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Crop Diversification in the Aral Sea Region: Long-Term Situation Analysis

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Abstract: Agriculture contributes the most to the economy and provides agro-ecological benefits in the environmentally unsustainable Aral Sea region, but its productivity is steadily dropping. To improve the resilience of farming communities in the region, crop diversification is proposed to enable farmers to grow high-value competitive crops and obtain more stable farm incomes. This study provides long-term, multidisciplinary analyses and strategies for strengthening crop diversification amongst farmers in the Aral Sea region. The study analyzed data provided by the Ministry of Agriculture of the Republic of Uzbekistan and the statistical yearbook of 2000–2020. According to the gross margin study findings, farmers who use diversified cropping systems made considerably higher revenues than farmers relying on mono-cropping practices. This study demonstrates that greater crop diversity contributes to the rational use of natural resources and optimization plans, environmental sustainability, and food security as important natural and socio-economic issues in this region. The study findings suggest that proper crop diversification strategies need to be developed in the Aral Sea region to improve the sustainability of farming systems with enhanced resilience to devastating environmental and climate challenges.

Keywords: agriculture; Aral Sea region; crop diversification; farmers' income; gross margin; Simpson Index; stress environment

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1. Introduction

Agriculture plays an essential role in the overall socio-economic conditions of the Aral Sea region in terms of food security, employment, and rural livelihoods [1]. However, there are many constraints for managing sustainable agriculture in this area, including critical factors such as increased soil salinity, water deficits, and climate variability. Furthermore, the Aral Sea drying up exacerbated increasing soil salinity, land degradation, and climate change, damaging agricultural systems and causing unsustainable crop production. The impact of this climatic change was very disastrous, leading to the destruction of the whole ecosystem's life cycle [2]. As a result, many farmers and rural households are struggling with declining agricultural production, food and nutrition insecurity, and income volatility.

During the Soviet Union, cotton was the main crop cultivated in this region. From the beginning of the county's independence in 1991, the national administration decided to rotate cotton with winter wheat to increase national food self-sufficiency and move away from cotton monoculture. The production of these crops accounted for 70% of the total cultivated area and 34% of gross agricultural output. Both winter wheat and cotton were subject to state procurement and state-regulated provisioning of inputs until March 2020. Additionally, the state planning system has only been retained for these crops, whilst fruits and vegetables obtained less policy attention in terms of the lack of a state procurement system [3]. The country has succeeded in gradually moving away from a cotton monoculture towards a more diversified pattern of agricultural production, including cereals, potatoes, vegetables, and melons [4]. Still, higher-value crops, such as fruits and vegetables, were constrained by limited access to land, inputs, modern crop-specific technologies, and finance, which are the most important requirements for crop diversification and food security [5].

The national administration planned to undertake new structural reforms and diversification in agriculture, more productive use of land and water, improved mechanization and infrastructure development, agribusiness development, and more market-oriented agricultural policies [6]. Farmers were encouraged to use larger parts of their farms for cultivating vegetables, but there is still a long way to go to reach the right balance of crop rotation [7]. Especially in the pre-urban zones, their share has been increased. Therefore, crop diversity plays an essential role in sustainable agriculture and can be an effective tool to help farmers deal with several types of risks [8]. Kemboi (2020) stressed the importance of crop diversification in shifting to highly profitable crops and increasing exports of fruits and vegetables through changing crop patterns [9]. Feliciano (2019) related crop diversification as a driver that ensures more profitable crop rotations [10], thereby sustaining soil fertility and crop productivity even in harsh environmental conditions. Crop diversification serves as a technique for boosting agricultural income, creating jobs, reducing poverty, and protecting soil and water resources.

The results of the previous studies emphasized that most of the achievements in cotton and wheat production are based on high-input use technologies such as water, seeds, fertilizers, and pesticides, which are not sustainable on a long-term basis [4]. Furthermore, the area available for high-value alternative crops is very limited despite high economic and ecological potential [11]. Depending on current agricultural strategies, crop producers prefer to implement resource-conserving technologies which ensure reducing soil tillage practices, water used for irrigation, and the use of harmful agrochemicals [12]. Hence, it is crucial to look for a suitable and realistic strategy by which cropping intensity could be enhanced and diversification achieved. Limited studies focus on cropping systems' diversification in the Aral Sea region, despite its environmental protection and restoration functions. Thus, it is important to exhibit the significance of crop diversification and provide additional comprehensive understanding of the status and extent of crop diversification according to a long-term (2000–2020) situation analysis.

2. Materials and Methods

2.1. Description of Study Areas

As shown in Figure 1, Karakalpakstan is located in the northwest of Uzbekistan and is situated at a latitude and longitude between 42.27° N and 58.75° E. Most of this region is occupied by the Kyzylkum desert, and therefore it has a harsh winter, with periodic absolute minimum air temperatures of −10.3 °C and lower in December and January. Summer, on the other hand, is exceedingly hot. The summertime temperature range is 26.3 to 32.0 °C, with a maximum of 41.0 to 45.3 °C. The drying of the Aral Sea has shown an adverse impact on natural ecosystems, which is being exacerbated by climate change, further deteriorating the environmental situation. Concretely, rainfall has become much less (less than 100 mm), along with extreme higher air temperatures in summer (above +45 °C) and lower in winter (below −22 °C). This anomalous climatic change has contributed to desertification of the area and invasion by sand.

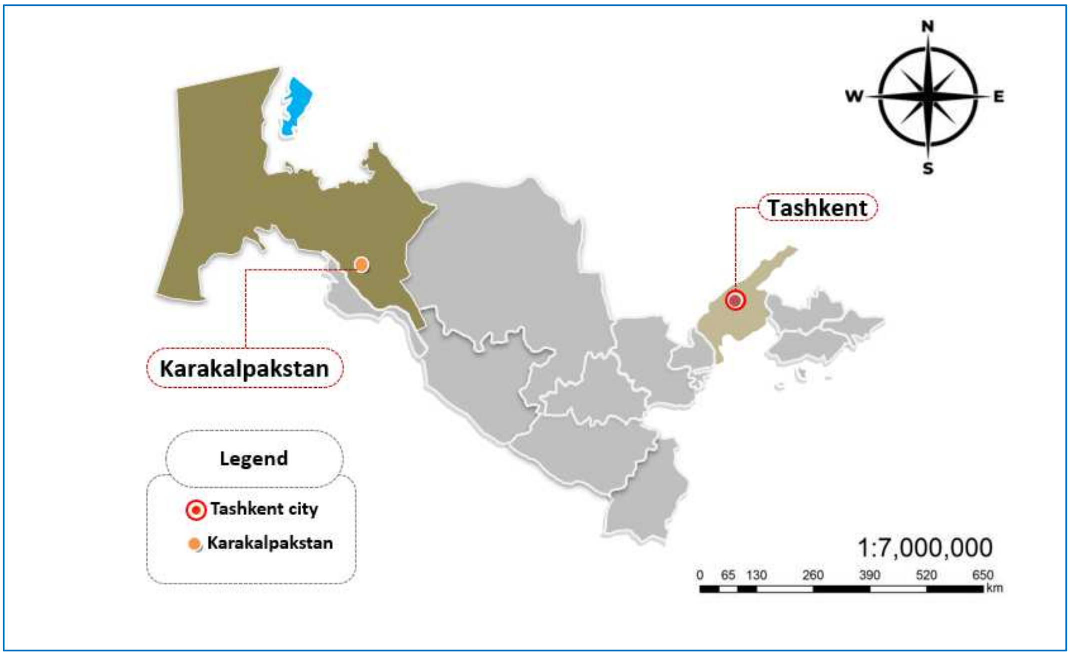

Figure 1. Map of the study area. Source: http://yourfreetemplates.com Author's illustration (accessed on 12 March 2023).

2.2. Data Source

The study used secondary data for the period 2000–2020. The secondary data were collected from the Ministry of Agriculture and Uzbekistan's National Statistical Agency's statistical yearbook. The data differ in terms of the way cropland data were gathered. Table 1 shows the land allocation of different crops in Karakalpakstan to measure the diversification index.

Table 1. Arable land allocation in the Republic of Karakalpakstan, 2000–2020 (thousand/ha).

	Wheat	Cotton	Potato	Vegetables	Melons	Fodder	Fruits	Grapes	Rice	Legumes
2000	38.3	129.8	1.8	7.3	7.2	72.7	4.6	0.4	60.1	0.4
2001	23.4	83.4	1.3	4.6	5.6	38.7	4.1	0.4	47.3	0.2
2002	18.3	74.1	1.3	5.1	5.8	38.2	3.7	0.4	24.1	0.5
2003	61.1	91.5	1.5	5.8	6.4	39.6	3.6	0.3	64.7	0.4
2004	58.7	102.9	1.9	5.5	5.6	34.2	3.5	0.3	26.2	1.0
2005	61.0	104.0	2.1	5.1	4.4	34.7	3.8	0.4	13.8	1.8
2006	64.1	106.7	2.1	7.3	5.3	32.4	4.5	0.5	22.8	1.3
2007	64.3	106.2	2.2	7.4	5.0	24.3	4.6	0.5	15.5	1.1
2008	64.8	102.8	2.9	8.7	6.5	23.3	4.6	0.5	9.1	0.7
2009	38.2	99.8	3.4	8.2	7.3	24.0	4.6	0.5	11.7	0.7
2010	66.7	101.0	6.0	6.8	5.9	35.9	4.6	0.5	30.1	0.7
2011	65.1	94.7	4.6	7.2	6.9	27.4	5.2	0.5	3.1	0.8
2012	64.2	94.7	5.1	8.5	7.8	24.1	5.2	0.6	39.5	0.7
2013	68.5	94.7	4.9	9.8	9.5	23.2	5.6	0.6	9.5	1.1
2014	64.4	94.7	4.3	10.5	9.2	22.6	5.6	0.7	10.7	0.9
2015	64.3	95.9	4.2	10.5	9.2	20.8	5.6	0.8	32.3	0.9
2016	64.4	94.4	4.4	10.9	10.6	22.3	5.5	0.8	34.5	2.6
2017	64.3	94.0	4.8	11.3	12.3	23.4	5.5	1.5	36.1	3.1
2018	63.0	88.6	5.1	14.1	10.1	20.3	5.2	1.2	14.8	2.3
2019	60.4	88.3	6.1	15.5	12.0	23.0	5.9	1.4	37.4	3.1
2020	62.0	87.5	6.8	16.3	11.8	23.6	6.3	1.6	27.9	4.6

Source: Statistical yearbook of the Republic of Uzbekistan.

2.3. Measurement of Crop Diversification

The status of crop diversification can be measured in several ways, including the Shannon Index, Entropy Index, Modified Entropy Index, and Simpson Index [8,13]. Each of these economic tools has its own drawbacks and limitations regarding data requirements. This study used the Stata 16 software tool to estimate the diversity index. Crop diversity was calculated using the Simpson Diversity Index (SDI) equation since it is the most commonly used index in numerous studies related to crop diversification [13]. TSDI is calculated using the following equation:

$$\mathrm{SDI} = 1 - \sum_{i=1}^{n} P_i^2 \quad (1)$$

$$P_i = \frac{A_i}{\sum_{i=1}^{n} A_i} \quad (2)$$

where A_i is the area under ith crop and P_i is the total cropped area. The index is bound between zero and one value. The values close to 1 point at a more diversified cropping pattern or complete diversification and those close to 0 indicate a contrast to a situation of monoculture.

2.4. Gross Margin Analysis

Gross margin analysis is a straightforward way of contrasting businesses' performance with comparable capital and labor. It offers data along with an extra planning tool to assist in comparing possibilities amongst various farm operations. Gross margin is defined as:

$$\mathrm{GM} = \mathrm{TR} - \mathrm{TVC}$$

which is the difference between total revenue and variable costs.

TVC stands for total variable costs, TR for total revenue (gross output), and GM for gross margin. In order to assess whether the agricultural system would be more lucrative in the near term, farmers who participated in various cropping systems were compared with those who did not. The use of gross margin analysis is dependent on a number of values; in this example, all prices were those in effect at the time of production.

3. Results

3.1. Crop Diversification Status

From the early 2000s, cotton production began to decline in Karakalpakstan, and land was transformed to more nutrient-sensitive fruits and vegetables as the government accepted a national program to intensify the production of fruits and vegetables to meet the growing demand. This is evident from publicly available official data demonstrating the growth in potato, tomato, and fruit gardening production both at the regional and national level (Table 1).

Nowadays, cotton and wheat production still occupy the majority of land: 38.5% and 54.4%, respectively. Potato is grown on 4.2%, vegetables on 10.1%, melon on 7.3%, fodder on 14.7%, and rice on 17.3%, while legumes are cultivated on only 2.9% of all available irrigated lands in this region.

Despite the rice production area decreasing more than two times due to water shortage since 1991, the legume area is slowly increasing.

Wheat is an important crop in Karakalpakstan and its production area has grown considerably due to its potential for food security in the region. Wheat has been part of programs in support of diversification and seed production to enhance the productivity of salt-affected lands and to increase the income of rural people. Similarly, on-farm results recommend legumes as a second crop after wheat harvest, as well as in rice crop rotation, in order to fill the gap in farm productivity and crop–livestock systems. However, opportunities for legumes and the development of their value chain in Karakalpakstan go beyond supporting production systems affected by heat, drought, and salinity, and include the production of foods and beverages.

In Karakalpakstan, the development of crop diversification through innovative value-added crops requires research, marketing, political support, and strong collaboration between the private and public sectors and has a great value. The level of crop diversification is presented in Figure 2. In addition, findings in this study reveal that the mean Simpson Index within the sample of farmers declined up to 0.68 in 2008 and 2009. This implies that the farmers in the study areas were not too diversified in their cropping pattern in 2000.

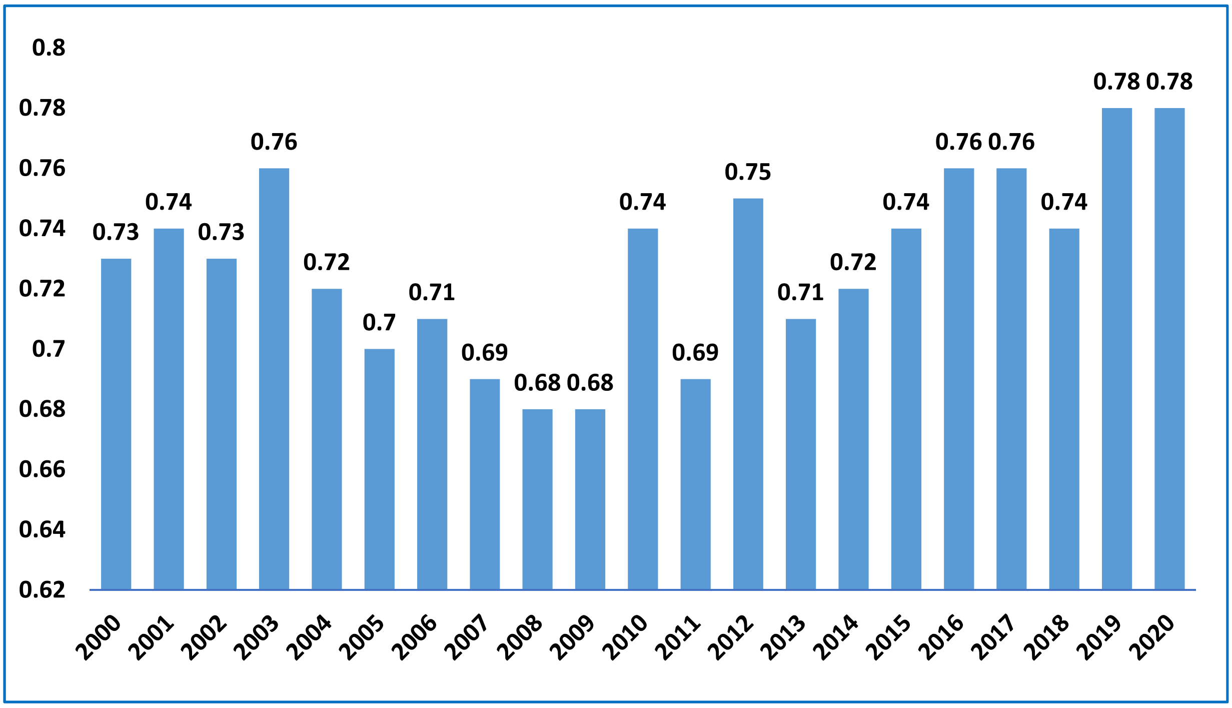

Figure 2. The mean crop diversification index in Karakalpakstan, (years 2000–2020). Source: Authors' calculation based on data.

While the crop diversification index was 0.73 in 2000 and it increased up to 0.76 in 2003, sharp decrease was observed the following years, declining up to 0.68 in 2009. This suggests that the farmers in the study areas were not too diversified in their cropping patterns. Starting from 2010, crop diversification began to develop again and reached 0.76 in 2016–2017. In 2020, this parameter reached 0.78—the highest value ever observed. According to this, farmers in Karakalpakstan have become more diversified in their cropping patterns over the past few years. These results imply that the farmers practicing diversified farming could see benefits of the crop diversification practice.

Crop diversification is a key potential strategy for improving inclusive household food security in this region. Therefore, the government of Uzbekistan has emphasized crop diversification, which may generate value addition through enhanced agricultural productivity, food security, and income growth. Nowadays, food security and sustainability issues generally depend on appropriate policy implementation. Yet, it is assumed that elderly farmers have experience and the opportunity to participate in diversified farming. Additionally, younger farmers tend to diversify because they are more dynamic and active enough to engage in productive agriculture.

3.2. Crop Productivity

The results in Table 2 show that the land allocated for wheat production raised six times since 1991, from 10.5 thousand hectares to 62 thousand hectares. In addition, fruits' production area doubled, and vegetable-covered land also increased 2.5 times. On the contrary, cotton production area decreased almost two times, from 149.6 thousand hectares in 1991 to 87.5 thousand hectares in 2020.

Table 2. Trends on area and productivity of crops in Karakalpakstan, 1991–2020.

	Wheat		**Cotton**		**Fruits**		**Intensive Orchards**		**Vegetables**	
Years	**Area, '000 ha**	**Yield, t/ha**	**Area, '000 ha**	**Yield, t/ha**	**Area, '000 ha**	**Yield, t/ha**	**Area, '000 ha**	**Yield, t/ha**	**Area, '000 ha**	**Yield, t/ha**
1991	10.5	0.29	149.6	0.18	3.0	0.14	0	0	7.0	0.09
2000	38.3	0.43	129.8	1.16	4.6	0.52	0	0	7.3	0.22
2010	66.7	0.33	100.1	0.52	4.6	3.15	2.1	0.22	6.7	0.87
2015	64.2	0.81	95.7	1.68	5.6	4.12	2.9	0.41	10.4	1.56
2020	62.0	1.15	87.5	1.91	6.3	5.52	4.2	1.12	16.9	2.11

Source: Statistical yearbook of the Republic of Uzbekistan.

This study showed that the wheat grain yield boosted 1.15 ton per hectare in 2020, while this indicator was only 0.29 ton per hectare in 1991. Notably, the production area and yield of intensive orchards and vegetables are considerably enhanced, even though they are the high-valued crops in the region. Major crop producers are fermers and dehkan farmers, also small landowners actively engage in processing activities. Popular crops include grains, seeds (e.g., sesame), vegetables (e.g., tomato), and fruits.

In order to close the production gap in farms and crop–livestock systems in rural communities in salty desert settings, on-farm data show that grain–legume crops were suggested as a second crop (mid-June to early July) after winter wheat harvest, as well as in rice crop rotation. Yet, the potential for these quick-growing grains and legumes as well as the growth of their value chain in Karakalpakstan go beyond assisting agricultural systems that are impacted by salt, heat, and drought.

3.3. Economic Benefits

Presently, agricultural commodities produced in Karakalpakstan have a great value, as they are used for both food and feed purposes. According to the findings of the gross margin analysis, smallholder farmers who use various cropping systems have greater incomes than farmers who rely on mono-cropping practices. The two most important crops farmed in Karakalpakistan are by far cotton and wheat in terms of area. Rice, fodder crops, tomatoes, carrots, and potatoes all grow in smaller spaces. Although orchards occupy a smaller area than wheat and cotton, Karakalpakistan's current climatic conditions are conducive to the increase in their production area.

Table 2 shows that winter wheat and cotton are the two primary crops in many Karakalpakstani areas. Some farmers grow sunflower, sorghum, sesame, and rice. Double cropping is not used, though. Legume crops in the cycle would have gained value due to improved soil quality and difficulties with food security. Therefore, there is plenty of room to boost yields, for example, by employing bed planting techniques. Switching from grains to higher-value commodities such as fruits and vegetables is also possible.

Table 3 compares the gross margins of farmers who are diversifying and those who are not. The total gross output values for wheat and cotton were found to be UZS 15,145,000 and 19,044,000, respectively, whereas potato production with little high total variable cost brought two times more revenue (UZS 43,040,000). However, the highest income was rice farming with UZS 90,440,000, followed by vineyard production with UZS 58,310,000. Additionally, the target area may be competitive in a variety of agricultural products, including winter wheat and barley, legumes, vegetables, and fruits, as well as processing agricultural crops.

Table 3. Gross margin analysis for different types of crops.

Variables	Wheat	Cotton	Potato	Vegetables	Melons	Fodder	Fruits	Vineyard	Rice	Legumes
Av. Yield	2330	2070	13,450	8500	18,900	16,000	18,500	23,800	32,300	1780
Av. Price	6500	8200	3200	2800	1470	1260	1340	2450	2800	8500
Total Gross Output	15,145,000	19,044,000	43,040,000	23,800,000	27,783,000	20,016,000	24,790,00	58,310,000	90,440,000	15,130,000
Av. Cost of seeds/seedlings	1,350,000	682,000	6,700,000	3,660,000	2,450,000	2,240,000	2,450,000	6,700,000	14,500,000	1,450,000
Av. Cost of fertilizers	2,225,000	3,250,000	4,350,000	4,350,000	4,450,000	3,750,000	3,800,000	4,500,000	6,700,000	2,500,000
Av. Cost of labor	2,455,000	5,600,000	3,250,000	4,680,000	5,400,000	3,700,000	4,500,000	3,450,000	13,500,000	2,350,000
Cost of agrochemicals	3,350,000	3,860,000	4,250,000	3,240,000	4,890,000	2,700,000	3,760,000	4,250,000	8,500,000	2,500,000
Consumables	2,500,000	3,250,000	5,400,000	4,700,000	4,350,000	3,150,000	4,400,000	5,400,000	25,800,000	2,500,000
Total Variable Cost	11,880,000	16,642,000	23,950,000	19,630,000	21,540,000	15,750,000	18,910,000	23,600,000	68,200,000	11,300,000
Gross Margins	3,265,000	2,402,000	19,090,000	4,170,000	6,243,000	4,266,000	5,880,000	34,710,000	22,240,000	3,830,000

1 USD is equal 11,400 USZ according to the Central Bank of the Republic of Uzbekistan for April 2023.

To achieve food security, the most effective and affordable production and processing techniques must be found in terms of food potential. To create a viable biorefinery and inclusive production models, close collaboration between the public and commercial sectors is both advised and encouraged during this process. Many rural households are compelled to rely on their agricultural production or foods grown nearby to meet their nutritional needs because of the region's inadequate infrastructure, high transportation costs, and isolation. Crop diversity can be a significant way to lower food insecurity under certain circumstances.

Meanwhile, various components of profitability created by each type of crop produced by farmers, return on capital, and labor were also employed. For each form of crop farming, returns to labor were estimated by dividing gross margin by labor expenses per hectare, and returns to capital were determined by dividing gross margin by total variable cost (TVC) per acre. Table 4 summarizes the findings. Return on farmers' capital for vineyard (1.47) was greater than that for other types of crops cultivated by farmers, whereas it was 0.80, 0.34, 0.33, 0.31, 0.29, and 0.27 for potatoes, legumes, rice, fruits, melons, wheat, and fodder.

Table 4. Returns to capital and labor.

Crops	Average GM UZS/ha	Labor Cost UZS/ha	Total Variable Cost UZS/ha	Return to Labor (GM/L.Cost)	Return Capital (GM/TVC)
Wheat	3,265,000	2,455,000	11,880,000	1.33	0.27
Cotton	2,402,000	5,600,000	16,642,000	0.43	0.14
Potato	19,090,000	3,250,000	23,950,000	5.87	0.80
Vegetables	4,170,000	4,680,000	19,630,000	0.89	0.21
Melons	6,243,000	5,400,000	21,540,000	1.16	0.29
Fodder	4,266,000	3,700,000	15,750,000	1.15	0.27
Fruits	5,880,000	4,500,000	18,910,000	1.31	0.31
Vineyard	34,710,000	3,450,000	23,600,000	10.06	1.47
Rice	22,240,000	13,500,000	68,200,000	1.65	0.33
Legumes	3,830,000	2,350,000	11,300,000	1.63	0.34

Compared with potato, legumes, rice, and fruits, cotton had a lesser return on capital (0.14); accordingly, it had the smallest gross margin (0.43). Because they have higher total variable costs than cotton, vineyard, potato, rice, and melon farming had a high return on capital. In addition, whereas cotton is a long-season crop, the other three are short-season crops. As a result, it was anticipated that overall variable costs for the short production season of potatoes, legumes, and rice would be lower.

Return on labor for producing vineyard was 10.06, followed by potatoes (5.87), rice (1.65), legumes (1.63), wheat (1.33), fruits (1.31), and melons (1.16). In terms of both return on capital and return on labor, cotton was the worst. This was brought on by a low gross margin (2,402,000) brought on by a low yield from the use of conventional seed selection, as well as a higher labor cost of UZS 5,600,000 per hectare.

Maximum rewards were earned by farmers who grew more than three crops. Potato, legume, and rice production together produced a profit margin of UZS 103,450,000. When compared with cultivating one crop, such as potato or rice, which produces UZS 19,090,000 and 22,240,000 per hectare, respectively, these crops generate an average gross margin/hectare of UZS 41,330,000 (Table 4).

These findings demonstrate that farmers may maximize their earnings by engaging in a diversified cropping system. As a result of Karakalpak's seasonality and varying rainfall patterns, it also helps farmers to distribute risk in the event that one of their agricultural ventures fails.

4. Discussion

Among the major problems that affect farmers' livelihoods in the Aral Sea regions are income variability, food availability, and nutritional instability [14]. Moreover, soil salinization, persistent weather degradation, poor water quality, and lack of water resources are the most significant risks experienced by farmers to facilitate proper crop diversification. It was found that a farmer with three or more different crop types produces considerably higher revenue than mono-cropping farming [15]. After independence in 1991, the area of cotton plantations has been significantly reduced towards an increase in wheat in order to reach higher food security. However, it should be noted that stress-tolerant and high-value crops have many advantages. It is impossible to deny that most farmers in the region follow a uniform cropping pattern rather than shifting crop diversification. Nevertheless, the combination of short- and long-duration crops, the use of modern harvesting and storage technologies to maintain continuous production, and the use of phased loan disbursement in the form of inputs, among other techniques to improve crop diversity, are necessary to mitigate this risk.

According to the fundamental rule, crops should ideally not follow each other in crop rotation. Continuous cropping (mono-cropping) of any crop leads to the accumulation of pests and illnesses unique to that crop and lower crop yields. Its effect will be larger the more times a crop has been produced there in the past. For instance, it is becoming more typical to cultivate cotton and wheat for two or more years. The increased spread of cotton boll weevils has most likely been the result of consecutive cotton-growing years. In order to enhance pest, water, and nutrient management, it is required to study modern land management techniques including conservation agriculture, legume intercropping, agroforestry, and organic farming [16].

The soils of Karakalpakstan are becoming more prone to erosion as a result of the increased number of years of cotton in the cropping cycle. The structure of the soils in cotton–wheat crop cycles is getting worse because there are not any organic returns to the soil. Fortunately, cotton's share of the overall irrigated land has decreased since 2000, whereas winter wheat's area expanded (Table 1). If wheat is produced on salty soils, switching to sesame will be advantageous since sesame is more salt- and drought-tolerant. Growing rice is a different choice for salty soils, although it requires more irrigation water [17]. In order to improve the productivity of salt-affected fields, sorghum as a drought- and salt-tolerant crop can be incorporated into agricultural programs that encourage crop diversification [18]. Sorghum is a unique cash crop and already adapted cereal; it has more than 2000 years of history in this region [19]. Sorghum's advantageous traits might be stressed, such as its potent antioxidant and nutritional qualities, i.e., being a gluten-free, easily digested starch, and having phenolic chemicals [20]. Sorghum is more widely available and used as a food in Karakalpakstan; however, processing, packaging, and marketing plans need to be thoroughly improved to gain more traction. This crop can produce high biomass and grain yield on nitrogen-deficient marginal lands under adverse circumstances, although its production area according to the FAO statistics barely covers 727 hectares in the Aral Sea [21,22]. As pointed out by Bobojonov et al., 2013, sorghum production proved feasible even on highly saline soil [11]. By encouraging farmers to grow alternative salt- and drought-tolerant small grain crops, i.e., sorghum, millets, and amaranths, may mitigate water deficit problems.

A malfunctioning irrigation system also prevents proper irrigation, which reduces crop production. As a result of water deficit during the vegetation period (May to August), secondary crops were not cultivated in major irrigated lands in the region [23]. According to Khamraev et al. (2020), the water volume in Syrdarya and Amydarya (the two rivers flowing to the Aral Sea) reduced by more than 90%, from 1080 km^3 in 1960 to 71.3 km^3 in 2020 [24]. Due to dependence on the crippled water supply system and restricted access to irrigation techniques, crop growing continues to be a very risky business [25]. Wide-scale implementation of water-saving technologies such as drip irrigation would be the best solution for this challenge in the near future. Another suggestion is limiting the cotton and rice production area to a minimum and increasing the area planted to wheat and maize to 32% of the total irrigated land in order to sustain agricultural production and the environment in the Aral Sea basin [26].

Nowadays, most farmers realize that crop diversification is a crucial coping strategy for agricultural revenue, production, and marketing hazards. Although farmers have access to inputs, they need more expertise on farm management techniques. A considerable number of diversifying farmers had access to credit facilities and were more inclined to use intercropping, crop rotation, and mixed cropping as compared with non-diversifying farmers who probably used just the mono-cropping and intercropping practices [27]. Additionally, farmers need more knowledge on improved agronomy, namely crop rotation, the use of legumes, decreased tillage, and crop residue retention, despite most farmers understanding that crop diversification is a predominantly important coping mechanism for agriculture's income, production, and marketing risks [28]. Basic technical and management skills have mostly been obtained from past experiences according to the benefits and drawbacks in managing farm activities [29].

Under the most extreme modeling findings, Karakalpakstan, which mainly depends on rice and cotton as its main food and cash crops, will also be negatively impacted by a significant temperature increase of up to 8.3 °C by the end of the century. The average temperature is expected to rise by 5.2 °C, followed by a little increase in precipitation. A rise in the amount of water needed for irrigation would be necessary given the high temperature growth and slight increase in precipitation. According to the CSIRO2 GCM running under the B1 scenario, the temperature would rise consistently by 0.9 to 2.4 °C in the 2020s for all five nations, with just a slight change in precipitation. The models predict substantially higher temperatures with a mild to moderate increase in 2050 [30].

The increased demand for cereals will also cause crop composition to shift in favor of food production, partially reducing irrigation water demand as less water-intensive crops such as grains, soybeans, fruits, and vegetables replace the cotton and rice that were previously grown in these areas. The study also discovered that farmers' knowledge is a key factor in creating a diverse farming system. Therefore, (i) the skills and knowledge of farmers are significantly increased via capacity building through extension services, resulting in improved agricultural output. (ii) Farmers who own a small amount of land should receive priority since they are more likely to engage in crop diversification. The government should increase and ensure access to inputs and subsidies from other stakeholders. (iii) Farmers must take the lead in order to learn from more forward-thinking farmers. This may be accomplished by forming local groups among farmers according to area to allow talent and experience exchange and provide a platform for their produce's negotiating power.

Since 2006, the International Center for Biosaline Agriculture (ICBA) has been doing field studies and research in this region to introduce halophytes that are resistant to cold, heat, and drought utilizing mineralized artesian water. The experiments and research are in response to the need to find alternative production strategies that can help the local community make use of limited resources, particularly low-quality water for irrigation [18].

The main challenge to growing small grain crops, i.e., millets, sorghum, amaranths and legumes, i.e., mung bean, cowpea, and sesbania, in this region, aside from the well-known obstacles, is that most farmers grow these crops on marginal land with little to no management and external inputs, which results in low yields. Hence, it is essential to encourage research and information sharing on suitable and sustainable small grain cropping systems that will boost production, attain food security, and improve climate change resilience. This study suggests the following tactics to help smallholder farmers increase their crop diversity, which will facilitate technology transmission and allow farmers to identify their issues and find the most efficient, practical, and agronomic approaches to crop growing: Agricultural transformational policies improving extension services with a particular emphasis on cropping systems, sustainable crop enterprises, return from the various types of crops, needs and access to financing, and irrigation infrastructure.

5. Conclusions

This study examined the extent of crop diversification in Karakalpakstan according to a long-term situation analysis. In recent years, the Uzbek Government initiated including more crops in the cropping system, i.e., short- and long-duration crops as a guarantee of improved health, nutrition status, food security, and ecological sustainability in this region, whereas priority should be given to the intensification of the transition process and strengthening agricultural support services. Moreover, policies should be worked out to ensure these farmers have access to preferential credits, education, tax exemption, and other priorities. Results show that the lowest Simpson Index value indicated that the mean computed diversity index was 0.68 in the 2008–2009 growing season. Despite this indicator, enhancing the next years and new approaches should be integrated to capture a balanced crop rotation system. Improvement of crop diversification can shed light on the latest transformations to implement best practices for fully autonomous sustainable farming, practical use cases of intelligent technology, and efficient strategies for building a thriving agri-food innovation ecosystem.

This case study proved that crop diversification is a key driver in the improvement of crop productivity, food security, and farmers' income in the Aral Sea regions, transforming the agricultural sector into a productive and functional system.

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