimated the total irrigation water requirement to be 316.13 mm over a crop period from November to June. Water demand peaked during the development and mid-season stages of the crop due to increased evapotranspiration and crop coefficient values. The results show that CRIWAR provides reliable and adaptable outputs for irrigation design and scheduling in large-scale schemes, helping to optimize water use and enhance agricultural productivity. The study recommends the application of CRIWAR across diverse ecological zones and for multiple crops to improve national food security strategies.

Keywords: CRIWAR, crop water requirement, wheat, Kano River Irrigation Project, irrigation modeling, semi-arid agriculture

1. Introduction

Agricultural water management plays a pivotal role in ensuring food security, especially in developing countries like Nigeria, where agriculture accounts for over 20% of the Gross Domestic Product (GDP) and employs nearly 70% of the rural population. Despite its importance, the sector faces severe challenges related to water scarcity, inefficient irrigation practices, and climate variability. Wheat—a high-value cereal crop and key ingredient in bread, pasta, and noodles—is witnessing increasing domestic demand due to rapid urbanization, population growth, and dietary shifts. However, Nigeria's local wheat production currently meets less than 10% of national consumption, making the country heavily reliant on costly imports. One of the main factors limiting domestic wheat output is the suboptimal management of irrigation water.

The Kano River Irrigation Project (KRIP), situated in northern Nigeria within the Kano River Basin, is a major gravity-fed surface irrigation scheme developed to support year-round cultivation, particularly during the dry season. Covering over 22,000 hectares under Phase I and Phase II development, KRIP utilizes water diverted from the Tiga and Challawa Gorge Dams through a system of main canals, secondary and tertiary channels. While KRIP has the infrastructure to support large-scale irrigation, water delivery is often inconsistent and lacks precision, leading to over-irrigation in some areas and water stress in others. This inefficiency not only limits yield potential but also contributes to waterlogging, salinity, and resource wastage.

Accurate estimation of crop water requirements (CWR) is fundamental to improving irrigation scheduling and water productivity. Traditional irrigation planning methods often rely on empirical estimates and fixed calendars, which fail to capture spatial and temporal variability in water demand. In contrast, simulation models such as CRIWAR (Crop Irrigation Water Requirement) offer a science-based approach to determine optimal irrigation needs based on local agro-climatic and agronomic conditions.

CRIWAR 3.0 is a decision-support tool developed by the International Water Management Institute (IWMI) and the Food and Agriculture Organization (FAO). It operates on the principle of calculating the crop evapotranspiration (ETc) by integrating reference evapotranspiration (ETo), derived from meteorological data using the FAO Penman-Monteith method, and crop coefficients (Kc) that vary with growth stages. The model also considers effective rainfall, soil moisture storage, rooting depth, and irrigation efficiency to estimate net and gross irrigation requirements. CRIWAR allows users to simulate irrigation needs on daily, 10-day (decadal), or seasonal time steps, making it suitable for both strategic planning and operational scheduling.

This study applies CRIWAR 3.0 to estimate the irrigation water requirements of wheat cultivated under KRIP during the dry season. Key input data include daily climate records (temperature, solar radiation, relative humidity, wind speed), soil physical properties (field capacity, wilting point, infiltration rate), and crop parameters (phenological stages, rooting depth, depletion fraction). The analysis aims to:

1. **1.** Quantify the seasonal water requirement of wheat under prevailing climatic conditions.
2. **2.** Evaluate the timing and volume of irrigation applications needed for optimal crop growth.
3. **3.** Assess the irrigation water use efficiency (IWUE) across different segments of KRIP.
4. **4.** Provide actionable recommendations for improving irrigation scheduling, reducing water losses, and enhancing wheat yield.

The results will inform farmers, irrigation managers, and policymakers on how to align irrigation practices with crop water demand, thereby promoting sustainable water use, increasing crop productivity, and reducing the dependency on wheat imports. Moreover, integrating CRIWAR-based irrigation planning into KRIP's management system can serve as a model for other large-scale irrigation projects across Nigeria and the Sahelian region.

Materials and Methods

1.1. Description of the study area

The study was conducted within the Kano River Irrigation Project (KRIP), located in Kura Local Government Area of Kano State, northwestern Nigeria. Geographically, KRIP is situated between latitudes 11°30'N and 12°03'N and longitudes 8°20'E and 8°40'E. The region falls within the Sudan savanna ecological zone and is characterized by a tropical savanna climate, exhibiting distinct seasonal patterns: a rainy season from May to September and a dry season from October to April.
The average annual rainfall in the area is approximately 696 mm, with the bulk occurring between July and August. Given the limited rainfall and prolonged dry season, agricultural production during the dry months is highly dependent on irrigation. Temperature ranges from an average of 21°C in the coolest months (December–January) to over 38°C during the hottest months (March–April), contributing to high evaporative demand. Relative humidity typically varies between 20% in the dry season and 80% in the wet season.

Soils in the KRIP command area are predominantly sandy loam to loam in texture, with moderate to high permeability and good drainage characteristics, making them suitable for a variety of crops under irrigated conditions. The soil profile generally has adequate water-holding capacity and supports root penetration, which is essential for deep-rooted crops like wheat. The area benefits from well-developed irrigation infrastructure, including a network of primary canals, secondary and tertiary channels, and drainage systems fed by the Tiga and Challawa Gorge Dams. This infrastructure enables year-round crop cultivation, particularly during the dry season, when natural precipitation is insufficient.CRIWAR Model Description
Selecting an appropriate type of performance assessment (PA) is a crucial step in the evaluation process, as the chosen type must align closely with the CRIWAR 3.0, developed by the International Institute for Land Reclamation and Improvement (ILRI), uses the FAO Modified Penman method to calculate reference evapotranspiration (ET_0). The model computes crop evapotranspiration (ETc) by multiplying ET_0 with crop coefficients (Kc) and deducts effective rainfall to determine net irrigation requirement. The model is designed for ease of use in large irrigation schemes and for decision-support by water managers.

1.2. Input Data Collection

Data used for the simulation were categorized into meteorological, soil and irrigation, and crop-specific parameters, all critical for accurately estimating wheat water requirements using the CRIWAR 3.0 model.

1.3. Meteorological Data

Monthly average climatic data were obtained from the Nigerian Meteorological Agency (NiMET) for the study period. The parameters included maximum and minimum temperature, total monthly rainfall, relative humidity, sunshine duration, and wind speed. These inputs were used to compute reference evapotranspiration (ETo) using the FAO Penman-Monteith method within CRIWAR, providing the climatic basis for estimating crop water use.

1.4. Soil and Irrigation Data

The study area comprised loamy soils with moderate water-holding capacity and good drainage. Key irrigation parameters included:

- Application depth: 75 mm per irrigation event,
- Irrigation interval: 10 days,
- Total irrigated area: 3 hectares.

These values reflect common farmer practices under the Kano River Irrigation Project and were used to simulate gross irrigation requirements and evaluate water use efficiency.

1.5. Crop Data

The crop under study was wheat (Triticum aestivum L.), sown in early November and harvested in late June, covering a growing period of approximately 200 days. The crop growth was divided into four distinct phenological stages, each associated with specific crop coefficient (Kc) values as recommended by FAO guidelines:

- Initial stage (40 days): Kc = 0.30 (low water use reflecting minimal canopy cover),
- Development stage (60 days): Kc increases linearly from 0.30 to 1.15, indicating rapid canopy development and increased transpiration,
- Mid-season stage (60 days): Kc = 1.15 (maximum water demand during peak canopy cover and active grain filling),
- Late-season stage (40 days): Kc declines to 0.25 as the crop matures and evapotranspiration reduces.

These inputs enabled precise simulation of wheat water requirements across the entire growing season, allowing for an accurate assessment of irrigation scheduling and potential improvements in water management practices

Results and Discussion

1.6. Reference Evapotranspiration (ET_0)

Reference evapotranspiration (ET_0), which represents the evaporative demand of the atmosphere under standard conditions, was computed using the FAO Penman-Monteith method within the CRIWAR 3.0 model. The annual ET_0 for the study area was estimated at 2820.2 mm, consistent with the high evaporative potential typical of semi-arid tropical climates.

Monthly ET_0 values ranged from a minimum of 4.5 mm/day in August, coinciding with the peak of the rainy season and high relative humidity, to a maximum of 10.5 mm/day in April, when solar radiation, temperature, and wind speed peak, while relative humidity drops sharply. These trends reflect the dominant influence of climatic variables on atmospheric water demand in the KRIP region.

1.7. Crop Evapotranspiration (ETc)

Crop evapotranspiration (ETc), calculated as the product of ET_0 and stage-specific crop coefficients (Kc), and varied in accordance with the wheat crop's growth stages.

- Initial stage (November): ETc was relatively low due to limited leaf area and minimal transpiration.
- Development to mid-season (December–February): ETc increased significantly, reaching peak values as the canopy expanded, coinciding with maximum stomatal activity and photosynthetic demand.
- Late season (March–May): ETc declined gradually as the crop approached physiological maturity and senescence set in.

This pattern demonstrates the correlation between crop phenology and water use, with the highest ETc observed between December and February, when the crop has full canopy cover and the climate remains dry and sunny.

1.8. Seasonal Irrigation Water Requirement (IWR)

The total irrigation water requirement (IWR) for wheat throughout the dry-season cultivation period was estimated at 316.13 mm. This value aligns with benchmark figures for wheat grown under irrigated conditions in similar semi-arid agro-ecological zones. The monthly distribution of IWR was as follows:

- November (Initial stage): 31.47 mm
- December (Early development): 60.53 mm
- January–March (Mid-season): Ranged from 42 mm to 48 mm per month
- April (Early late-season): 38.1 mm
- May (Late-season maturity): 26.5 mm
- June (Harvest period): 0 mm (no irrigation needed)

Due to minimal effective rainfall during the dry season (typically <10 mm/month), nearly 100% of the crop water demand had to be met through supplemental irrigation. This highlights the importance of accurate scheduling and water-use efficiency in such systems.

1.9. Model Sensitivity and Practical Application

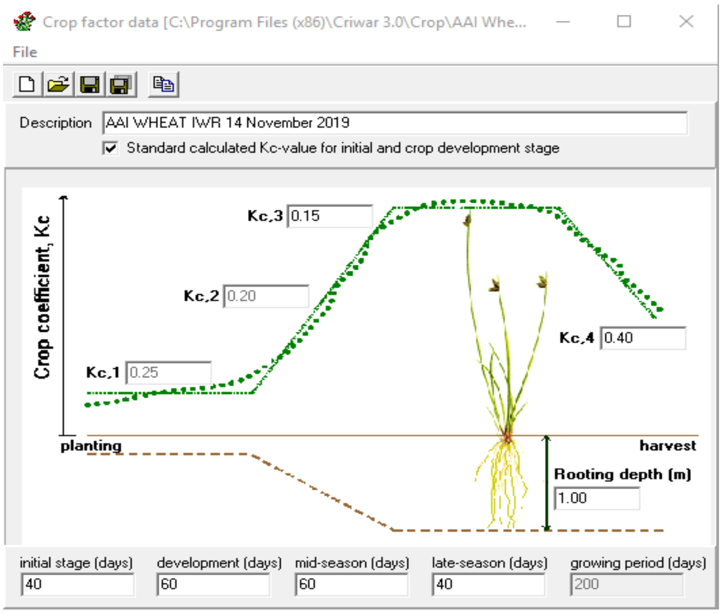
CRIWAR 3.0 provides a flexible platform for simulating various irrigation scenarios through sensitivity analysis. Parameters such as crop growth stage duration, irrigation interval, application depth, and climatic inputs can be adjusted to assess their impact on irrigation requirements.

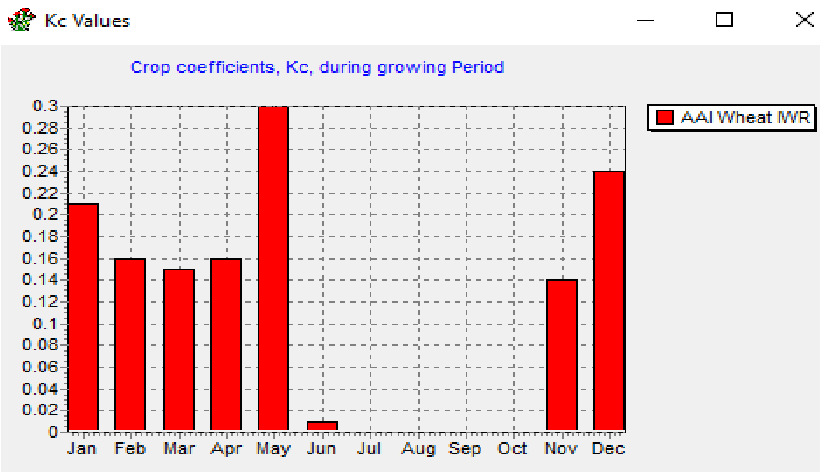
This study demonstrated that:

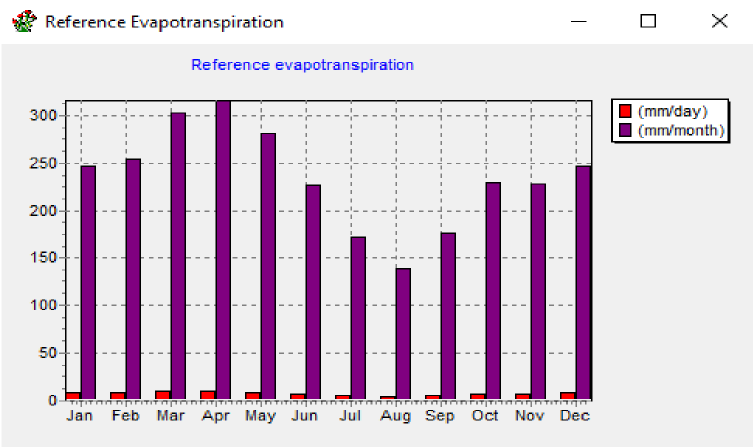
- Reducing the irrigation interval (e.g., from 10 to 7 days) can enhance soil moisture stability but may increase total water use if not properly managed.
- Altering Kc values based on local crop performance helps calibrate the model to reflect actual field conditions.
- Simulating climate variability (e.g., increasing temperature or reducing humidity) allows planners to evaluate the resilience of irrigation schedules under changing climatic conditions.

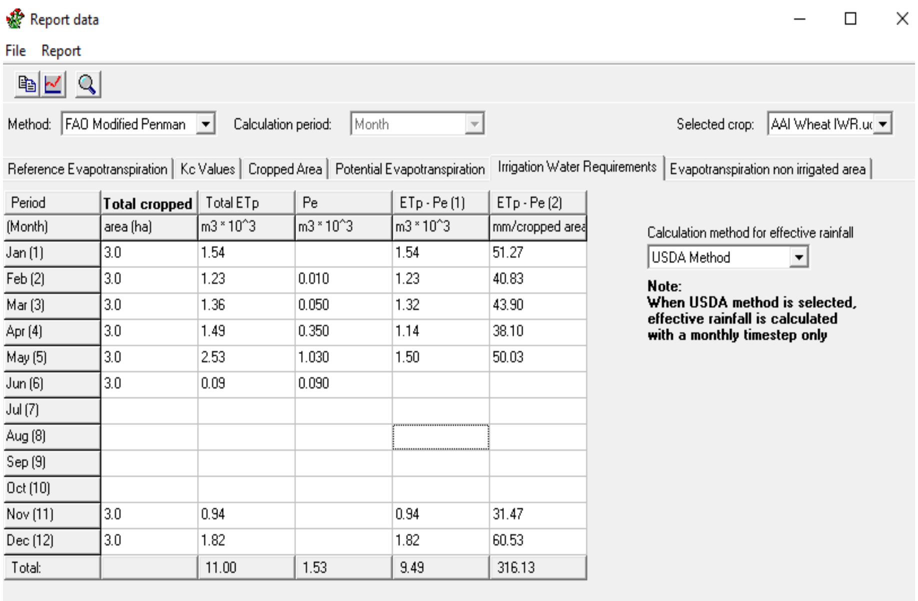
CRIWAR proved to be a user-friendly and context-appropriate tool for Nigerian irrigation schemes, offering practical insights for water managers, extension agents, and policymakers aiming to improve on-farm water management, especially in resource-constrained environments.

Illustrations









Period	Total cropped	Total ETp	Pe	ETp - Pe (1)	ETp - Pe (2)
(Month)	area (ha)	m3 * 10^3	m3 * 10^3	m3 * 10^3	mm/cropped area
Jan (1)	3.0	1.54		1.54	51.27
Feb (2)	3.0	1.23	0.010	1.23	40.83
Mar (3)	3.0	1.36	0.050	1.32	43.90
Apr (4)	3.0	1.49	0.350	1.14	38.10
May (5)	3.0	2.53	1.030	1.50	50.03
Jun (6)	3.0	0.09	0.090		
Jul (7)					
Aug (8)					
Sep (9)					
Oct (10)					
Nov (11)	3.0	0.94		0.94	31.47
Dec (12)	3.0	1.82		1.82	60.53
Total:		11.00	1.53	9.49	316.13

Fig. 1 – (a) Crop factor data (b) Graph of Kc Values (c) Chart of Reference Evapotranspiration (d) Irrigation Water Requirement of Wheat

Conclusions

The CRIWAR 3.0 model successfully simulated the irrigation water requirements for wheat cultivation during the dry season in the Kano River Irrigation Project (KRIP). Based on local agro-climatic and crop data, the model estimated a total seasonal irrigation requirement of 316.13 mm for one full cropping cycle. The highest water demand occurred during the development and mid-season stages, corresponding to the crop's vegetative growth and reproductive phases, when canopy expansion and evapotranspiration rates are at their peak.

The results confirm the effectiveness and reliability of CRIWAR in estimating crop water requirements under field conditions in KRIP. The model's performance highlights its potential as a decision-support tool for irrigation scheduling, particularly in regions with limited access to high-resolution climatic and field data. Its ability to integrate soil, climate, and crop parameters in a user-friendly interface makes it especially valuable for irrigation planners, agricultural extension agents, and water managers operating in data-scarce, semi-arid environments like northern Nigeria.

These findings underscore the importance of model-based irrigation planning in enhancing water use efficiency, reducing waste, and ensuring sustainable agricultural productivity amid increasing climate variability and water scarcity.

Recommendations

To enhance the efficiency and sustainability of irrigated agriculture in Nigeria, the following strategic actions are recommended:

1. Mainstream CRIWAR in Irrigation Planning and Policy Development: National and sub-national water resources and agricultural agencies should institutionalize the use of CRIWAR in irrigation planning and decision-making processes. Integrating simulation models into planning frameworks can improve allocation of scarce water resources, support climate-resilient agriculture, and promote data-driven policy formulation.
2. Capacity Building for Extension Officers and Farm Managers: Implement training programs and workshops for agricultural extension officers, irrigation engineers, and farm managers to build technical capacity in the use of crop-water simulation models such as CRIWAR. This will empower stakeholders to make informed decisions on irrigation scheduling, reduce water wastage, and increase crop productivity.
3. Model Validation through Comparative Analysis: To enhance confidence in model outputs, compare CRIWAR's results with those of other well-established models such as CROPWAT, DSSAT (Decision Support System for Agrotechnology Transfer), and AquaCrop. Cross-validation helps identify discrepancies, improve model calibration, and ensure robust, location-specific recommendations.
4. Investment in Meteorological Infrastructure: Invest in automated weather stations (AWS) at irrigation project sites to collect real-time, high-resolution data on temperature, humidity, wind speed, radiation, and rainfall. These data are critical for accurate estimation of reference evapotranspiration (ET_0) and improving the reliability of CRIWAR simulations and similar tools.

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