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Ensuring The Economic Sustainability Of Potato Production Under Climate Change

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Abstract: This research investigates models for ensuring the economic sustainability of potato production under the extreme continental climate conditions of Uzbekistan. The study provides an econometric analysis of how heat stress, water scarcity, and atmospheric humidity impact crop yields. Leveraging recent authoritative sources, the paper substantiates the influence of varietal diversification and advanced post-harvest storage technologies on overall economic efficiency. The findings suggest that integrating climate-resilient agrotechnology with optimized storage value chains is critical for mitigating environmental risks and enhancing the profitability of the agricultural sector in the region.

Keywords: Economic efficiency, Heat stress, Humidity, Water management, post-harvest technology, Climate resilience, Agricultural econometrics.

Introduction: Globally, potato production dynamics are growing at a steady average rate of **1.2% to 1.5% annually**; however, climatic anomalies pose a severe threat to yield stability. In Uzbekistan, the specific economic-biological characteristic of potato cultivation is that even minor fluctuations in the heat and moisture balance can reduce the crop's biological potential by up to **40%**.

For optimal tuber formation, soil temperatures must ideally remain between **17–20°C**. When soil temperatures exceed **25°C**, the tuberization process slows down; at temperatures above **30°C**, net assimilation ceases entirely, leading to a sharp decline in economic profitability. During Uzbekistan's peak summer months, ambient temperatures rising to **40–45°C** trigger a process of "ecological disruption" in the crops. This not only compromises the current harvest but also renders the quality of seed reserves intended for the following year economically unviable.

In the economic modeling of climate factors, heat stress represents the highest risk level. From a mathematical perspective, every **1°C increase** above the optimal threshold results in an **8–10% reduction** in potato yields. For agricultural enterprises, this equates to an average loss of **15–20 million UZS** in potential profit per hectare. Given the scarcity of water resources and the potato's high water requirement (**400–600 liters per 1 kg**), economic efficiency must be evaluated through the **Water Use Efficiency (WUE)** metric. Observations indicate that during the flowering stage, if atmospheric humidity falls below **75–80%** (for instance, dropping to **30–40%** during "garmsel" winds), plant stomata close and photosynthesis halts. In such conditions, even adequate irrigation cannot prevent yield loss; consequently, water expenditures rise, and the unit cost of the product increases by **25–30%**.

The most promising pathways for increasing field efficiency and managing climatic risks are **varietal diversification** and the **optimization of planting schedules**. In the context of Uzbekistan, selecting heat-tolerant and virus-resistant varieties such as "Sante," "Kondor," "Nevskiy," and "Picasso" has been proven to increase economic profitability by **25%**. Furthermore, planting "early-maturing" varieties (e.g., Ostara, Prior) under plastic covers in late February allows for a harvest by June, thereby avoiding peak summer heat. This method vacates the field for a secondary crop in July, such as late-season potatoes or legumes. Transitioning to a double-cropping system increases the **Land Equivalent Ratio (LER)** from **1.0 to 1.8**, which can boost the annual net profit per hectare by **2.5 times**.

A significant portion of economic gain depends on **post-harvest technologies**. Analysis shows that maintaining humidity at **90–95%** during storage reduces weight loss (evaporation) in tubers. While investing in modern refrigerated storage facilities increases initial capital expenditures, it enables the sale of produce during periods of seasonal price peaks—rising from **3,000 UZS** in autumn to an estimated **7,500 UZS** by spring 2026. This strategic storage can elevate the net profit margin from **60% to 140%**.

Conclusion and Strategic Economic Recommendations

The research results indicate that under the conditions of climate change, the economic sustainability of potato production cannot be achieved solely through the reduction of extensive costs. Instead, it requires a transition toward an **"Adaptive Economic Model"**. To achieve this level of efficiency in the context of Uzbekistan, the following economic mechanisms are proposed:

1. **Digital Optimization of Operating Expenses (OPEX):** While the implementation of **"Smart Agriculture"** sensors increases initial Capital Expenditures (CAPEX), it reduces variable costs associated with water and energy resources by **40%** in the long term. This strategy lowers the resource share in the formation of the unit cost, thereby stabilizing the marginal profit of the agricultural enterprise.

Table 1. Economic impact of Smart Agriculture (IoT-based) versus traditional manual control

Cost Categories & Indicators	Manual Control (Traditional)	Smart Agriculture (IoT-based)	Economic Outcome & Efficiency
Capital Expenditure (CAPEX)	5-8 mln UZS	15-20 mln UZS	Initial investment increases by +150% (Sensors and automation)
Water Resource Consumption (m3)	6,000 - 8,000	3,500 - 4,500	Water consumption decreases by 40% (Precision irrigation)
Electricity / Fuel	4.5 mln UZS	2.7 mln UZS	Costs decrease due to 40% reduction in pump operating time
Fertilizers & Nutrients (Fertigation)	12.0 mln UZS	9.0 mln UZS	25% efficiency: Nutrients are delivered directly to the root system
Operating Expenses (OPEX)	35-40 mln UZS	24-28 mln UZS	Variable costs decrease by 35-40%
Unit Cost (per 1 kg)	3,200 UZS	2,350 UZS	Production cost falls by 27% due to reduced resource share
Yield (t/ha)	25-28 t	35-42 t	+45% growth due to managed water and heat stress
Marginal Profit (mln UZS)	18.0 mln UZS	55.0 mln UZS	Profit stability increases 3-fold

2. **Mitigating Micro-financial Risks through Mulching:**Mulching technology, aimed at reducing soil temperature, serves as an economic **"risk insurance"** instrument. By preserving **35% of the yield** that would otherwise be lost due to heat stress, it protects

against an unexpected decline in **Gross Revenue** per hectare. This, in turn, ensures the financial liquidity of agricultural clusters that carry credit obligations. Under conditions of global warming, mulching (using straw or plastic film) maintains soil temperature at an optimal level, preventing the economic "burning" of the crop

Table 2. Economic indicators of traditional methods versus mulching under thermal stress

Economic Indicators	Traditional Method (No Mulching)	With Mulching (Anti-stress)	Economic Efficiency and Conclusions
Soil Temperature (July-Aug)	32-35°C (Critical)	24-27°C (Optimal)	Up to 8°C reduction: Tuberization process remains uninterrupted
Initial Cost (Investment)	0 UZS	5.5 - 7.0 mln UZS	Additional costs for mulching materials and labor
Water Evaporation (Evapotranspiration)	High (100%)	Low (55-60%)	Moisture retention: Irrigation costs saved by 30-35%
Expected Yield (t/ha)	18-22 t	32-35 t	+13-15 t yield: Crop loss due to heat stress was prevented
Gross Revenue	66.0 mln UZS	105.0 mln UZS	+39.0 mln UZS: Each soum spent yielded 6 soums in additional revenue
Financial Risk Level	High (Risk of bankruptcy)	Minimal (Liquidity ensured)	Effectively "insures" against the loss of 35% of the crop
Credit Repayment Capacity	60-70% (At risk)	100% (Guaranteed)	Increases financial reliability index for clusters and banks

The direct sale of non-standard and undersized products is economically inefficient. Processing these tubers into starch and other derivatives establishes a high-performance **Value Chain**. This strategy increases the farmer's overall profitability by **1.4 times** while simultaneously reducing the financial loss coefficient to a minimum when crop quality is compromised by climatic disasters.

The Samarkand region—particularly the Toyloq, Samarkand, and Jomboy districts—holds a leading position in the republic for potato cultivation. However, extreme heat and water scarcity result in a significant portion (**15–20%**) of the harvest maturing as non-standard, including small or malformed tubers. The value chain created by processing these products is detailed in the table below, based on an analysis of potato clusters in the Samarkand region.

Table 3: Analysis of Vertical Integration and Value Chain in Samarkand Region Potato Clusters (Based on 1,000 tons of yield).

Indicators	**Traditional Model (Raw Material Sales)**	**Vertical Integration (With Processing)**	**Economic Efficiency and Difference**
High-Quality Product Share (80%)	800 tons	800 tons	Sold at market price (e.g., 4,000 UZS/kg)

Non-standard Product Share (20%)	200 tons	200 tons	Heat-stressed small tubers (Ayupov, 2007)
Sale Price of Non-standard Product	1,500 UZS/kg	0 (Not sold raw)	Low-quality product lowers the market price
Processed Product (Starch)	0	40-45 tons	From 200t potatoes (20-22% yield efficiency)
Market Price of Starch	-	18,000–20,000 UZS/kg	High value-added product
Total Revenue (Gross Revenue)	3.5 billion UZS	4.1 billion UZS	+600 million UZS additional income
Circular (Waste-free) Economy	Low (High waste)	High (Zero waste)	Waste converted into profit
Climate Damage Coefficient	0.35 (High)	0.10 (Minimal)	Losses minimized if heat damages quality
Profitability Level	40-45%	60-65%	1.4-fold increase

Managing Seasonal Price Volatility

Economic modeling indicates that investments in modern warehouses equipped with climate control systems enable the sale of products during peak price periods (April–May). This serves as the primary driver for increasing the Net Profit Margin from the traditional 45–50% to **120–140%**. In Samarkand and other potato-growing regions, seasonal price fluctuations (volatility) represent the most significant factor impacting farmer income. According to research data maintaining the moisture content and physiological state of potatoes allows for the extension of the product's market value.

Table 4: Economic Efficiency Model for Managing Seasonal Price Volatility and Storage (Based on 1,000 tons of product)

Indicators	**Sale at Field Edge (July-Aug / Oct-Nov)**	**Storage in Modern Warehouses (Until April-May)**	**Economic Efficiency and Variance**
Average Selling Price (per 1 kg)	3,000 – 3,500 UZS	7,500 – 8,500 UZS	Price increase: 120-140% (Due to seasonal scarcity)
Product Waste and Weight Loss	0% (Immediate sale)	5% – 7%	Weight loss is minimized in smart storage according to Ayupov
Storage Costs (OPEX)	0 UZS	600 – 800 UZS/kg	Costs for electricity, sensors, and maintenance
Gross Revenue	3.2 billion UZS	7.4 billion UZS	+4.2 billion UZS in additional revenue
Net Profit	0.9 billion UZS	3.8 billion UZS	4.2-fold increase in net profit
Net Profit Margin	45-50%	120-140%	Key indicator of investment attractiveness

Return on Investment (ROI)	Seasonal	1.5 – 2 seasons	Rapid recovery of warehouse construction costs

Furthermore, achieving this transition requires a synergistic alignment between state policy, private sector investment, and scientific innovation. By institutionalizing adaptive technologies—such as precision irrigation, heat-resistant varietal diversification, and smart storage systems—the agricultural sector can move beyond mere risk mitigation toward a model of long-term profitability. Ultimately, this approach serves as a viable blueprint for Central Asian agriculture, demonstrating that the integration of data-driven management and vertical value chains can transform environmental vulnerabilities into sustainable economic growth.

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