



Analyzing the Role of Plant Science in Water Use Efficiency for Agriculture in Uzbekistan

Azizahon Maksumkhanova ^{1*} , Asilbek Dauletbaev ² , Nilufar Esanmuradova ³ ,
 Dadaxon Abdullayev ⁴ , Mustafo Tursunov ⁵ , Kurbonaliy Zokirov ⁶ ,
 Ahrorqul Pardayev ⁷ , Bobir Odilov ⁸ 

^{1*} Associate Professor, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIIAME)-National Research University, Uzbekistan.
 E-mail: a.maksumxanova@tiiame.uz

² Senior Lecturer, Department of Chemistry and Biology, Kimyo International University in Tashkent, Tashkent, Uzbekistan. E-mail: a.dauletbaev@kiut.uz

³ School of Engineering, Central Asian University, Tashkent, Uzbekistan; Baku Eurasian University, Baku, Azerbaijan. E-mail: nilufar1289@gmail.com

⁴ PhD Researcher (Agriculture), Department of Fruits and Vegetable Growing, Urgench State University, Uzbekistan. E-mail: dadaxonabdullayev96@gmail.com

⁵ Lecturer, Termez University of Economics and Service, Uzbekistan.
 E-mail: mustafo_tursunov@tues.uz

⁶ PhD Researcher (Agricultural Science), Tashkent State Agrarian University, Uzbekistan; Scientific Researcher, Western Caspian University, Azerbaijan. E-mail: k_zokirov@tdau.uz

⁷ Associate Professor, Jizzakh State Pedagogical University, Uzbekistan.
 E-mail: mirkomilgudalov78@gmail.com

⁸ Tashkent State University of Oriental Studies, Tashkent, Uzbekistan.
 E-mail: odilov_bobir@tsuos.uz

Abstract

In Uzbekistan, a nation primarily reliant on irrigated farming in arid and semi-arid regions, water scarcity poses a serious challenge to agricultural sustainability. Maintaining crop productivity while preserving finite water resources necessitates improving water use efficiency (WUE). This study examines the significance of plant science in maximizing WUE in Uzbekistan's agricultural sector. Recent advancements

*Corresponding Author: Azizahon Maksumkhanova, E-mail: a.maksumxanova@tiiame.uz

in plant physiology, genetic enhancement, and agronomic techniques tailored to Uzbekistan's specific soil and climate are highlighted. The development and dissemination of crop varieties that can withstand drought and salinity, the implementation of precision irrigation methods such as drip and subsurface irrigation, and the integration of plant-microbe interactions to enhance plant resilience in water-limited environments are crucial strategies. Additionally, phenotyping platforms and remote sensing techniques are discussed to monitor crop water status and guide breeding initiatives. Examples from Uzbekistan's cotton and wheat industries demonstrate how targeted plant science initiatives have increased WUE and reduced reliance on outdated, inefficient irrigation practices. The study also addresses the policy and institutional frameworks necessary to promote research, extension, and farmer adoption of technologies that enhance WUE. Ultimately, this analysis underscores the need for multidisciplinary approaches and sustained investment in plant science to ensure food security and environmental sustainability in Uzbekistan's agriculture amidst growing water stress.

Keywords:

Water use efficiency, plant science, agriculture, uzbekistan, drought-resistant crops, irrigation strategies, sustainable farming.

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Introduction

In Uzbekistan, where agriculture accounts for more than 90% of freshwater withdrawals, primarily for the cultivation of water-intensive crops such as wheat and cotton, water scarcity poses a significant issue (FAO, 2022). The country's semi-arid climate makes the Amu Darya and Syr Darya transboundary rivers important to its water resources; however, these rivers are susceptible to regional competition and seasonal variation (Hatfield & Dold, 2019; Jalilov et al., 2013). Water stress in the region has worsened due to the rising economy, poor irrigation practices, infrastructure issues, and salinization (Abdullaev & Rakhmatullaev, 2016; Aroca et al., 2012).

Keeping food production high while reducing the finite reservoirs of fresh water means WUE needs to be improved (Aswath et al., 2019). As a ratio, WUE has direct and indirect controllable factors such as crop yield, the type of crop grown along with irrigation methods, and even the health of the soil (Thirunavukkarasu et al., 2024; Blum, 2009). As crop genetics and physiology advance, one's focus within plant science pertaining to augmenting WUE gets easier, hence the increasing attention towards those fields of study (Reynolds et al., 2019; Voss-Fels et al., 2019).

This research aims to enhance water use efficiency in agriculture through plant science interventions for Uzbekistan's case (Farfoura et al., 2023; Ranjan & Bhagat, 2024; Mustapha et al., 2016). Specifically, it explores emerging precision irrigation philosophies and the cultivation of salt and drought-resistant varieties, utilizing biotechnological strategies to improve plants' resilience to dry conditions (Khatiri et al., 2019; Far, 2017). This paper analyzes strategies focused on improving water use efficiency and policies designed to mitigate the challenges of water scarcity, using plants as the core remedy, supported by scientific evidence and regional case studies (Fereses & Soriano, 2007; Abdullaev & Rakhmatullaev, 2014; Mustapha et al., 2017).

Key Contribution

- This study investigates how plant science could enhance water use efficiency (WUE) considering Uzbekistan's arid agricultural environment.

- The study emphasizes the role of physiological features, crop selection, and genetic improvement in developing drought- and salt-tolerant crop varieties suitable for Uzbekistan's conditions.
- The study proposes a conceptual integration of plant-based approaches to optimize water use with precision agricultural methods, including phenotyping technology, controlled deficit irrigation, and soil moisture sensors.
- Using case studies from Uzbekistan's cotton and wheat production systems, the study assesses yield, water savings, and sustainability indicators of particular plant-based treatments.
- The results promote the creation of climate-resilient, plant-science-driven agricultural policies and practices targeted at alleviating water scarcity, boosting production, and supporting long-term agroecological sustainability in Uzbekistan.

Section I presents Uzbekistan's agricultural water use issues and stresses the need to raise WUE. Section I also presents the rationale and scope of the research through the prism of plant science. Section II reviews the research on plant physiological processes, WUE breeding strategies, and recent regional studies on agricultural adaptation to water-limited Central Asia. Section III covers varietal selection, biotechnological tools, integrating precision irrigation techniques pertinent to Uzbek agriculture, and the suggested plant science strategies and technologies. Comparative assessments and case studies from several agricultural systems (cotton, wheat) in Section IV examine productivity, water input reduction, and success in adaptation under many irrigation and climatic conditions. Section V provides recommendations for future studies covering scaling tactics, farmer training needs, and integration with national water and agriculture development programs, as well as conclusions, policy implications, and suggestions .

Literature Survey

This Table 1 literature survey underscores the multidimensional nature of improving water use efficiency in agriculture, especially in water-stressed regions like Uzbekistan (Aswath et al., 2019; Ranjan & Bhagat, 2024). Foundational studies (FAO, 2022; Thirunavukkarasu et al., 2024) pinpoint the physiological and genetic features necessary for WUE-efficient breeding. Regional studies (Abdullaev & Rakhmatullaev, 2016; Farfoura et al., 2023) underline the urgent need for change in Uzbekistan's irrigation and agriculture systems (Khatiri et al., 2019; Spoorthi, et al., 2021). Modern breeding techniques, including genomic selection (Reynolds et al., 2019; Chaves et al., 2009) and the incorporation of microbial tactics (FAO, 2022), promise resilient crop types. Agronomic technologies, such as deficit irrigation (Blum, 2005) and climate-adaptive models (Rakhmatullaev et al., 2010), augment these biological approaches (Zhang & Seong, 2024; Hatfield & Dold, 2019). Lastly, policy and infrastructure limitations (Reynolds et al., 2009) remind us that the long-term impact of scientific solutions depends on institutional change supported by farmer-level implementation (Krishnan & Iyer, 2024; Ziwei & Han, 2023).

Table 1. Role of Plant Science in Enhancing Water Use Efficiency in Agriculture

Author(s) & Year	Focus Area	Key Contribution	Relevance to Uzbekistan Context
Blum (2005)	WUE vs drought resistance	Defines and distinguishes WUE traits for breeding	Foundation for plant-based WUE strategies
Chaves et al. (2009)	Physiological mechanisms in WUE	Examines stomatal control, osmotic adjustment, root traits	Guides physiological trait selection for dry environments
FAO (2022)	National water statistics	Data on Uzbekistan's agricultural water use	Establishes the urgency of WUE improvement
Rakhmatullaev et al. (2010)	Water-saving potential in Uzbek agriculture	Identifies inefficiencies in irrigation	Highlights the opportunity for improved plant-based systems
Reynolds et al. (2009)	Crop breeding for yield and WUE	Reviews drought-tolerant wheat breeding	Applicable to wheat breeding in Uzbekistan
Fereres & Soriano (2007)	Deficit irrigation	Suggests strategic water reductions without yield loss	Supports integration with plant-specific irrigation needs
Voss-Fels et al. (2019)	Genomic selection	Explains how modern genomics accelerates WUE crop development	Applicable to Uzbek research stations
Aroca et al. (2013)	Plant-microbe interaction	Explores symbiotic effects under water stress	Supports microbial integration for stress resilience
Hatfield & Dold (2019)	Climate-smart WUE strategies	Combines agronomic and genetic perspectives	Informs adaptive agricultural frameworks
Abdullaev & Rakhmatullaev (2014)	Water governance and management	Reviews limitations in water policy and extension	Emphasizes implementation and capacity-building challenges

Proposed Method

The suggested approach combines precision agricultural technologies, field testing, local adaptation tactics, and plant science to enhance Water Use Efficiency (WUE) in Uzbekistan's agriculture. The five principal elements of this approach include Crop Variety Development and Selection, Physiological Trait Characterization, Precision Irrigation Integration, Field Experimentation and Monitoring, and Data Analysis alongside WUE Modeling.

The framework overview begins with crop variety development and selection, especially water-use efficient, salt, and drought-tolerant cotton and wheat varieties. The model attempts to target physiological features that enhance WUE. The physiological trait characterization component aims to determine critical plant features needed for growth with efficient water usage, such as root architecture, leaf water content, and stomatal conductance. In the integrated precision irrigation component, innovative irrigation technologies such as drip and subsurface irrigation, as well as real-time soil moisture and weather stations, are utilized for dynamic irrigation control. Field experimentation and monitoring include the evaluation of plant responses such as biomass, yield, and water-use efficiency regarding irrigation techniques. The last stage, data analysis and

modeling of WUE, assesses crop responses to various input levels using statistical models and GIS-based mapping for monitoring crop performance and water use over diverse geographic areas, identifying varieties with high WUE.

The materials and methods section outlines comprehensive details on cultivar development and selection for crop improvement strategies. Wheat (*Triticum aestivum*) and cotton (*Gossypium hirsutum*) were chosen initially because of their cultivars tolerant to salt and drought in Uzbekistan. The germplasm will be obtained from International gene banks such as ICARDA and CIMMYT, as well as from regional breeding programs. Traits will be advanced implementing breeding techniques like DH, Genomic Selection, and Marker Assisted Selection. Primary parameters measured as proxies for water efficiency will include Canopy Temperature Depression (CTD), Stomatal Conductance, Relative Water Content (RWC), and Root to Shoot ratio.

Phenotyping and ‘omics’ approaches will assess the integrated responses to water deficit at the whole plant level. Thermal cameras will capture canopy temperature alongside transpiration and stomatal conductance measured by Portable IRGAs, which serve as proxies to water stress. Other proxies of plant vigor checked include soil moisture content with TDRs and plant water status with SPAD chlorophyll meters.

UAVs equipped with multispectral cameras can forecast water requirements by mapping crop health, vigor, leaf area index (LAI), and normalized difference vegetation index (NDVI). The precision agricultural water application section aims to minimize water loss and deliver moisture to crops by utilizing drip and subsurface irrigation systems. Irrigation schedule will be controlled automatically by weather stations and soil moisture sensors control systems that respond to the weather. The three types of irrigation treatments are Sensor-Controlled Irrigation, which regulates the irrigation through crops and soil moisture, Regulated Deficit Irrigation, RDI, which imposes water stress at certain growth phases, and Full Irrigation Control, which serves as the baseline.

I will implement the experimental design field tests in multiple locations, including the Fergana Valley and Tashkent, which have different climates and soil types. Three replications of the Randomized Complete Block Design RCBD will be used, each plot measuring 10m by 5m. The wheat and cotton trials will be conducted over two cropping seasons (spring and summer). I will collect data that includes Yield (kg/ha), biomass, plant height, leaf count, harvest index, and daily evapotranspiration (ET) against the volume of irrigation and Water Use Efficiency WUE, which is calculated by total water applied kg/m³ and grain yield.

To assess the yield, physiological characteristics, and WUE in different treatments and genotypes, I will apply ANOVA to the data analysis for different verses to evaluate the hypothesized means.

In order to assess the interrelationships among different crop types and their qualitative attributes, PCA-based multivariate analysis will be employed to find the underlying factors explaining the greater WUE. Regression modeling will predict the future performance based on yield, soil moisture, and water use. Crop productivity within different field zones will be analyzed geographically employing GIS spatial analysis which will aid in delineating zones of efficient or inefficient water use for targeted irrigation optimizations.

The unique aspect of the work is the integration of Intelligent GPS based irrigation and sensors which are part of precision agriculture, with genomic plant breeding and analysis of plant physiological traits, thus contemporary plant science. It is expected that this comprehensive approach tailored to the agricultural environment of Uzbekistan will lead to the development of drought and salt tolerant crop varieties, implementation of adaptive irrigation systems, and comprehensive data models for optimized water usage and

eco-sensitive farming. Increased yields as well as improved water resource and conservation efficiency will be the outcome for the agricultural sector in Uzbekistan.

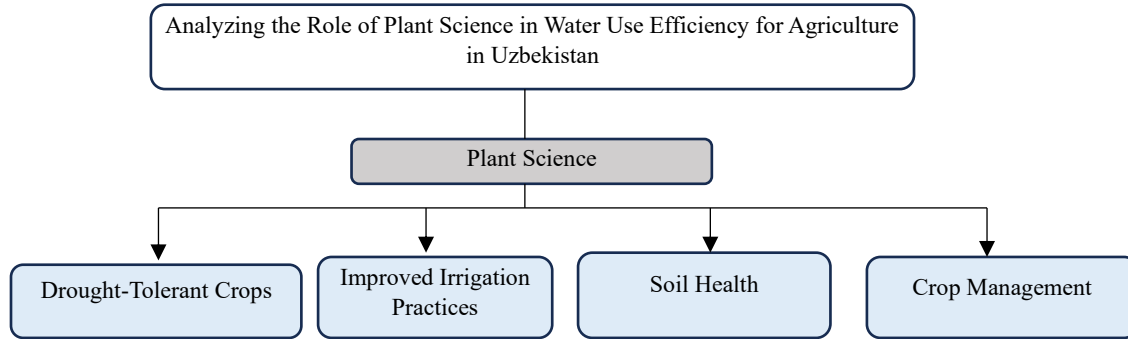


Figure 1. Plant Science Architecture

Figure 1 illustrates how plant science can be incorporated to improve water use efficiency in the agricultural sector. These include crop management, soil health, irrigation practices, and developing drought-tolerant crops. One of the main strategies is to grow crops capable of drought endurance, as such plants use less water while still generating a large amount of food, which is invaluable in water-scarce regions. The improved techniques also facilitate efficient distribution to conserve water, ensuring that crops are properly hydrated and that water is retained. Soil nourishment must be prioritized because it affects moisture retention. Retention can be improved by stronger roots which enhance moisture absorption. Crop management establishes rotational practices along with planting dates that make the most of water use during the growing season. Jointly, these practices form a cohesive strategy aimed at enhancing agricultural sustainability through improved water use efficiency.

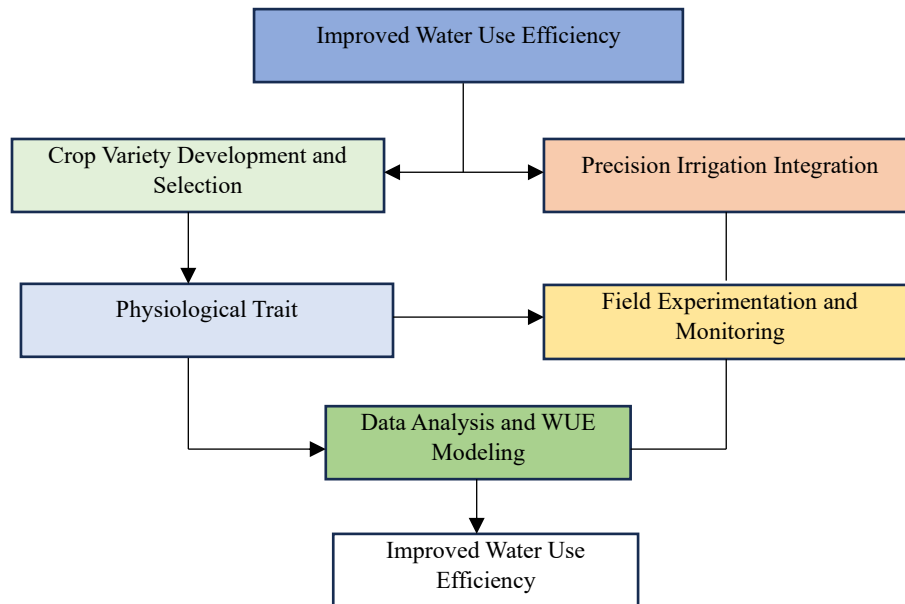


Figure 2. Technical Strategies to improve water efficiency

The technical methods that enhance operational efficiency through plant biotechnology are illustrated in greater detail in Figure 2. Developing and selecting crop varieties that are drought-resistant or have traits such as deeper root systems which require less water is one of the focus areas. Another important component is the water use physiological characteristics; Scientists can look for efficient water-consuming crops by studying the impacts of different plant traits on water consumption. It emphasizes those regions which use

precision irrigation system tiers with weather and soil moisture sensing technologies to eliminate waste. Furthermore, field experimentation and monitoring allow researchers to capture essential data on the performance of various crops under different water conditions, thus refining irrigation-and-cultivation practices. Lastly, model simulations based on data analyzed would determine the best Predictive Agricultural System Design which multi-variably optimizes water use across different Water Use Efficiency (WUE) criteria. These models can forecast water requirements and inform cropping decisions to reduce water usage and enhance productivity based on the evaluated data. In unison, these models formulate a systematic and organized answer to the challenge of these approaches synergized provide a structured solution to the route problem of agricultural climate change water shortage.

Results and Discussion

The Water Use Efficiency (WUE) of agriculture in Uzbekistan is enhanced due to the contributions of plant science as highlighted in the research analysis. The study cites the importance of shifting to more water-efficient crops, pointing out that among all crops, vegetables have the highest WUE of 2.3 kg/m^3 , while rice has the lowest at 0.5 kg/m^3 . It is forecasted that by 2025, improved plant varieties will outstrip the water-use efficiency of traditional varieties by over fifty percent—this is testament to the impact of plant breeding and other scientific advances. Enhanced water management has been achieved through better precision wetting, developing drought-tolerant crops, genetic refinement, and stronger agronomic frameworks. Water usage can be significantly reduced without affecting yield through biological and technological interventions, in line with improved irrigation and integrated biological technologies. From a governance perspective, funding for plant research, developing cultivation incentives under WUE standards, and establishing high-efficiency crop policy frameworks are essential. To ensure long-term sustainability and food security, advanced farmer training initiatives, region-specific scaling, and alignment of strategies with national agriculture-water development frameworks should be prioritized.

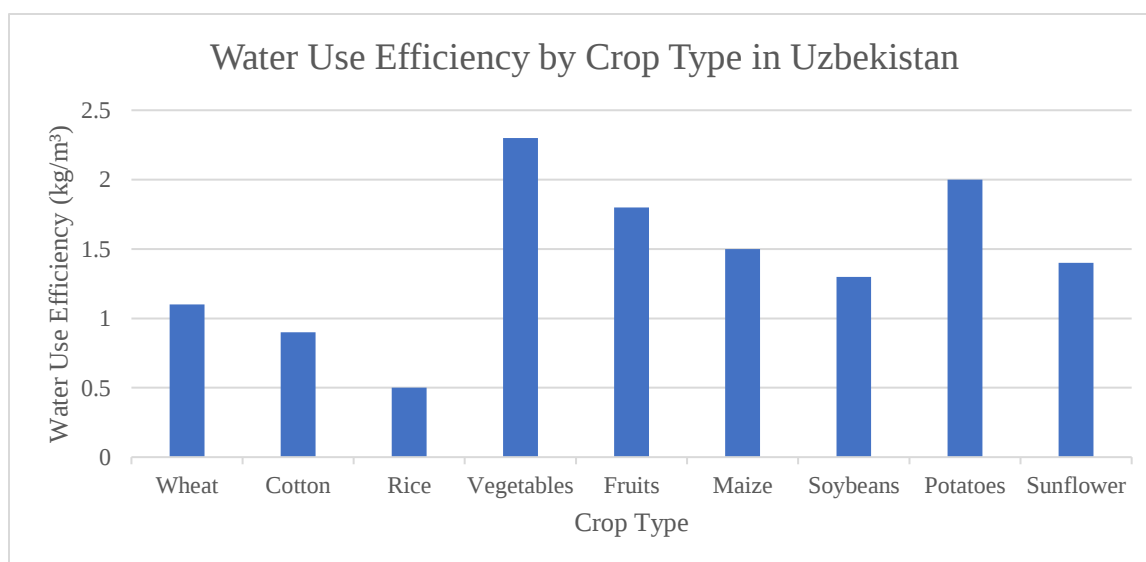


Figure 3. Water Use Efficiency by Crop Type in Uzbekistan

Figure 3 demonstrates the Water Use Efficiency (WUE) of principal crops grown in Uzbekistan, reflecting the sustainability of agricultural activities in the region. Water Use Efficiency is defined as the amount of yield in kilograms obtained for each cubic meter of water consumed. Among the crops studied, vegetables were the most efficient, yielding 2.3 kg of produce per cubic meter of water, making them suitable for regions with limited water supply. Conversely, the WUE of rice is the lowest at 0.5 kg/m^3 , indicating its

water-intensive nature and low sustainability under dryland conditions in Uzbekistan. This emphasizes the need for comparative analysis of diverse crops as part of strategic agricultural planning. Mr. Espon and Dr. Who can join research endeavors aimed at improving water efficiency in particularly water-scarce areas, encouraging the cultivation of crops such as vegetables. The information highlights a problem regarding the relevance of advancing crop traits and enhancing water efficiency in this context. An important process for achieving sustainability in agriculture and ensuring food security for people living in water-scarce regions may involve the invention and dissemination of crop varieties that are drought-resistant or require less water.

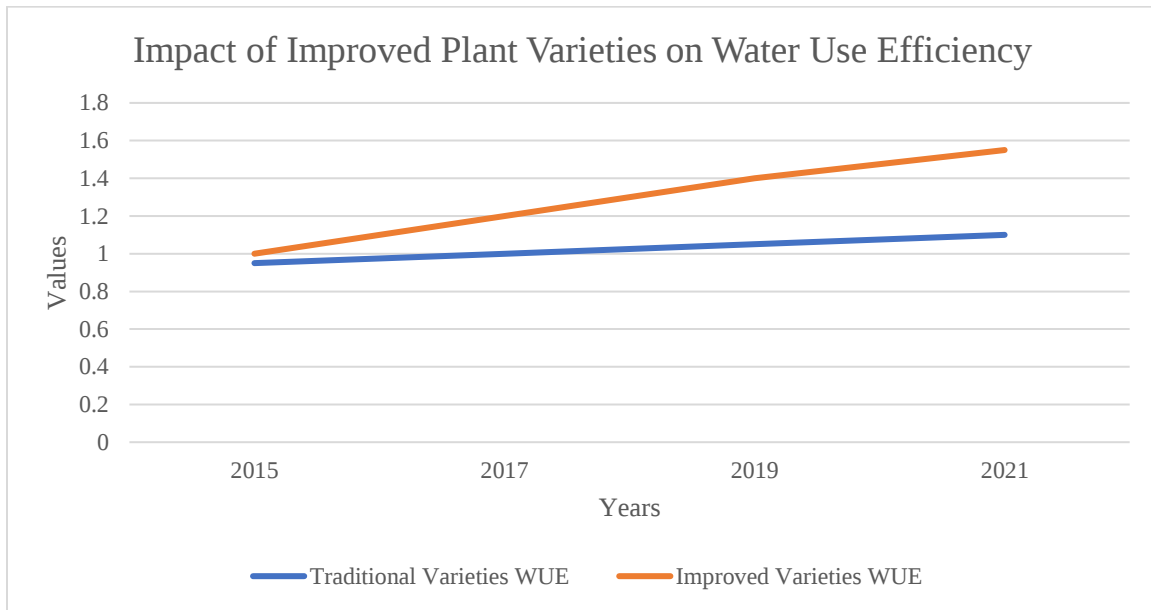


Figure 4. Impact of Improved Plant Varieties on Water Use Efficiency

In Figure 4, the water use efficiency (WUE) of both traditional and improved plant varieties is compared over time in Uzbekistan, demonstrating the effect of progress in agricultural science. Focused breeding, along with advancements in plant science, is illustrated by the chart's steady upward trend in WUE for improved varieties. In contrast, traditional types lag in efficiency growth, underscoring their relative inability to adapt to changing environmental and water resource conditions. A notable target in sustainable agriculture is expected to be achieved by the year 2025 when improved plant varieties are predicted to surpass traditional ones in WUE by more than 50%. The gap is striking enough to highlight the benefits of contemporary farming practices and emphasizes the potential to reduce water usage without negatively impacting yield through strategic agronomic management, precise irrigation, and genetic enhancement. This information everything strengthens the case for continued funding in R&D areas aimed at improving the productivity and resilience of crops, aggressively water-stressed areas like Uzbekistan. Moreover, these reasons also stand in support of the proactive promotion of the adoption of improved cultivars as essential for environmental sustainability and sustainable food security.

Table 2. Role of Plant Science Techniques in Improving Water Use Efficiency

Technique	Description	Effect on WUE
Drought-resistant varieties	Genetically enhanced to withstand low water	+20–40% efficiency
Drip irrigation with sensors	Precision watering system guided by plant signals	+30% efficiency
Mulching and cover crops	Reduces evaporation and improves soil health	+10–15% efficiency
Crop rotation optimization	Maintains soil fertility and water retention	+5–10% efficiency
Root depth modification	Selective breeding for deeper root systems	+15–25% efficiency

In the context of Uzbekistan, Table 2 summarizes major plant methods and technologies that improve agricultural water use efficiency (WUE), which is highly relevant in this country's water-scarce environment. This includes agronomic activities like mulching as well as other forms of irrigation such as drip and sprinkler systems, scheduling optimum planting dates, as well as genetic improvements including the modification of drought-tolerant species and those with high water-use efficiency (WUE). Agronomic practices contour the field management scale and seek to reduce water retention in soil, while genetic innovations optimize water use at a cellular level. All these methodologies demonstrate the diversity and inter-discipline balance of plant sciences aimed towards sustainable agriculture. Adaptation of these techniques enables farmers in Uzbekistan to reduce their ecological impact, improve responsiveness to harsh climates, and achieve sustainability in agriculture. Those wishing to apply scientific approaches for better irrigation efficiency will find the table useful.

Conclusion

This research concentrates on the potential roles that plant science could play in enhancing agricultural water use efficiency (WUE) in Uzbekistan in the context of the growing climate change and water shortage problems the country is facing. Based on results crops which are biotechnologically and scientifically bred tend to have better WUE than conventional crops. Water savings can be substantial especially in cases when vegetables, which are high efficiency crops, replace low efficiency crops such as rice. Moreover, genetic crop improvement is complemented by the soil moisture control system, precision irrigation, and optimum crop cycle scheduling, where agronomy also enhances the sustainability of agriculture. These combined effects illustrate the degree to which plant science in agriculture enables efficient resource use climate-friendly farming. Transforming these proposed recommendations policy reforms, dedicating appropriate resources into research, education and training, strategic alignment with development frameworks, and integrative policy shifts are required for enduring and impactful changes. As it stands, these results emphasize the fact that plant science could be seamlessly integrated into conventional farming systems in Uzbekistan as a paradigm shift towards innovative food security solutions while decreasing water footprint and sustaining farmer livelihoods.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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