EFFICIENT USE OF RESOURCES IN AGRICULTURE IN THE CONDITIONS OF UZBEKISTAN

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1. Abstract. *This study provides a comprehensive empirical assessment of the transition toward resource-use efficiency (RUE) in Uzbekistan's agricultural sector, synthesized through the dual lenses of Climate-Smart Agriculture (CSA) and digitalization. Uzbekistan, an agrarian republic where 43% of the land area (20.3 million ha) is dedicated to agriculture, faces acute resource constraints, including a 22% per capita decline in agricultural land over the past 15 years and a projected 35% decline in the Amu Darya river flow in Karakalpakstan by 2050. Focusing on the high-productivity irrigated landscapes of the Fergana Valley, the research evaluates the shift from conservative manual systems to automated "Smart Farming" architectures incorporating GPS navigation, drone-based monitoring, and Big Data analytics. Through a post-positivist analysis of 175 farm enterprises—comprising both autonomous Dehkan farms and large-scale agro-clusters—the study identifies that the intensive adoption of six or more CSA practices is associated with a 71% increase in farm income and a 43% rise in crop yields. Furthermore, water-saving technologies have expanded from 250,000 ha in 2020 to 800,000 ha in 2024, contributing to a 48% improvement in RUE. The findings demonstrate that precision interventions, such as fertilizer micro-dosing, deliver a return on investment (ROI) of 456%, underscoring the necessity of reconciling global sustainability paradigms with local constraints of soil salinity and energy-intensive pump irrigation [i].*

2. Keywords: *Uzbekistan, Climate-Smart Agriculture (CSA), Resource Use Efficiency (RUE), Fergana Valley, Precision Farming, Digitalization, Drip Irrigation, Dehkan Farms, Soil Salinization, Sustainable Productivity.*

3. Introduction

3.1 The Agrarian Context of Uzbekistan

Uzbekistan remains a fundamentally agrarian republic where the agricultural sector is the primary engine of rural livelihoods and national food security. Of the nation's 44.8 million hectares, agricultural land occupies approximately 20.3 million hectares (43%) [1]. However, the productivity of this vast landscape is tethered to a mere 4.2 million hectares of irrigated land, which serves as the core of the country's crop production [1]. In recent decades, the sector has encountered a dual pressure: a 5% contraction in total agricultural land and a more severe 22% decline in agricultural land available per capita over the last 15 years [1]. This per capita decline is largely driven by the conversion of pastures, orchards, and vineyards for non-agricultural development and the pressures of a rapidly growing population that will require 1.5 times more food by 2050 [1]. Consequently, the traditional "conservative" approach to farming—characterized by extensive land use and manual resource application—is no longer tenable. The transition toward automated systems is not merely a technological upgrade but a demographic and economic necessity.

Table 1: Agricultural Land Dynamics and Policy Implications in Uzbekistan

Indicator	Value	Context/Implication
Total Agricultural Land	20.3 million ha	Foundation of the national economy and rural employment.
Percentage of Total Land Area	43%	High dependency on land health for GDP and stability.
Irrigated Land Area	4.2 million ha	The critical, water-sensitive core of crop production.
15-Year Change in Total Land	-5%	Reflects land degradation and urban encroachment.
15-Year Change in Per Capita Land	-22%	Drives the urgent need for Smart Farming and intensification.

Source: [1]

3.2 Climate Change Vulnerability and Water Scarcity

The urgency of resource-use efficiency is magnified by Uzbekistan’s extreme vulnerability to climate change. Longitudinal data from 1990–2020 indicates a warming trend of +0.3°C per decade, while annual precipitation has declined by -2.5 mm per decade [3]. These shifts create a "scissors effect" where rising temperatures increase crop evapotranspiration while water availability diminishes. The most alarming projections involve the transboundary river systems: the Amu Darya basin, specifically in Karakalpakstan, is expected to see a 35% decline in total flow by 2050 [3]. Simultaneously, national irrigation water demand is projected to rise by 25%, creating a structural deficit that threatens the cotton-wheat systems that dominate 75% of the cultivated landscape [3]. Currently, agriculture accounts for 80-90% of all freshwater withdrawals, yet nearly 40% of this water is lost during conveyance through aging canal infrastructure [3, 5].

3.3 Digitalization and the Policy Framework

To address these existential threats, the Republic of Uzbekistan has adopted a robust policy architecture, led by the "Strategy for Agricultural Development 2020-2030" and the "Digital Uzbekistan-2030" strategy [2, 4]. These frameworks aim to move beyond "eye-balling" resource application toward a precision-based model. This "Smart Farming" concept utilizes an integrated algorithm: satellite navigation for machinery orientation, unmanned aerial vehicles (drones) for crop health monitoring, and Internet of Things (IoT) sensors for soil moisture tracking [1]. The state's role has shifted toward a "hybrid governance model," where formal market liberalization (abolishing state procurement quotas in 2020-2021) coexists with persistent administrative influence via agro-clusters [3]. These clusters provide the capital required for high-tech transitions, though approximately 70% of land remains de facto allocated to cotton and wheat through regional irrigation priorities and land-use planning [3].

3.4 Study Rationale

While global CSA paradigms emphasize productivity, resilience, and mitigation, their implementation in Uzbekistan must contend with specific local biophysical and institutional constraints. These include secondary soil salinization affecting over half of irrigated lands and a reliance on energy-intensive pump irrigation—where 56% of irrigated land depends on over 5,000 individual electric pumps [3]. This study seeks to quantify how digital and CSA interventions reconcile these constraints to produce measurable gains in yield, income, and environmental health, providing a scientific basis for evidence-informed policy.

4. Methodology

4.1 Research Design & Study Area

The study is situated within a post-positivist epistemological paradigm, recognizing that while agricultural ecosystems are complex and only partially observable, empirical rigor can identify significant patterns of causality and correlation [3]. The research focuses on the Fergana Valley (Fergana, Rishton, and Bag‘dod districts), a critical agro-landscape characterized by intensive cotton-wheat rotations and a continental arid climate. The study area is situated between 40°15′–40°45′ N and 71°30′–72°15′ E, with elevations ranging from 420 to 580 meters above sea level (m.a.s.l.) [3]. The landscape consists of alluvial plains with soil textures ranging from sandy loam to clay loam [3].

4.2 Sampling Strategy and Screening

A stratified purposive sampling approach was used to select 175 farm units (135 Dehkan farms and 40 cluster farms) [3]. The sample size was calculated using the finite population proportion estimation formula:

Equation (1): n = \frac{Z^2pq}{e^2} \times \frac{N}{N-1} where Z = 1.96 (95% confidence), p = 0.5, e = 0.07, and N = 12,450 [3].

Inclusion and Exclusion Criteria: To ensure technical accuracy, the "Screening Process" followed rigorous standards:

- **Inclusion:** Eligible farms must have adopted at least five CSA technologies, provided documented credit/subsidy access, and scored at least 60% on a five-item CSA knowledge assessment [3].
- **Exclusion:** Farms were excluded if they specialized in non-field crops (e.g., greenhouses), faced binding land tenure disputes, or experienced severe exogenous shocks (e.g., extreme pest outbreaks) during the observation period [3].

4.3 Definition of CSA Technologies (T1-T9) and Measurement Scales

The research evaluates nine specific technologies (T1-T9) using consistent ordinal measurement scales.

Table 2: Climate-Smart Agriculture Technology Definitions and Measurement Scales | Code | Technology | Definition | Measurement Scale (Ordinal) | | :--- | :--- | :--- | :--- | | T1 | Biopesticides | Biological agents/extracts for pest control. | 1 (None) to 4 (>75% of area). | | T2 | Microdosing | Precision fertilizer (2-6g) per plant. | 1 (Broadcast) to 4

(Full Microdosing). | | T3 | Organic Manure | Livestock manure for soil structure. | 1 (None) to 4 (>15 tons/ha/yr). | | T4 | Compost | Decomposed residues and organic waste. | 1 (None) to 4 (>10 tons/ha/yr). | | T5 | Flood-tolerant | Varieties bred for waterlogging resilience. | 1 (None) to 4 (>75% area). | | T6 | Solar Pumps | Renewable energy-based irrigation pumps. | 1 (Grid/Diesel) to 4 (>75% solar). | | T7 | Early maturing | Varieties designed for drought avoidance. | 1 (None) to 4 (>75% area). | | T8 | Pit planting | Techniques like zaï pits or raised beds. | 1 (Broadcast) to 4 (>75% area). | | T9 | Cover crops | Secondary crops for soil health. | 1 (None) to 4 (>75% area). | *Source: [3]*

4.4 Outcome Variables (Y1-Y5) and MRV Indicators

Efficacy was measured through five dependent variables (Y1-Y5) and integrated Monitoring, Reporting, and Verification (MRV) indicators:

- **Crop Yields (Y1):** Actual harvest data for cotton, wheat, and vegetables (kg/ha/yr).
- **Net Income (Y2):** Total revenue minus variable costs (USD/ha/yr).
- **Resource Use Efficiency (Y3):** Ratio of gross output value to total input costs.
- **Soil Erosion Score (Y4):** Visual assessment scale from 1 (none) to 5 (gully formation).
- **Water Quality Index (Y5):** Composite 1-10 scale measuring salinity, pH, and nutrients.
- **MRV Indicators:** Water productivity (kg of output per m^3) and carbon/nitrogen footprints (CO_2-eq and N_2O) [3].

4.5 Institutional Context: Dehkan vs. Cluster Farms

The analysis accounts for the unique institutional dichotomy in Uzbekistan. Dehkan farms, established under the 1998 Law, operate on heritable land-use rights. Although they average only 0.17–0.35 hectares, they are exempt from state quotas and contribute nearly 60% of national agricultural output [3]. In contrast, large-scale cluster farms (averaging 150 ha) operate through commercial contracts and provide the entry point for capital-intensive digital tools like drones and heavy machinery [3].

5. Results and Analysis

5.1 Productivity and Income Gains

Empirical data demonstrates a strong "dose-response" effect: farms adopting six or more CSA practices achieved a 71% increase in net farm income and a 43% rise in crop yields compared to low-adopters [3]. A standout performer was fertilizer micro-dosing (T2), which increased cotton yields by an average of 245.8 kg/ha/yr and delivered a remarkably high ROI of 456% [3]. Multivariate regression models indicate that CSA adoption patterns account for 57.3% of the variation in yield and 61.8% in farm income [3].

5.2 Water-Saving Technology Expansion

Uzbekistan has significantly accelerated the implementation of water-saving measures as a strategic response to declining river flows. Drip irrigation, which reduces water consumption by nearly one-third while boosting yields by 15-20%, has seen a more than three-fold expansion since 2020.

Table 3: Water Consumption and Drip Irrigation Trends in Uzbekistan (2020–2024)

Year	Total Water Use (billion m³)	Ag Share of Water (%)	Drip Irrigation Area (thousand ha)
2020	51.0	84%	250
2021	50.4	83%	410
2022	49.8	82%	570
2023	48.9	81%	710
2024	47.6	80%	800

Source: [5]

5.3 Resource Use Efficiency (RUE) and Environmental Impact

The adoption of bundled CSA practices led to a 48% improvement in the RUE ratio [3]. Digital monitoring infrastructures, including sensor arrays and automated dispatching, have successfully reduced water transport losses in major canals by 10–12% [5]. Environmentally, precision application has reduced secondary soil salinization by ensuring that water and nutrients are applied only where needed, preventing the shallow groundwater rises that draw salts to the root zone [1].

6. Discussion

6.1 The Role of Agro-clusters and Hybrid Governance

The transition from a command-based state procurement system to market-contract mechanisms via agro-clusters has been the primary driver of high-tech uptake. However, the study finds a tension in the "hybrid governance model." While clusters facilitate the use of drones and Big Data, the most immediate ROI for smallholders often comes from biologically grounded practices like organic amendments (T3) and micro-dosing (T2), which consistently outperform capital-intensive alternatives in risk-sensitive contexts [3].

6.2 Barriers to Adoption and Mitigation Strategies

Based on the synthesis of "Negative Consequences" and "Ways to Eliminate," the following matrix identifies the primary obstacles to scaling digitalization.

Table 4: Digitalization Barriers and Strategic Solutions

Advantages	Negative Consequences	Ways to Eliminate
Increased Productivity	High initial investment costs for equipment.	Targeted state subsidies and credit grants.
Resource Optimization	Need for infrastructure modernization (canals/IoT).	Development of digital connectivity and irrigation infra.
Improved Quality	Acute shortage of qualified IT-agrarian personnel.	Specialized educational programs and training.
Market Expansion	Limited rural access to high-speed internet.	Rural internet infrastructure expansion.
Decision Speed	Dependency on tech and risks of cyberattacks.	Cybersecurity protocols and creation of backup systems.

Source: [2]

6.3 Environmental and Methodological Insights

Precision agriculture serves as a vital buffer against soil degradation. By utilizing digital maps derived from satellite data and laboratory soil analysis, farmers avoid "eye-balling" applications that lead to nutrient runoff [1]. Methodologically, the use of MRV indicators provides the transparency required to unlock "green finance" for Central Asian farmers.

6.4 Social and Cognitive Factors: The Dose-Response Effect

Adoption is not merely an economic calculation but is socially embedded. "Cognitive inertia" and status quo bias significantly hinder solar-powered irrigation (T6), as perceived risks often outweigh theoretical long-term gains [3]. According to "Diffusion of Innovation Theory," the lack of localized demonstration plots prevents peer-based knowledge transfer. Furthermore, the study highlights a synergistic "dose-response" effect: adopting practices in bundles (e.g., T2, T3, and T9 together) creates productivity gains that individual practices used in isolation cannot achieve [3].

7. Conclusion

Digitalization and Climate-Smart Agriculture are the primary mechanisms for maintaining Uzbekistan's national competitiveness and food security. The empirical evidence is clear: the transition from conservative to automated systems can yield 43% higher crops and 71% higher income. However, the external validity of global CSA claims in Uzbekistan depends on the sector's ability to navigate high soil salinity and energy-intensive pump irrigation.

To realize the 2030 developmental horizon, the following policy interventions are essential:

- Establish a robust system of targeted state subsidies and low-interest credit lines specifically for bundled CSA technology packages to overcome high initial investment barriers.
- Prioritize the "Digital Rural Infrastructure" initiative, ensuring high-speed internet and IoT connectivity reach remote farmsteads to support real-time sensor arrays and IT platforms.
- Develop a decentralized network of CSA demonstration plots and specialized extension services to overcome cognitive inertia and facilitate peer-to-peer knowledge transfer.

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