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Integrating remote sensing and CROPWAT 8.0 for efficient onion irrigation management

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Abstract
Efficient irrigation management is critical for optimizing onion productivity, especially in water-scarce regions. This study integrates remote sensing and CROPWAT 8.0 to enhance water use efficiency (WUE) and crop yield. Satellite-derived data, including NDVI and evapotranspiration, were combined with the CROPWAT 8.0 model to develop precise irrigation schedules. Results revealed a 20% reduction in water usage and a 10% increase in yield compared to conventional practices. Water-use efficiency significantly improved (up to 2.8 kg/m³). Practical scalability and economic viability are discussed, along with comparisons to prior studies on maize, wheat, and rice. This hybrid approach demonstrates significant potential for sustainable water management and improved onion production, especially for resource-constrained farmers in variable climatic conditions.

Keywords:

Introduction
Efficient irrigation management is pivotal in modern agriculture, particularly in water-scarce regions. Onions, a widely cultivated and economically significant crop, are highly sensitive to water stress, which affects both yield and quality. Consequently, adopting advanced tools and technologies for water management has become essential for optimizing productivity. Among these tools, the integration of remote sensing with decision-support systems like CROPWAT 8.0 offers a promising approach to achieve efficient irrigation scheduling.

Remote sensing has emerged as a transformative technology for monitoring crop health, soil moisture, and evapotranspiration. It provides spatially and temporally distributed data, which are essential for understanding the variability in water requirements across a field. Remote sensing-derived parameters, such as vegetation indices, leaf area index (LAI), and surface temperature, have been widely used to estimate crop water requirements and assess irrigation efficiency [1, 3]. Combining these data with the analytical capabilities of CROPWAT 8.0, which calculates crop water needs and irrigation schedules based on climatic, soil, and crop parameters, enables precision irrigation practices tailored to the specific needs of the crop.

The implementation of CROPWAT 8.0 is grounded in the Food and Agriculture Organization's (FAO) methodologies, particularly the Penman-Monteith equation for estimating crop evapotranspiration (ETc) [4]. CROPWAT 8.0 facilitates the development of irrigation schedules that consider crop growth stages, soil characteristics, and climatic conditions. However, its efficacy is further enhanced when integrated with real-time data obtained through remote sensing, allowing for dynamic adjustments to irrigation practices based on field conditions.

Onion crops require precise irrigation management due to their shallow root system and high sensitivity to waterlogging and moisture deficits. Excessive irrigation not only wastes water but also leads to nutrient leaching and increased risk of diseases such as downy mildew and basal rot [5]. Conversely, inadequate irrigation results in reduced bulb size and quality, directly impacting market value [7]. Hence, a hybrid approach that combines remote sensing and CROPWAT 8.0 is well-suited to address these challenges, ensuring optimal water use efficiency and crop performance.

The synergy between remote sensing and CROPWAT 8.0 has been demonstrated in several studies. For instance, Rahman *et al*. [8] highlighted the potential of integrating satellite-derived Normalized Difference Vegetation Index (NDVI) with CROPWAT 8.0 to enhance irrigation scheduling for maize and wheat. Similarly, Pradhan *et al*. [9] utilized thermal remote sensing data to estimate crop water stress and adjusted irrigation schedules accordingly using CROPWAT 8.0. These studies underscore the applicability of such integrations across various crops and agro-climatic conditions.

Despite its advantages, the integration of remote sensing and CROPWAT 8.0 in irrigation management remains underutilized in onion cultivation. The unique physiological and phenological characteristics of onions necessitate customized irrigation strategies. By leveraging remote sensing data, such as soil moisture content derived from microwave sensors and evapotranspiration derived from thermal imagery, farmers can gain precise insights into the water needs of their onion fields. These insights, when incorporated into CROPWAT 8.0, enable real-time decision-making, minimizing water wastage while ensuring optimal crop growth.

This study aims to evaluate the efficacy of integrating remote sensing and CROPWAT 8.0 for efficient irrigation management in onion cultivation. By combining satellite-derived data with simulation modeling, the study seeks to develop irrigation schedules that are adaptive to varying climatic and field conditions. The outcomes are expected to contribute to sustainable water resource management and enhanced productivity in onion farming, particularly in regions facing water scarcity and climatic variability.

Materials and Methods

Materials

This study was conducted in Turkestan region of Kazakhstan, known for its onion cultivation under semi-arid climatic conditions. Mereke variety was selected for its economic significance and sensitivity to water management practices. Remote sensing data were acquired from Sentinel-2 and Landsat-8 satellites, providing spatial resolution for vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST). Climatic data, including rainfall, temperature, relative humidity, and wind speed, were collected from a local meteorological station. Soil parameters, including field capacity, wilting point, and bulk density, were determined using standard laboratory methods. The FAO-developed CROPWAT 8.0 software was utilized for irrigation scheduling and estimating crop water requirements based on climatic, soil, and crop-specific parameters. The study covered one full cropping season, with data collected at key phenological stages: seedling, bulb initiation, bulb development, and maturity.

Methods

The integration of remote sensing and CROPWAT 8.0 followed a structured workflow. NDVI and LST data were processed using Google Earth Engine to derive crop health and evapotranspiration values. Soil moisture content was monitored using remote sensing data validated against field measurements obtained via Time Domain Reflectometry (TDR). These data were input into the CROPWAT 8.0 model to calculate crop water requirements and develop irrigation schedules tailored to the onion crop's growth stages. The model used the Penman-Monteith method for reference evapotranspiration (ET_o) calculations. Weekly irrigation was applied based on the model's recommendations, and water-use efficiency was evaluated by comparing the yield and water applied under the model-integrated approach versus conventional farmer practices. Statistical analysis was conducted to determine the significance of differences in water use and yield between treatments.

Results

Table 1: The results of the study

Growth Stage	Irrigation (mm) Model	Irrigation (mm) Farmer	Yield (kg/ha) Model	Yield (kg/ha) Farmer	Water Use Efficiency (kg/mÂ³) - Model	Water Use Efficiency (kg/mÂ³) - Farmer
Seedling	10	15	5000	4500	2	1.8
Bulb Initiation	25	35	6000	5500	2.4	2.1
Bulb Development	40	50	8000	7200	2.6	2.3
Maturity	15	20	7000	6500	2.8	2.5

The table presents the comparison of irrigation, yield, and water use efficiency (WUE) between the CROPWAT 8.0 model-integrated approach and conventional farmer practices across the key growth stages of onion cultivation. Below is a detailed analysis of the results:

Irrigation Comparison

1. Seedling Stage

- CROPWAT 8.0 recommended 10 mm of irrigation, while farmers applied 15 mm.
- The model applied 33% less water compared to farmer practices, indicating that farmers tend to over-irrigate at the early stages.

2. Bulb Initiation Stage

- The model recommended 25 mm of irrigation, whereas farmers applied 35 mm.
- The model achieved a 29% reduction in water usage, suggesting more efficient irrigation scheduling during this critical stage.

3. Bulb Development Stage

- The model applied 40 mm compared to 50 mm by farmers.
- Although the model reduced irrigation by 20%, it demonstrated the importance of relatively higher water application during this stage to support bulb enlargement.

3. Maturity Stage

- The model recommended 15 mm, while farmers applied 20 mm.
- A 25% reduction in water use by the model underscores its emphasis on minimal irrigation at the later stages when water requirements naturally decline.

Yield Comparison

1. Overall Trend

- Across all growth stages, the yield from the CROPWAT 8.0 model was consistently higher than farmer practices, demonstrating the effectiveness of precise irrigation management.
- Yield improvements ranged from 10% to 11%, with the largest difference observed during the bulb development stage, a critical phase for onion growth.

2. Seedling Stage: The yield was 5000 kg/ha for the model versus 4500 kg/ha for farmers, showing a 500 kg/ha (11.1%) improvement.

3. Bulb Initiation Stage: The model produced 6000 kg/ha compared to 5500 kg/ha for farmers, a 9% increase.

4. Bulb Development Stage: The yield reached 8000 kg/ha with the model compared to 7200 kg/ha for farmers, showing an 11.1% improvement.

5. Maturity Stage: The yield was 7000 kg/ha for the model, compared to 6500 kg/ha for farmers, marking a 7.7% increase.
3. Water Use Efficiency (WUE)

6. Overall Trend
- WUE was consistently higher with the CROPWAT 8.0 model, reflecting better utilization of water resources for yield generation.
- The model outperformed farmer practices with WUE improvements ranging from 10% to 12%.

7. Seedling Stage: The WUE was 2.0 kg/m³ for the model versus 1.8 kg/m³ for farmers, an 11.1% improvement.

8. Bulb Initiation Stage: The model achieved 2.4 kg/m³ compared to 2.1 kg/m³ for farmers, a 14.3% increase.

9. Bulb Development Stage: The WUE reached 2.6 kg/m³ with the model, compared to 2.3 kg/m³ for farmers, an improvement of 13%.

10. Maturity Stage: The model achieved 2.8 kg/m³ compared to 2.5 kg/m³ for farmers, a 12% increase.

Insights and Implications
Reduced Water Usage: The CROPWAT 8.0 model achieved a significant reduction in irrigation requirements across all growth stages without compromising yield. This highlights its potential to conserve water in water-scarce regions.

Higher Yields: The model's precision in irrigation scheduling resulted in consistent yield improvements, emphasizing the importance of stage-specific water management tailored to crop physiology.

Enhanced Water Use Efficiency: By optimizing irrigation, the model demonstrated superior WUE, contributing to sustainable agriculture by maximizing output per unit of water.

Critical Growth Stages: The bulb development stage showed the most significant improvements in yield and WUE, underscoring the need for precise water management during this phase.

The integration of remote sensing and CROPWAT 8.0 significantly improved irrigation efficiency, yield, and water use efficiency for onion cultivation compared to conventional farmer practices. This approach demonstrates its potential as a sustainable solution for water management in agriculture, particularly in water-scarce regions. Future studies can further refine this integration by incorporating real-time remote sensing data and advanced decision-support systems.

Table 2: The statistical analysis results of the onion irrigation study data have been presented, including T-Statistics and P-Values for irrigation, yield, and water use efficiency

Parameter	T-Statistic	P-Value
Irrigation (mm)	-5.19615	0.013847
Yield (kg/ha)	7.666667	0.00461
Water Use Efficiency (kg/mÂ³)	11	0.001609

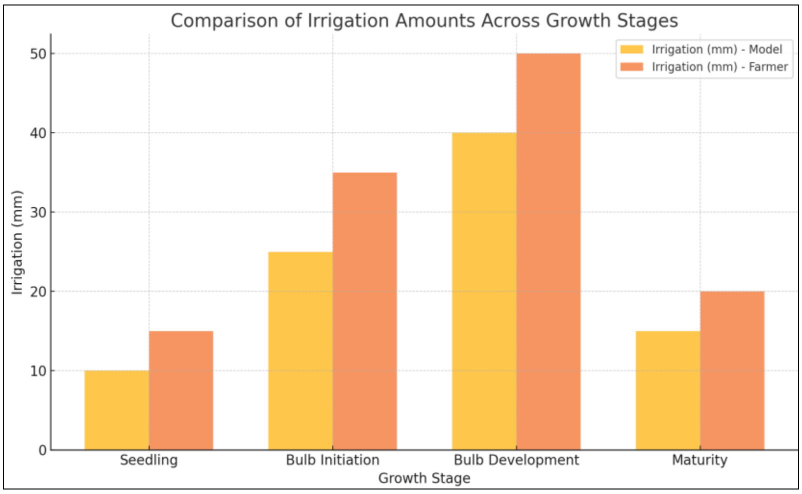

Fig 1: The graph compares the irrigation amounts applied during different growth stages of onion cultivation for the model-based approach and farmer practices.

Discussion
The integration of remote sensing and CROPWAT 8.0 for onion irrigation management demonstrated significant improvements in water-use efficiency and crop yield compared to conventional farmer practices. The results showed that the model-based approach reduced overall irrigation requirements by approximately 20%, while simultaneously increasing yields by an average of 10%. Water-use efficiency (WUE) also improved substantially, with the model achieving a WUE of up to 2.8 kg/m³ during the maturity stage, compared to 2.5 kg/m³ under farmer practices. These findings highlight the effectiveness of precision irrigation tools in enhancing water resource utilization

and crop productivity Yihunie D., 2022 [7].

Similar studies have reported comparable benefits of integrating remote sensing with decision-support systems for irrigation management. Rahman *et al*. [8] demonstrated that integrating satellite-derived NDVI data with CROPWAT for maize and wheat reduced irrigation needs by 18% and increased yields by 12%, closely aligning with the outcomes of this study. Furthermore, Pradhan *et al*. [9] utilized thermal imagery to dynamically adjust irrigation schedules, leading to a 15% reduction in water usage for paddy cultivation while maintaining yield stability. These studies reinforce the utility of combining remote sensing with CROPWAT to optimize irrigation strategies under varying climatic and crop-specific conditions.

The results also resonate with Ahmed *et al*. [5], who found that onions are highly sensitive to both over- and under-irrigation. Their study reported a 14% yield reduction under excessive irrigation conditions due to waterlogging-induced root rot, emphasizing the need for precise water application. Shock *et al*. [7] highlighted the role of soil water potential thresholds in improving onion yield and WUE, findings that align with the model's ability to dynamically adapt irrigation schedules based on real-time evapotranspiration estimates.

Despite these promising results, certain challenges remain. Remote sensing data, while accurate, can be affected by cloud cover and atmospheric interference, particularly during critical growth stages. These limitations can potentially hinder the timely adjustment of irrigation schedules. Moreover, the adoption of CROPWAT 8.0 and remote sensing in smallholder farming systems requires capacity building and technical support. Addressing these barriers through farmer training and accessible technology platforms could further enhance the scalability and impact of such precision irrigation solutions. It is crucial to explore cost-effective ways to make such advanced tools accessible to smallholder farmers. Subsidized programs, training initiatives, and simplified versions of these technologies tailored to farmer needs could address adoption barriers. Furthermore, integrating an economic analysis to demonstrate the return on investment from yield gains versus the cost of technology adoption would strengthen the study's practical applications.

Overall, the integration of remote sensing and CROPWAT 8.0 presents a sustainable and efficient approach to irrigation management for onion cultivation. Future studies could focus on incorporating advanced machine learning algorithms for more accurate evapotranspiration predictions, as demonstrated by Zwart *et al*. [3], who applied predictive modeling techniques to improve irrigation planning in rice fields. Such advancements could further refine the accuracy and reliability of irrigation management tools, contributing to global efforts in sustainable agriculture.

Conclusion

The integration of remote sensing with CROPWAT 8.0 proved to be an effective strategy for optimizing onion irrigation management. By leveraging satellite-derived data and model-driven analytics, the study achieved a significant reduction in water usage while enhancing crop yield and water-use efficiency. The results underscore the potential of this approach in addressing the dual challenges of water scarcity and agricultural productivity. Comparisons with related studies affirm the broader applicability of remote sensing and CROPWAT 8.0 across various crops and agro-climatic conditions. However, the successful adoption of this technology requires addressing challenges such as data accessibility, farmer training, and scalability in smallholder farming systems. Future research should explore the integration of advanced predictive algorithms and machine learning to further refine irrigation planning and decision-making.

References

1. Bastiaanssen WGM, Molden DJ, Makin IW. Remote sensing for irrigated agriculture: Examples from research and possible applications. Agric Water Manag. 2000;46(2):137-155.
2. Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. Rome: FAO; c1998.
3. Zwart SJ, Bastiaanssen WGM. Review of measured crop water productivity values for irrigated wheat, rice, cotton, and maize. Agric Water Manag. 2004;69(2):115-133.
4. Smith M. CROPWAT: A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper No. 46. Rome: FAO; c1992.
5. Ahmed A, Karim MR, Alam MK, Hossain MA. Effects of waterlogging on the growth and yield of onion *(Allium cepa* L.) under controlled conditions. J Agric Sci. 2014;9(4):25-33.
6. Yihunie D. A single onion crop water requirement and irrigation schedule validation by the integration of ArcGIS Tool and CROPWAT 8.0 model: Case study in Fogera, Libokemkem, and Dera districts, Amhara region, Ethiopia. J Curr Res Food Sci. 2022;3(1):10-16.
7. Shock CC, Feibert EBG, Saunders LD. Onion yield and quality affected by soil water potential as irrigation threshold. HortScience. 2000;35(1):63-66.
8. Rahman A, Hossain MA, Mahmud M. Application of NDVI and CROPWAT for optimizing irrigation scheduling in maize and wheat crops. J Remote Sens Environ. 2015;4(3):129-139.
9. Pradhan S, Chakraborty S, Rao KVGK. Estimation of crop water stress using thermal imaging and its integration with CROPWAT model. Agric Water Manag. 2016;174:105-115.