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SORGHUM AS A CLIMATE-RESILIENT CASH CROP IN KARAKALPAKSTAN: YIELD AND PROFITABILITY ANALYSIS

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ABSTRACT---
Karakalpakstan – an Aral Sea basin region of Uzbekistan – faces severe soil salinity and water scarcity, pressuring farmers to diversify beyond water-intensive cotton and wheat. This study evaluates the economic feasibility of sugar sorghum as a climate-resilient alternative crop in the region. We conducted farm surveys and field interviews in 2024, and analyzed secondary data to compare yield and profitability of four sorghum varieties. Cost–benefit analysis per hectare shows that all tested varieties are profitable under local conditions, with the highest-yielding cultivar ("O'zbekiston 18") yielding 105.0 t/ha of biomass and net income of ~29.88 million UZS/ha (≈2,353 USD). A cash-flow simulation for a typical 0.7 ha smallholding indicates that even at moderate yields (≈30 t/ha), sorghum can generate substantial seasonal profit. Comparative analysis with other semi-arid regions (India, Sudan, Nigeria, Ethiopia) highlights sorghum's competitive advantage in drought tolerance and income stability under marginal conditions. The results underscore sugar sorghum's potential to enhance rural livelihoods and land productivity in Karakalpakstan. We conclude that with supportive policies – including improved seed dissemination, farmer training, and market development – sugar sorghum could significantly contribute to sustainable agricultural diversification in arid environments.
KEYWORDS: *Arid Regions; Cash Crops; Dryland Farming; Uzbekistan; Profitability; Sorghum*--------------

1. INTRODUCTION

Over the past three decades, Uzbekistan has undertaken substantial agricultural reforms to transition from a state-order system to a market-oriented framework. These reforms – especially since 2017 – have reduced mandatory state procurement of cotton and wheat, promoted agricultural cluster formation, and increased farmers' autonomy in crop selection [1]. In formerly centralized regions like Karakalpakstan, greater cropping flexibility provides an opportunity to replace or rotate traditional crops with more climate-resilient alternatives. This is critical as Karakalpakstan lies in the downstream Amudarya River basin and suffers from severe ecological degradation, including the desiccation of the Aral Sea, land salinisation, and recurrent droughts [2]. These challenges have heightened the urgency for introducing crops that can withstand water and soil stresses while sustaining farm incomes.

Sugar sorghum has emerged as a promising candidate in this context. It is a C_4 cereal known for exceptional drought and heat tolerance, and an ability to grow on saline soils where other staples underperform [3]. Grown primarily as a cash crop for fodder, syrup, and bioethanol, sugar sorghum requires relatively low inputs and can produce high biomass yields under dryland conditions [4]. Crop diversification with sorghum is therefore seen as a strategy to improve the resilience of farming systems and livelihoods in arid regions. Farmers who traditionally rely on subsistence grains often struggle to generate sufficient cash income; introducing a marketable crop like sorghum can bolster household earnings and spread risk. Indeed, sorghum contributes to food security and rural economies across Africa and South Asia due to its reliability in harsh climates [19]. At the same time, as a commercial monoculture, sorghum cultivation is not without risks – including price volatility and potential pest or disease pressures – which necessitates supportive agronomic and policy measures [5]. Moreover, in many countries sorghum remains underutilised in high-value markets, being largely confined to traditional uses; consumer perceptions and limited product development impede its competitiveness in modern value chains [6]. These factors underscore that simply growing a resilient crop is not enough – farmers need institutional support (extension services, credit access, stable markets) to fully realise its benefits.

Considering the above, this study examines the yield performance and economic profitability of sugar sorghum in the Republic of Karakalpakstan. We analyse field data for four locally grown sorghum varieties to determine their per-hectare costs and returns under real farm conditions. We also compare the economics of sorghum production in Karakalpakstan with those reported in other dry and semi-arid regions - such as India and sub-Saharan Africa - to contextualise the crop's potential. In addition, a cash-flow analysis is presented for a hypothetical smallholder sorghum farm, illustrating the timing of expenses and revenues over a growing season. The overall objective is to evaluate whether sugar sorghum can serve as a financially feasible, climate-smart crop for Karakalpakstan's farmers, and to identify what supporting measures would enhance its adoption in the region. As a transitioning economy heavily reliant on agricultural production, Uzbekistan is compelled to rethink its water-intensive farming model, notably revolving around cotton, rice, and wheat monocultures. Drawing on theories of agricultural modernization and resilience, the shift toward crop diversification and drought-tolerant food systems aligns with both sustainable livelihood frameworks [34] and agroecological transition models [35]. In this context, sorghum emerges as a theoretically sound alternative: its integration into crop rotation systems not only improves resource-use efficiency (water, nutrients, soil structure) but also enhances ecological resilience and livelihood stability, consistent with theoretical expectations for sustainable intensification in water-scarce drylands.

Empirical evidence from arid and semi-arid regions strongly supports sorghum's suitability in environments similar to Karakalpakstan. Globally, sorghum is recognized as a drought- and heat-tolerant cereal, capable of enduring high temperatures and low water availability—conditions typical of Uzbekistan's continental climate [28]. In Senegal, certain sorghum varieties maintain positive water balances even under prolonged drought. In Kyrgyzstan, field trials indicate that cultivating drought-tolerant crops like sorghum significantly improves resilience in arid systems [30]. Locally, Uzbekistan's conservation agriculture and crop-rotation experiments—shifting away from cotton monoculture—involve grain crops under crop rotation systems, further reinforcing the empirical case for sorghum [13]. Moreover, sorghum's integration into crop rotation can help reduce soil salinity, improve soil structure, and increase soil organic matter—benefits seen in no-till legume rotations in Central Asia [31]. These empirical insights provide a solid foundation for assessing sorghum's economic and ecological feasibility in Karakalpakstan.

Uzbekistan's historical pivot toward cotton and wheat monocultures during the Soviet era led to severe soil degradation, salinization, and water resource depletion. Shifting toward diversified cropping, including crop rotation with drought-resilient species, is now recognized as a strategic necessity for both land restoration and economic viability [31]. National drought risk-mitigation policies underscore the importance of diversified cropping portfolios and drought-resistant cultivars, noting their co-benefits for resource efficiency, climate resilience, and food security. Incorporating sorghum aligns directly with these policy directions—promoting water efficiency, soil health, and farmer income diversification.

2. MATERIALS AND METHODS

Study Area

The study was conducted in Karakalpakstan, an autonomous republic in north-western Uzbekistan. The region spans about 16.1 million hectares, of which roughly 5.15 million ha (32%) is agricultural land which is located mostly in the Amudarya River delta, while over one-third is unused desert or salt-affected land [8]. The climate is continental arid, characterised by hot, dry summers and annual precipitation below 100 mm. Soils are predominantly saline, especially in irrigated districts near the former Aral Sea. Agriculture remains a main livelihood in Karakalpakstan, despite the harsh environment. The majority of farms are small family holdings; according to our survey, the average land area cultivated with sugar sorghum is only ~0.7 ha per farmer, typically located 0.5–2 km from the homestead for ease of access.

Data Collection

We employed a mixed-methods approach combining farm surveys, expert interviews, and secondary data analysis. Primary data were obtained through structured questionnaires administered to 120 randomly selected sorghum-growing farmers across three districts of Karakalpakstan during June–August 2024. The survey gathered detailed information on land use, cultivation practices (land preparation, planting method, fertilizer and pesticide use, irrigation frequency), labour inputs, yields, and production costs for the 2023 growing season. In addition, we conducted 15 semi-structured interviews with agricultural extension officers, agronomists, and local agribusiness representatives to gain qualitative insights into typical farm management and market conditions for sorghum. Secondary data on crop production were collected from the National Statistics Committee of Uzbekistan – including regional sorghum output from 2018–2023 – and from international databases (e.g. FAOSTAT) for cross-country comparisons. Key socioeconomic indicators (e.g. population working in agriculture) were sourced from regional statistical reports.

Analytical Methods

Data analysis was carried out using STATA 17 for quantitative statistics and ArcGIS 10.8 for spatial mapping. Descriptive statistics (means, percentages) were used to characterise the sample farms and summarize yield and cost data. A cost–benefit analysis was performed for four dominant sugar sorghum varieties grown in the study

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area – Massino, Qorabosh, Daulet, and O‘zbekiston 18. For each variety, we computed gross revenue per hectare (yield × farmgate price), total cultivation cost per hectare, and net income (profit) per hectare (gross revenue minus cost). All costs and prices were recorded in Uzbek soums (UZS); an average farmgate price of 350 UZS per kg of raw sorghum stalk was used, based on prevailing 2023 rates. To facilitate interpretation, financial figures were also converted to US dollars at an exchange rate of 1 USD = 12,700 UZS (2024 average rate). A cash-flow analysis was developed to illustrate the timing of expenditures and income for a representative smallholder cultivating 0.7 ha of sugar sorghum. This involved itemising typical costs at different stages of the growing season (land preparation, inputs, harvest) and the revenue at harvest, using the survey-average yield and cost values.

Comparative analysis was undertaken by reviewing literature on sorghum farming in climates similar to Karakalpakstan. We drew on peer-reviewed case studies from South Asia and Africa to gather benchmark figures on sorghum yields, input use, and profitability under rain-fed versus irrigated conditions. In particular, studies from India, Sudan, Nigeria, and Ethiopia were reviewed to contextualise our findings. These external data are used in the discussion to highlight similarities or gaps in sorghum performance across regions. Throughout the analysis, we followed the journal’s ethical guidelines and ensured all data sources (tables, figures) are properly cited.

3 RESULTS AND DISCUSSION

3. Crop Production and Land Use Context

Fig. 1 presents a map of Karakalpakstan’s irrigated lands, illustrating that arable farming is concentrated along the Amudarya River and delta, amidst vast expanses of uncultivated desert. According to official statistics, the total land area of Karakalpakstan is 16,100.6 thousand ha, of which only 2.6% is arable and 32% is classified as agricultural (including pastures) [8]. A large portion – about 5,758.7 thousand ha (35.8%) – remains unused or barren, largely due to salinity and water constraints [9]. Table 1 summarises sugar sorghum production in Uzbekistan’s regions over 2018–2023. Notably, Karakalpakstan consistently leads the country in sorghum output, reflecting its historical role as a sorghum-growing area.

Table 1. Sugar sorghum production in all regions of the Republic, 2018-2023 (in thousand tons)

Regions	2018	2019	2020	2021	2022	2023
Rep. of Karakalpakstan	18.10	12.60	17.60	20.00	15.30	16.20
Andijan Region	0.03	0.20	0.01	0.10	0.10	0.10
Bukhara Region	0.10	0.40	0.60	0.60	0.60	0.50
Jizzak Region	0.00	0.01	0.01	0.01	0.00	0.00
Kashkadarya Region	0.00	0.20	0.10	0.05	0.10	0.03
Navoi Region	0.00	0.30	0.10	0.10	0.02	0.02
Namangan Region	0.20	0.00	0.00	0.60	0.30	0.30
Samarkand Region	0.00	0.02	0.10	0.10	0.10	0.01
Surkhandarya Region	0.01	0.10	0.10	0.01	0.00	0.00
Syrdarya Region	0.00	0.00	0.00	0.00	0.00	0.00
Tashkent Region	0.03	0.40	0.10	0.20	0.10	0.20
Fergana Region	0.70	0.50	0.30	0.30	0.30	0.20
Khorezm Region	1.90	0.04	0.02	0.02	0.10	0.02
Tashkent City	0.00	0.00	0.00	0.00	0.00	0.00

Source: Source: National Statistical Agency under the President of the Republic of Uzbekistan

For instance, in 2023 Karakalpakstan produced the highest volume of sorghum (far exceeding other provinces), demonstrating that this crop thrives even on the region’s salt-affected soils (see Fig. 1 for the map). Other regions showed either modest sorghum cultivation or significant year-to-year fluctuations – e.g. Khorezm region’s output dropped sharply after 2018, while Andijan and Jizzakh maintained low but stable production [10]. These trends suggest that sugar sorghum’s comparative advantage is greatest in the Aral Sea basin, where it can outperform less salt-tolerant crops.

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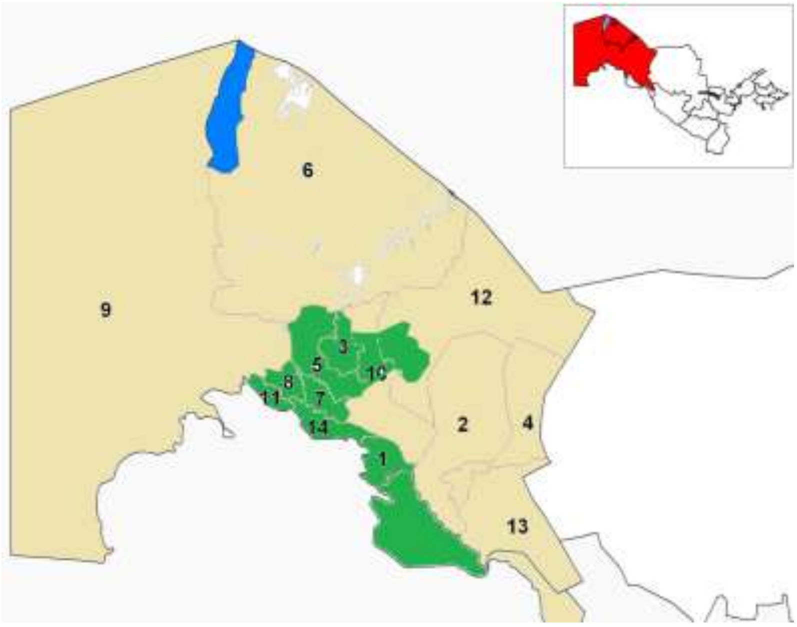

Source: ArcGIS 10.8 Image

Fig. 1. Map of irrigated lands of the Republic of Karakalpakstan

The extensive uncultivated lands in Karakalpakstan also indicate considerable scope for expanding sorghum cultivation if key constraints (irrigation, soil amelioration) are addressed. Indeed, Table 2 shows that pastures make up the bulk of agricultural land (28.8% of total area) and a significant portion of land remains idle. Converting even a fraction of the unused 5.76 million ha to sorghum or other drought-tolerant crops could boost regional output and farm incomes, provided investments are made in land reclamation and water management.

Table 2. Classification of the land in Karakalpakstan

Name	Area *(in thousand hectares)*	% of Total Area
Total Area	**16100.60**	**100.00**
Arable Land	**419.90**	**2.60**
Perennial Plantings	8.62	0.05
On the utilized	9.32	0.06
Hayfields	68.70	0.43
Grasslands	4640.80	28.80
Total Agricultural Land	5147.10	32.00
Homesteads	46.50	0.30
Gardens and Vineyards	0.09	0.01
Unused land	5758.70	35.80

Source: National Statistical Agency under the President of the Republic of Uzbekistan

The surveyed farms confirm that sugar sorghum is grown on a very small scale per household – plots averaging 0.7 ha – yet it plays a vital role in farm economics. Farmers typically cultivate sorghum on their own land (rather than leased), usually within a few kilometers of their homes for ease of supervision [11]. Most farmers reported using flood irrigation from canals and minimal chemical inputs for sorghum, which keeps production costs low. The crop serves multiple purposes: a portion of the harvest is often used as livestock fodder or boiled for syrup in the household, while the rest is sold to local markets or processing clusters (e.g. a bioethanol plant under development). Given these characteristics, sugar sorghum represents a strategic climate-smart crop for Karakalpakstan – it survives on marginal land, meets on-farm feed needs, and generates cash income.

Yield and Profitability of Sorghum Varieties

The economic performance of the four studied sorghum varieties is summarised in Table 3. All varieties achieved appreciable biomass yields under the 2023 growing conditions, but there is a wide variation: from Massino at 28.50 t/ha up to O‘zbekiston 18 at 105.00 t/ha. This translated into gross revenues ranging from about 9.98 million UZS/ha for Massino to 36.75 million UZS/ha for O‘zbekiston 18 (at the common price of 350 UZS/kg). After accounting for production costs, net incomes per hectare were all positive, indicating profitability for each variety, but the magnitudes differed substantially. The local variety "O'zbekiston 18" stands out with an extraordinarily high net income of ~29.88 million UZS/ha (≈2,353 USD/ha), far above the net gains from the other cultivars. In fact, O'zbekiston 18's benefit–cost ratio (gross revenue divided by cost) was approximately 5.3, meaning every 1 UZS of cost generated over 5 UZS in revenue – a remarkably high return. By contrast, the Italian cultivar Massino and the local variety Daulet had more modest net profits of about 5.62 million and 5.64 million UZS/ha respectively (≈443 USD/ha each), with benefit–cost ratios around 2.1. The hybrid Qorabosh performed intermediately, yielding 41.45 t/ha and net income ~9.29 million UZS/ha (≈732 USD/ha), for a cost–benefit ratio of ~2.8. These differences illustrate the critical impact of variety selection on sorghum profitability: under the same price and climate, a high-yielding improved variety can earn nearly four to five times the profit of a lower-yielding one. O'zbekiston 18's exceptional output (105 t/ha) may be attributed to its genetic traits and suitability to local conditions – it was bred in Uzbekistan for sugar content and biomass, and it appears to flourish with proper agronomy in Karakalpakstan's environment. The other varieties, while also adapted to dry conditions, did not exhibit such extreme productivity. This finding suggests that scaling up the cultivation of top-performing varieties (like O'zbekiston 18 and Qorabosh) could dramatically increase farm revenues in the region. It also underscores the importance of agronomic support: all varieties were profitable in our study, implying that even average-performing sorghums can be viable if farmers employ recommended practices (e.g. timely planting, adequate weeding and fertilisation) [12]. Notably, the production costs per hectare were relatively similar for the varieties (ranging ~4.36–6.87 million UZS), so the higher profits of O'zbekiston 18 and Qorabosh stem mainly from their higher yields rather than higher expenditures. This is a favorable scenario for farmers – it means improved seeds and perhaps slight management tweaks, rather than significantly higher costs, can lead to outsized income gains.

It should be clarified that the yields reported here are in terms of fresh stalk biomass, as sugar sorghum is harvested and sold by weight of stalk (containing juice for syrup/ethanol or fodder). These figures are not directly comparable to grain yields of sorghum often cited in other countries. For instance, average sorghum grain yields in rain-fed systems of Sudan and Nigeria are on the order of 0.7–1.2 t/ha [13] – a tiny fraction of the biomass yields measured in our study. Even accounting for moisture content and the fact that grain constitutes only part of the sorghum plant, the productivity of sugar sorghum in Karakalpakstan appears impressive. Under irrigation and low salinity stress, sweet sorghum can produce 40–100 t/ha of cane in other regions as well [14], so our results are in line with agronomic potential. The key point is that, because of these high tonnages, the gross revenues from sugar sorghum (per hectare) can be substantial, reinforcing its attractiveness as a cash crop. All four varieties in Table 3 yielded net profits considerably above typical returns from cotton or wheat in this region, according to local experts interviewed. Farmers also noted that sorghum's shorter growing cycle which is about four months, allows flexibility to plant another crop or forage in the same year, which can further augment annual income. Of course, such profitability assumes a stable market for the sorghum biomass – either processing facilities (e.g. for syrup or biofuel) or robust demand for fodder. Currently, local market demand in Karakalpakstan is moderate but growing, as sorghum silage gains popularity among livestock producers. Developing the sorghum value chain (e.g. bioethanol plants, sweetener factories) would greatly enhance and stabilise farm-gate prices and could make sorghum even more lucrative for farmers [15].

Table 3. Yield and Economic Outcomes of Sugar Sorghum Varieties in Karakalpakstan (per hectare, 2023)

Indicator	Massino	Qorabosh	Daulet	O'zbekiston 18
Yield (t/ha)	28.5	41.45	30	105
Price (UZS/kg)	350	350	350	350
Gross Revenue (UZS)	9,975,000	14,507,500	10,500,000	36,750,000
Gross Revenue (USD)	785	1,142	827	2,894
Cost Of Cultivation (UZS)	4,359,000	5,215,000	4,865,000	6,870,000
Cost Of Cultivation (USD)	343	411	383	541
Net Income (UZS)	5,616,000	9,292,500	5,635,000	29,880,000
Net Income (USD)	442	732	444	2,353

Source: Field survey (2024) and authors' calculations.

Comparative Perspective

Our findings in Karakalpakstan align with broader evidence that sorghum can be a profitable crop in dry, resource-limited environments. Across semi-arid regions of Asia and Africa, sorghum's drought resilience and low input requirements often give it an advantage over crops like maize in terms of risk-adjusted returns [16]. However, actual yields and profits achieved by farmers vary widely by country, reflecting differences in climate, soil, farm management, and support systems. In India, for example, sorghum is predominantly grown under rainfed conditions in the post-rainy season on smallholder plots. Yields are modest (typically 1–2 t/ha of grain), yet the crop remains important for dryland farmers' livelihoods. Studies in the dryland regions of Maharashtra and

Karnataka in India have shown that improved agronomic practices and varieties can significantly boost sorghum productivity – on-farm trials reported yield increases of 20–30% and corresponding profit gains when farmers adopted better seed and management packages [17]. Patil and Mula (2020) document how participatory breeding and management training in India's sorghum belt led to higher yields and more stable incomes for farmers [18]. Likewise, Singh et al. (2022) found that factors such as education, access to credit, and membership in farmer groups had a positive impact on the technical efficiency of rainfed crop production in India [19]. These findings resonate with the situation in Karakalpakstan – improving farmers' know-how and input access could help close the gap between the highest and lowest sorghum yields observed in our study.

In sub-Saharan Africa, sorghum is typically grown by millions of smallholders on plots of 2 ha or less [20], often under erratic rainfall. Yields in traditional systems are low; for instance, Sudan's average sorghum yield has been about 0.7 t/ha, though it rose to nearly 0.9–1.0 t/ha by the late 2010s with some adoption of improved practices [21]. Neighbouring countries like Nigeria and Ethiopia achieve higher national average yields (~1.2 t/ha and ~2.6 t/ha respectively) [13], partly due to better varieties and, in Ethiopia's case, more favourable highland environments. Even so, these yields are a fraction of what was attained in Karakalpakstan's irrigated test plots. This indicates considerable upside potential if semi-arid countries can leverage improved sorghum technologies. In fact, recent initiatives have demonstrated promising results: a Gates Foundation-supported project to accelerate sorghum varietal improvement in Africa found that adopting improved, climate-resilient sorghum seeds led to an average 13% increase in yield and 17% increase in net income for smallholder farmers [22]. Similarly, on-farm evaluations in Mali showed that newly released sorghum hybrids delivered net profits of $70–124 per hectare, whereas local traditional varieties often resulted in losses under the same conditions [23]. These studies echo the pattern we observed – modern sorghum cultivars, when combined with adequate inputs, can substantially outperform local landraces in terms of profitability. Another relevant factor is market development: in Nigeria, rising demand from the brewing and food-processing industries has driven sorghum farm expansion and provided price support [17][24]. By contrast, in regions where sorghum is seen purely as a subsistence or "poor man's crop," prices tend to be low and farmers invest little in the crop. The case of Nigeria shows that commercial utilisation (e.g. for malt, beer, syrup) can transform sorghum into a cash engine for farmers, given the right linkages to industry. For Karakalpakstan, this suggests that parallel efforts to develop sorghum-based enterprises (such as bioethanol plants or fodder pellet production) could amplify the economic benefits to farmers. Overall, the comparative evidence reinforces that Karakalpakstan's experience is not isolated: sorghum has proven to be a resilient, income-generating crop in many dry areas. However, realising its full potential typically requires improved seed varieties, farmer training, and market integration – all of which are areas that warrant attention in Karakalpakstan's agricultural development planning.

4. FARM-LEVEL CASH-FLOW ANALYSIS

To further illustrate the feasibility of sugar sorghum for smallholders, we present a simplified cash-flow scenario for a hypothetical 0.7 ha farm in Karakalpakstan (Table 4). This scenario uses the average yield (≈30 t/ha) and cost structure observed in our survey, corresponding roughly to the variety Daulet or Massino performance. All values are in Uzbek soums for a single growing season. The table breaks down the farmer's expenditures (cash outflows) and income (cash inflow) over time. In this scenario, the farmer undertakes land preparation in March (ploughing, harrowing) at a cost of about 800,000 UZS for 0.7 ha. In April, they sow sorghum using purchased seed (≈150,000 UZS) and apply basal fertiliser and other inputs (≈1,200,000 UZS spread over April–June for fertilizer, fuel, etc.). During the crop's growth (spring–summer), the farmer incurs additional costs for irrigation and weeding – roughly 600,000 UZS, mainly for labor or pumping costs. At harvest time in September, the farmer hires workers and transports the biomass to a buyer, costing about 900,000 UZS. The total cash outlay for the season sums to approximately 3.65 million UZS (listed as a negative net cash flow prior to harvest). Finally, in September, the farmer sells the sorghum harvest (estimated 21 t of stalks from 0.7 ha, at 350 UZS/kg) for about 10.15 million UZS gross. Subtracting all costs, the net profit realized is ~6.50 million UZS for the season – equivalent to roughly $510. This net income is in addition to the fodder or grain the farmer might retain from that area (if any), and it is earned within a 4–5 month crop cycle. The cash-flow timing highlights an important aspect: the farmer must cover all expenses from March until September, which may require savings or credit, but the return at harvest is quite rewarding, more than doubling the investment. In many developing country contexts, smallholders struggle with such upfront costs, so access to short-term credit can be crucial to enable input purchases (e.g. fertiliser) that ultimately increase yields [25][26]. In Karakalpakstan, government programs or microfinance tailored to sorghum growers could help bridge this gap – fortunately, the required capital (under $300/ha in this scenario) is relatively modest. The positive margin of 6.5 million UZS per 0.7 ha also indicates that if a household allocates a few hectares to sorghum, they could earn several thousand dollars of profit annually, a significant boost in a region with otherwise limited income opportunities.

Table 4. Simplified Seasonal Cash-Flow for A Smallholder Cultivating 0.7 ha of Sugar Sorghum (Moderate-Yield Scenario)

Activity	Timing	Cash outflow (UZS)	Cash inflow (UZS)
Land Preparation (Ploughing, Harrowing)	March	–800,000	
Sowing (Seed Purchase and Planting)	April	–150,000	
Fertilizers and Agro-Chemicals	Apr–Jun	–1,200,000	
Irrigation and Weeding (Labor/Fuel)	Jun–Jul	–600,000	
Harvesting and Transport	September	–900,000	
Total Cost (Pre-Harvest)	Mar–Sep	**–3,650,000**	
Sale Of Sorghum Harvest (≈21 T @ 350 UZS/Kg)	September		**10,150,000**
Net Income (Profit for Season)	September		**6,500,000**

Note: Scenario assumes a yield of 30 t/ha on 0.7 ha = 21 t total, sold at 350 UZS/kg. Costs are approximate, based on survey averages for moderate input use. A negative sign indicates an expense (cash outflow) and a positive sign indicates revenue. Net income is calculated as total revenue minus total costs.

From the above cash-flow analysis, we see that sorghum cultivation can generate a healthy seasonal profit for a small farm, even under moderate yield conditions. The break-even yield in this scenario (where revenue equals cost) would be on the order of 10.4 t/ha – well below the actual yields farmers achieved. This margin of safety means that even if weather or pests reduced the yield significantly, the farmer would likely still cover costs, making sorghum a relatively low-risk crop financially. By contrast, higher-input crops could have higher break-even thresholds, making them riskier if conditions are poor. The cash flow also emphasizes timing: all expenditures occur in spring/summer, while the payoff comes only at harvest. Improving farmers' access to seasonal credit or input financing could therefore remove constraints on yield-improving investments such as fertiliser or quality seeds. Extension agents in Karakalpakstan noted that some growers hesitate to spend on inputs for sorghum because of liquidity issues, despite the crop's high returns at harvest. Linking farmers with microfinance or implementing contract-farming schemes in which a processor provides inputs against a guarantee of harvest delivery, could be solutions to explore. Furthermore, if farmers can organise into cooperatives or clusters, they might reduce costs via bulk input purchases and shared machinery use, thereby increasing their net margins from sorghum.

All in all, wide introduction of sorghum in Karakalpakstan lead to:
• Low input and water demand: Sorghum generally requires less water than maize or rice, thrives in poor soils, and performs well under minimal fertilizer regimes—making it well-suited for resource-constrained farming systems [33]
• Crop-rotation benefits: Diversified cropping with sorghum boosts soil structure, organic matter, and breaks disease and pest cycles—as demonstrated in no-till systems in arid Central Asia [33].
• Salt and drought tolerance: In saline and arid regions, sorghum (and pearl millet) contribute to erosion control, soil productivity, and dual use as grain and fodder—particularly important in Karakalpakstan's agro-pastoral context.
• Economic advantages: Sorghum's low seed costs, combined with its resilience and suitability for rotation, offer both agronomic and economic returns—making it economically viable for farmers.
—These factors are especially salient for Karakalpakstan, where agricultural livelihoods depend equally on crop and livestock systems, and require both soil enrichment and adaptive capacity to climate stress.

5. CONCLUSION

This study demonstrates that sugar sorghum can be a highly economically feasible crop under the saline and arid conditions of Karakalpakstan. Empirical results from the 2023 season show that even with modest inputs, sorghum yields were impressive (30–40 t/ha for common varieties, and over 100 t/ha for the best variety), translating into substantial profits per hectare. The top-performing local variety, O'zbekiston 18, in particular, exhibited outstanding productivity and income potential, reinforcing its suitability for wider adoption. Our comparative analysis indicates that Karakalpakstan's sorghum productivity is on par with, or surpasses, that in other semi-arid regions, thanks in part to the availability of irrigation and locally adapted cultivars. This points to an opportunity for the region to become a leader in sorghum-based agriculture, capitalising on the crop's climate resilience (tolerance to drought and salinity) to address both environmental and economic challenges. Cultivating sugar sorghum on currently unused or marginal lands could convert unproductive areas into profit-generating farms, thereby improving rural livelihoods while requiring relatively low water and input resources. Moreover, sorghum's multipurpose nature – serving as food, fodder, and feedstock for biofuel – aligns well with sustainable development goals, offering flexibility and value addition in farming systems.

At the same time, realising sorghum's full potential in Karakalpakstan will require supportive measures and informed policymaking. Farmers will benefit from targeted interventions to overcome knowledge and market barriers. Based on our findings, we propose the following key recommendations:

- **Disseminate high-yielding sorghum varieties:** Agricultural authorities should facilitate broader access to elite cultivars like *O'zbekiston 18* and improved hybrids, perhaps through certified seed multiplication programs and demonstration plots (e.g. on research stations or lead farmers' fields) [28]. Demonstration trials can showcase proper agronomic techniques and the yield advantage of these varieties to skeptical farmers.
- **Enhance farmer training and extension services:** Expanding extension outreach on sorghum agronomy is crucial. Training should focus on optimal practices for dryland cultivation – such as soil moisture conservation, timely planting, and integrated pest management – that can further boost yields. Improving farmers' technical efficiency through education and cooperative membership has been shown to raise productivity in similar contexts. Karakalpakstan's relatively young and literate rural workforce is an asset that extension programs can leverage in disseminating innovations.
- **Improve access to inputs and credit:** Ensuring availability of affordable inputs (quality seeds, fertilisers) and short-term credit will enable farmers to invest in sorghum cultivation at recommended levels. Given the favorable benefit–cost ratio of sorghum, microcredit schemes or input loan programs (possibly guaranteed by the state or NGOs) could have high payoffs. For instance, a loan of a few hundred dollars per hectare could more than double in value by harvest time (as shown in our cash-flow analysis), making a strong case for lenders and farmers alike.
- **Develop sorghum value chains and markets:** To sustain sorghum profitability, market outlets need strengthening. Investment in processing infrastructure – such as bioethanol distilleries, sweet sorghum syrup mills, or feed pellet factories – would create stable demand and better prices for farmers. Public–private partnerships could be pursued to establish such facilities and integrate local growers as suppliers. Additionally, supporting agro-processors in product innovation (e.g. gluten-free flour blends, sorghum-based beverages) can help overcome consumer biases and expand sorghum's market. Policies like price supports or procurement programs in the initial years could also encourage farmers to scale up production.
- **Integrate sorghum into climate adaptation strategies:** Finally, regional agricultural policy should formally recognise sugar sorghum as a priority crop for climate adaptation and land reclamation in Karakalpakstan. This entails incorporating sorghum expansion into state programs for improving food security and rural incomes in the Aral Sea disaster zone. By aligning regional plans with national goals of crop diversification and resource-efficient farming, policymakers can ensure that sorghum development receives the necessary institutional backing (research funding, subsidies, and inclusion in crop rotation schemes).

In conclusion, sugar sorghum presents a viable and promising avenue for diversifying agriculture in Karakalpakstan and similar dryland areas. Our research confirms that with the right varieties and practices, sorghum can deliver robust yields and profits even on marginal lands. Embracing this resilient crop could help transform unused or underutilised lands into productive assets, enhance farm income stability amid climate change, and contribute to the sustainable development of Uzbekistan's arid regions. The next steps should focus on scaling successful pilot results to the broader farming community – through policy support, capacity building, and market development – so that sugar sorghum can truly take root as a cornerstone of Karakalpakstan's agricultural future.

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