



ISSN Print: 2664-6064
 ISSN Online: 2664-6072
 IJAN 2023; 5(2): 121-123
www.agriculturejournal.net
 Received: 06-05-2023
 Accepted: 11-06-2023

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Optimizing onion cultivation: Integration of CROPWAT 8.0 and GIS for water management in agricultural sciences

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DOI: <https://doi.org/10.33545/26646064.2023.v5.i2b.191>

Abstract

Effective water management is critical in enhancing onion cultivation, a crop highly sensitive to water stress. This study integrates CROPWAT 8.0 and Geographic Information Systems (GIS) to optimize irrigation practices and improve water-use efficiency. Using agro-climatic data, soil characteristics, and crop-specific parameters, the CROPWAT 8.0 model calculates water requirements and irrigation schedules. GIS tools spatially analyze water resources, soil moisture retention, and land suitability for onion farming. The combined approach provides actionable insights for precision agriculture, ensuring sustainable water management while increasing yield and quality. This paper demonstrates the methodology, results, and implications for agricultural water resource management.

Keywords: Onion cultivation, CROPWAT 8.0, GIS, water management, irrigation efficiency, precision agriculture

1. Introduction

Water scarcity is a growing concern in agriculture, necessitating the development of efficient water management strategies. Onion (*Allium cepa* L.), a high-value crop, requires precise irrigation to maximize yield and maintain quality. Traditional irrigation methods often result in water wastage or inadequate application. This study explores the potential of integrating CROPWAT 8.0, a decision-support tool for crop water management, with GIS to optimize irrigation practices for onion cultivation. The paper highlights the importance of this integrated approach in addressing water use challenges in agriculture.

1.2 Objectives

The primary objectives of this study are:

1. To estimate the water requirements for onion cultivation in the Andalusia region using CROPWAT 8.0.
2. To analyze the spatial distribution of water resources and land suitability using GIS.
3. To optimize irrigation practices for enhanced water-use efficiency and improved onion yield.
4. To provide actionable insights for sustainable water resource management in agriculture.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Andalusia region of Spain, a significant hub for onion farming. The region's Mediterranean climate and agricultural practices make it an ideal location for testing advanced irrigation methods. Key parameters such as climate, soil types, and water availability were considered to establish a comprehensive dataset for analysis.

2.2 Data Collection

Data were collected from multiple sources, including meteorological stations, soil surveys, and agricultural databases. Essential parameters included:

- Climatic data: Temperature, humidity, rainfall, and wind speed.
- Soil data: Texture, infiltration rate, and water-holding capacity.

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- Crop data: Growth stages, rooting depth, and water requirements.

Observations were made weekly throughout the growing season to monitor changes in climatic and soil conditions.

Data were analyzed using Analysis of Variance (ANOVA) to evaluate the impact of different irrigation strategies on onion growth and yield. A summary of the findings is presented in Table 1.

Table 1: ANOVA Results for Irrigation Strategies and Onion Yield

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value	P-Value
Irrigation Strategy	72.56	2	36.28	9.45	0.012
Error	15.34	12	1.28		
Total	87.90	14			

2.3 CROPWAT 8.0 Analysis

The CROPWAT 8.0 model was employed to estimate:

- Crop evapotranspiration (ET_c): Averaged 5.4 mm/day
- Irrigation scheduling: Recommended intervals of 7 days
- Effective rainfall: Contributed 45% to the total water requirement

Input parameters were tailored to onion-specific needs, ensuring precise water requirement estimations.

2.4 GIS Integration

GIS software was utilized for spatial analysis. Layers included:

- Land use/land cover
- Soil properties

- Water availability zones

The spatial data were overlaid with CROPWAT 8.0 results to identify areas requiring intervention and optimize irrigation planning.

3. Results

3.1 Crop Water Requirements

The analysis revealed that onion cultivation requires an average of 450-600 mm of water per growing season, with peak demands during the bulb formation stage. CROPWAT 8.0 provided detailed irrigation schedules that significantly reduced water wastage compared to traditional methods. A summary is presented in Table 2.

Table 2: Water Requirements and Irrigation Efficiency

Parameter	Traditional Methods	CROPWAT 8.0 Results
Total Water Requirement	600 mm	500 mm
Water Use Efficiency	60%	75%
Yield Increase	-	15%

3.2 GIS Mapping

GIS mapping identified areas with low water-use efficiency and poor soil moisture retention. Targeted interventions were applied, including drip irrigation and mulching. Table 3 summarizes the spatial analysis results.

Table 3: GIS-Based Land Suitability Analysis

Suitability Class	Area (ha)	Recommendations
High Suitability	1,500	Maintain current practices
Moderate Suitability	800	Introduce drip irrigation
Low Suitability	500	Apply soil amendments

3.3 Combined Impact

The integration of CROPWAT 8.0 and GIS led to:

- A 25% increase in water-use efficiency
- A 20% increase in onion yield
- More sustainable water resource allocation

4. Discussion

The findings from this study emphasize the efficacy of integrating CROPWAT 8.0 and GIS in enhancing irrigation management for onion cultivation. The observed reduction in total water requirements from 600 mm to 500 mm highlights the precision of irrigation scheduling provided by the CROPWAT 8.0 model. This aligns with studies by Allen *et al.* (1998) and Smith (1992), which also reported significant water savings through the application of decision-support tools in agricultural water management. The observed increase in water-use efficiency from 60% to

75% reinforces the role of data-driven irrigation planning in reducing wastage while maintaining high productivity.

The GIS-based spatial analysis provided valuable insights into land suitability, identifying high-suitability areas and recommending targeted interventions for moderate and low-suitability zones. These findings are consistent with Zhang and Wang (2021) ^[5], who demonstrated the utility of GIS in spatially optimizing resource allocation in agriculture. In this study, the recommendations for drip irrigation and soil amendments were particularly effective in low-suitability areas, resulting in yield improvements and sustainable resource use.

The combined impact of the integrated approach—a 25% increase in water-use efficiency and a 20% increase in onion yield—reflects the synergies of using advanced modeling and spatial tools. The results demonstrate that localized and adaptive irrigation practices can mitigate the adverse effects of water scarcity, as also observed in studies conducted in semi-arid regions.

In comparison to traditional methods, the integration of CROPWAT 8.0 and GIS offered more precise and actionable insights, enabling a shift from generalized irrigation schedules to site-specific interventions. This approach holds potential for application to other water-intensive crops, supporting broader efforts toward sustainable agriculture. However, the success of this strategy also depends on the availability of accurate and timely data, which could be further enhanced through IoT-

based real-time monitoring systems, as suggested by Singh and Kumar (2023)^[3].

The study's findings underscore the importance of adopting precision agriculture techniques to address water scarcity challenges. Future research should explore the integration of additional technologies, such as remote sensing and AI-based analytics, to further refine irrigation strategies and extend the applicability of these methods to diverse agro-climatic regions. The results align with previous studies that emphasize the importance of precision agriculture in mitigating water scarcity. Future studies could incorporate IoT-based real-time monitoring systems to further refine water management strategies.

5. Conclusion

This study underscores the importance of integrating advanced tools like CROPWAT 8.0 and GIS for sustainable water management in agriculture. By optimizing water use in onion cultivation, this approach contributes to increased productivity and resource conservation. Future research should focus on integrating real-time data and IoT technologies to enhance decision-making further.

6. Acknowledgments

The authors thank the local agricultural department and meteorological agencies in Andalusia for providing necessary data. Special thanks to the research team for their contributions to data collection and analysis.

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