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Assessing current cropping patterns in a semi-arid basin using cost-benefit and water productivity indicators

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Abstract

Optimal crop patterns improve both profitability and sustainability in land resource management. This study assessed current crop patterns in the Baliqlu Chay River Basin using water productivity, efficiency, labor, and net profit indices. Data from Ardabil, Nir, and Sareyn (2022–2023) show that potato is the most water- and labor-intensive crop (~6,000 m³/ha and >30 person-days/ha) but yields the highest net profit (~2.67 billion IRR/ha). Wheat has the lowest profit (0.5–0.6 billion IRR/ha) due to lower input requirements. Barley, alfalfa, and canola are more suitable for water-limited conditions. Spatially, Ardabil accounts for 91.8% of basin profits, while Nir and Sareyn contribute less than 5%, indicating strong regional disparities. The results show that expanding cultivated area alone does not ensure higher returns; instead, adaptive water management and efficient use of inputs are crucial. Crop performance was further assessed using water productivity indicators, including PWP, GEWP, and NEWP. Despite its relatively high water requirement, potato exhibits the highest water productivity among the studied crops, with PWP values ranging from approximately 5.0 to 5.8 kg/m³, GEWP from 454 to 527 thousand IRR/m³, and NEWP from 348 to 526 thousand IRR/m³. Wheat, although characterized by lower physical productivity (PWP≈1.1-1.9 kg/m³), remains a strategic staple crop with comparatively favorable economic water productivity (NEWP≈133-250 thousand IRR/m³). In contrast, barley, canola, and particularly alfalfa demonstrate lower water productivity levels, with alfalfa exhibiting the lowest net economic water productivity (NEWP≈38-79 thousand IRR/m³). This lower efficiency indicates alfalfa's agro-ecological role in fodder production and soil improvement rather than economic water productivity. The results support adaptive cropping systems that combine economic and hydrological indicators to reduce water stress while improving watershed-scale sustainability.

Key Keywords: Economic analysis, Net crop profit, Crop water requirement, Baliqlu Chay Watershed, Regional agricultural policy

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1. Introduction

The emerging water resources crisis in Iran (especially in the semi-arid/arid countries) has led to serious problems with agricultural management (legal and economic) and continued sustainability of development (Abbaspour et al., 2009). While agriculture uses approximately 90% of the total water used in Iran, there needs to be a complete re-evaluation of cropping pattern selection and optimum use of water resources and agricultural economic inputs (FAO, 2017). Selecting a suitable cropping pattern can affect both the effective use of water resources and improve the potential economic growth of agriculture (Amini Fasakhodi et al., 2010). However, in addition to the above, the issues of water supply/demand, improving the economic capacity for people who live within the watershed, how much agricultural land is to be used by those people on their farm(s), and the extent of environmental degradation also are very important for water resources to be managed properly and to support the development of IWRM. (Asiabi Hir et al., 2018). In many areas of Iran, many crops are still grown according to traditional farming techniques, local customs, and the availability of input supplies from the government. By taking into account information based on economic criteria and water productivity, decision-making can be improved regarding crop choices made by farmers. The province of Ardabil has 788,614 hectares of agricultural land, with 37% under irrigation and 63% rainfed (Davarpanah et al., 2017). The Baliqlu Chay river basin, located in the central part of the province, supports agriculture, industry, and domestic water use. However, in recent years, river flow has significantly decreased due to both cultural and natural factors, leading to economic, social, and environmental challenges. This decline shows the need for optimizing cropping patterns under limited water and land resources. Economic analyses, such as calculating net income from gross revenue minus production costs, offer valuable insights into the profitability of crops and the sustainability of agricultural practices in the region.

Over the past several years, researchers in Iran and worldwide have investigated and evaluated how cropping patterns can be optimally arranged as economically feasible. Fallahi and Gholinezhad (2016) combined the Analytic Hierarchy Process with linear programming to propose an optimal cropping pattern for the Sari area that boosts profits 11% greater than the existing pattern. By using the system dynamics model, Amiri et al. (2020) also investigated wheat production sustainability in relation to precipitation, technology, and support policies based on the level of variability in precipitation and the technology level that significantly influence sustainability in wheat production. Factors influencing cropping patterns were studied in Silakhor region by Sabzevari et al. (2020), who used factor analysis and the TOPSIS method to reveal that six major factors determine cropping patterns, including government control, mechanization, climatic conditions, and recommended including sugar beet and canola as crops to maximize production potential. The investigation of how Water and Energy interact and interrelate through their modeling of System Dynamics in Qazvin Plain and the outcome of this study is reported by Naderi et al. (2021) that there was a continual annual decrease in Ground Water Levels and a continual increase in Energy Consumption, based on a Business-as-Usual Scenario. They have shown that through a combination of water conservation and the reuse of wastewater, their research demonstrates a way to Improve Sustainability. Therefore, through Azizi et al. (2022) we see conduction of research regarding the effect of climate change on Barley Yield as Irrigated in Iran National Scale has shown that if we consider only temperature and precipitation, at increasing levels until maximum temperature (threshold), increasing temperature and precipitation continue to Increase Yield Productivity on the opposite end if exceeding maximum precipitation (Threshold) will decrease yield productivity, thus indicating the relationship between climate change and Barley yield productivity.

Khazaei et al. (2023) took an integrated approach by comparing the agricultural water productivity of the Basht aquifer from both a physical and economic standpoint. Using the FAO Penman-Monteith method implemented in CROPWAT, they calculated how much water would be needed for the main producing crops and determined that the current cropping pattern consumes approximately 45 million m^3 per year. This pattern currently has very low values for both physical and economic productivity. Akhavan Giglou et al. (2023) investigated the physical and economic water productivity and virtual water content of major crops in the Moghan irrigation network using benefit per drop (BPD), net benefit per drop (NBPD), and unit virtual water value (UWV) indices. Their results revealed considerable differences among crops in terms of water-use efficiency and economic performance, providing a basis for crop prioritization under water-scarcity conditions. Sedighkia et al. (2023) showed that incorporating environmental flow constraints into climate-informed reservoir operation optimization reduces irrigation water allocation and agricultural profit, and that cropping pattern optimization alone is inadequate under water scarcity. Meanwhile, Azizi Mobaser and Faraji Amogein (2024) revisited the irrigation planning of the Ardabil plain and found that relying solely on NETWAT outputs results in inaccurate crop water requirement estimates due to its reliance on old climate data, overlooking the impact of microclimatic variation within the area, and only partially covering important crops.

In a study conducted by Javanbakht-Sheikhahmad et al. (2024), the researchers developed a model using System Dynamics that focused on the Gavshan Basin. The study revealed that water productivity and crop yield are limited by the inefficient use of the irrigation infrastructure and that wastewater recycling could help improve water resources within the basin. In Karkheh Basin, Mallah et al. (2025) utilized satellite imagery and machine learning techniques to assess the extent of rainfed agriculture in the basin and to find that increasing amounts of land dedicated to high water demand crops have significantly increased the level of water stress in the region, and recommended adopting more water-efficient cropping practices in order to address the current and future threats to agriculture from drought. Research conducted outside the United States has emphasized the economic and hydrologic aspects of crop systems. For example, Rodríguez-Pose and Hardy (2015) pointed to the importance of local participation and collaboration in developing sustainable development initiatives in rural regions. In addition, Osama et al. (2017) demonstrated the benefit of changing production practices on the quantity of land devoted to strategic, high-yield crop systems in order to increase profits and maintain food security in Egypt using a linear programming model. Finally, Chouchane et al. (2020) examined the average water productivity of crop systems throughout the world and determined that limitations on the expansion of irrigated areas will reduce the amount of water consumed by agriculture by at least twenty-one percent (21%).

Asadzadeh and Raoof (2018) evaluated water use efficiency in the Yamchi and Ghoorichay irrigation systems in Ardabil Plain. Their results showed that Ghoorichay, with a higher irrigation water productivity (4.08 kg/m^3), outperformed Yamchi (2.16 kg/m^3), indicating greater economic and water-use efficiency in the low-pressure hydro flume system. Adaptive water resource management and reduction of cultivated land can lessen the drought impact, according to a study conducted by Pham et al. 2021 in Vietnam using system dynamic modelling. Liu et al. (2022) conducted a study in Northwestern China that used the SWAT model and cellular automata to maximize economic water productivity (EWP), enhance water use efficiency, and change cropping patterns towards regions with lower stress levels. Zhu et al. (2024) have demonstrated that the absence of resource management will lead to increased environmental pressure due to economic growth in China, and through system dynamics modelling, balanced policies between development and conservation can achieve sustainable agriculture. Recent studies have shown an increase in the use of remote sensing technologies and machine learning for examining and monitoring crop patterns. Tariq et al. (2023) and Mohammad et al. (2025) have used Sentinel imagery and Landsat imagery, respectively, to study seasonal changes of the cultivated area and labor migration and its effects on cropping structure in Pakistan and India.

Most existing studies focus on economic optimization, system dynamics, or water productivity, but they often analyze these elements separately. Although they indicate key links between climate variability, water use, and crop profitability, the combined spatial and economic dimensions of cropping patterns at the basin scale remain only partly addressed. Research has examined groundwater decline, water demand, and crop water requirements, yet few works integrate these factors with spatial variability. Issues such as outdated climate inputs, limited crop coverage, and weak attention to microclimatic and infrastructural differences show that localized spatial-economic performance is still insufficiently explored. Given these gaps, a spatial-economic assessment in the Baliqlu Chay river basin can provide a clearer picture of where crops are grown, how efficiently they use water, and how much profit they generate. This integrated view helps identify areas with low water productivity or poor economic returns and supports more precise, basin-level strategies for sustainable agriculture. Water resources, dynamics, and cropping pattern optimization have been addressed by past studies; however, few studies have combined economic analysis of net income with constraints of water resources across a watershed scale, particularly for areas such as the Baliqlu Chay river basin, which contains diverse land use and high agricultural value. Most cropping patterns currently exist in the Baliqlu Chay river basin because of the historical evolution of those crops, as well as due to government support and available resources; however, studies focusing on the integrated approach to economic sustainability, resource productivity, and food security have received little attention. Due to the growing loss of water resources and the combined economic, social, and environmental impacts associated with this trend, indicators such as net income can serve as an essential criterion when developing an integrated approach to resource allocation, economic sustainability, productivity, and agricultural sustainability.

The objective of this study is to perform an economic analysis of the cropping pattern in the Baliqlu Chay river basin by evaluating and comparing the net income generated by various crops. This analysis aims to determine the most economically viable crop mix based on key performance indicators such as gross revenue, irrigation water costs, input costs, and net profit per hectare. The study employs a computational model using data from the 2022–2023 agricultural year and utilizes the Python programming language for data management and calculations. The results will provide valuable insights to guide policy development for water and agriculture resource management, and inform decision-making processes for local stakeholders, including policymakers, agricultural managers, and local communities.

2. Material and Method

2.1 Study area

Figure 1 illustrates the geographical location of the Baliqlu Chay river basin within Ardabil Province, Iran.

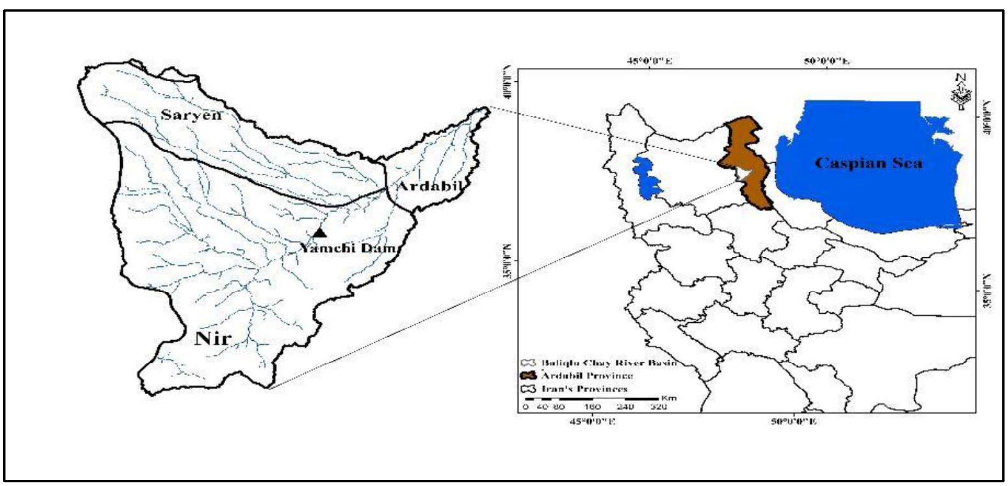


Figure 1. Geographical location of the Baliqlu Chay river basin in Iran and Ardabil Province

Ardabil Province is located in northwestern Iran and covers 17,953 km² in total. The Baliqlu Chay river basin has an approximate surface area of 1,093 km², situated from 47°46′E to 48°06′E and from 37°52′N to 38°15′N. The distance between the head of the Baliqlu Chay River and its terminus located in Ardabil City is about 65 km. The Yamchi dam, situated in the eastern part of Ardabil Province, has been constructed on the Baliqlu Chay river within the Aras sub-basin. The dam's watershed covers an area of 730 km² and has a storage capacity of 80 million m³ (Raoof and Alioghli, 2020). The management and assessment of water resources in the Baliqlu Chay river basin are of great importance due to its diverse land uses (agriculture, forest, rangeland, industrial, and residential), the substantial volume of surface and groundwater resources, and the presence of the agriculturally significant Ardabil plain within the basin.

2.2. Methodology

Agricultural data for the Baliqlu Chay river basin in Ardabil County were obtained from the Statistical Center of the Iranian Ministry of Agriculture (https://www.maj.ir/). The dataset covers three major crops and includes information on crop yield, product prices, irrigation water type, and labor requirements for the 2022–2023 agricultural year (Table 1). The crops grown in Ardabil County are: Potato, Wheat, Barley, Alfalfa, and Canola. The main crop grown in Ardabil County is Potato which occupies an area of 14,455 hectares, and has an average yield of 30.17 tons per hectare, representing the largest area of Land planted (23.92%). Potatoes also have a very high profit potential with a high market price of approx 90.74 million IRR per ton and have the highest water requirements of all the main crops at an average use of 6,030 m³ per ha. Due to this very high profit potential and large amounts of water used, Potatoes are at the forefront of the Economy and Hydrology of the Basin. The other two main irrigated crops are Wheat and Barley which represent 37.24% and 18.40% respectively of the area planted, but their water use in comparison to that of Potatoes is moderate, Wheat and Barley use 2,560 and 1,860 m³ per ha respectively.

Table-1: Agricultural data and key crop parameters for major crops in the Baliqlu Chay river basin by county

Region	Crop	Cultivated area (ha)	Share of cultivated area (%)	Yield (t ha⁻¹)	Crop price (thousand IRR t⁻¹)	Water requirement (m³ ha⁻¹)	Labor requirement (person-days ha⁻¹)
Ardabil	Potato	14455.19	23.92	30.17	90740	6030	32.0
	Wheat	22502.71	37.24	4.92	149950	2560	1.20
	Barley	11119.30	18.40	3.01	100855	1860	0.80
	Alfalfa	2565.59	4.25	6.00	47479	5540	0.00*
	Canola	235.80	0.39	1.42	310462	3500	2.60
Nir	Potato	238.95	0.40	35.00	90740	6030	0.00
	Wheat	2291.85	3.79	4.19	149950	2560	1.90
	Barley	765.25	1.27	3.65	100855	1860	0.10
	Alfalfa	47.00	0.08	9.50	47479	5540	0.60
Sareyn	Potato	54.20	0.09	32.00	90740	6030	15.00
	Wheat	2740.00	4.53	2.73	149950	2560	2.10
	Barley	2023.90	3.35	2.46	100855	1860	2.80
	Alfalfa	1331.30	2.20	10.00	47479	5540	6.10
	Canola	56.00	0.09	1.00	310462	3500	2.10

The crops grown in Ardabil County are: Potato, Wheat, Barley, Alfalfa, and Canola. The main crop grown in Ardabil County is Potato which occupies an area of 14,455 hectares, and has an average yield of 30.17 tons per hectare, representing the largest area of Land planted (23.92%). Potatoes also have a very high profit potential with a high market price of approx 90.74 million IRR per ton and have the highest water requirements of all the main crops at an average use of 6,030 m³ per ha. Due to this very high profit potential and large amounts of water used, Potatoes are at the forefront of the Economy and Hydrology of the Basin. The other two main irrigated crops are Wheat and Barley which represent 37.24% and 18.40% respectively of the area planted, but their water use in comparison to that of Potatoes is moderate, Wheat and Barley use 2,560 and 1,860 m³ per ha respectively.

2.2.1 Economic evaluation of the cropping pattern

Table 2 presents the economic indicators and formulas used to evaluate the profitability of the current cropping pattern.

Table 2. Economic indicators and formulas for evaluating the profitability of the current cropping pattern

No.	Economic variable (IRR)	Formula	Description
1	Gross revenue	$GR_i = Y_i \times P_i \times A_i$	Gross revenue represents the total income obtained from crop production in each region. This indicator is calculated based on crop yield (Y_i, t ha^{-1}), crop price (P_i, IRR t^{-1}), and cultivated area (A_i, ha). It reflects the potential revenue-generating capacity of each crop in the study area.
2	Labor cost	$LC_i = L_i \times A_i \times 1{,}250{,}000 \times 8$	Labor cost represents the total human labor expenditure required for the production of each crop. It is calculated based on the labor requirement (L_i, person-days ha^{-1}), cultivated area (A_i, ha), the hourly wage rate (1,250,000 IRR), and an 8-hour working day.
3	Input cost	$IC_i = IC_i\text{,ha} \times A_i$	Input cost denotes the average cost of agricultural inputs (IC_i, ha) per hectare for crop i, multiplied by the cultivated area (A_i, ha). This cost includes seeds, fertilizers, chemical pesticides, and mechanization services, collected from the Statistical Center of the Iranian Ministry of Agriculture.
4	Net profit	$NP_i = GR_i - (IWC + LC_i + IC_i)$	Net profit is obtained by subtracting the total costs (irrigation water cost, labor cost, and input cost) from gross revenue. This indicator represents the final profitability of each crop in each region and is used to assess the economic efficiency of the existing cropping pattern.
5	Physical water productivity (PWP)	$\text{PWP}_i = \frac{Yield(t/ha) \times 1000}{WR\ (m^3/ha)}$	Physical water productivity represents the crop yield produced per unit of water requirement. It is calculated by dividing yield (Y_i, t ha^{-1}) converted to kg ha^{-1} by crop water requirement (WR_i, m^3 ha^{-1}), resulting in kg m^{-3}
6	Gross economic water productivity (GEWP)	$\text{GEWP}_i = \frac{GR_{i,ha}}{WR_i}$	Gross economic water productivity represents gross revenue generated per unit of water requirement. It is computed as gross revenue per hectare (GR_i, ha, IRR ha^{-1}) divided by crop water requirement (WR_i, m^3 ha^{-1}), resulting in IRR m^{-3}.
7	Net economic water productivity (NEWP)	$\text{NEWP}_i = \frac{NP_{i,ha}}{WR_i}$	Net economic water productivity represents net profit generated per unit of water requirement. It is calculated as net profit per hectare (NP_i, ha, IRR ha^{-1}) divided by crop water requirement (WR_i, m^3 ha^{-1}), resulting in IRR m^{-3}.

Note: Water-use efficiency is quantified here using water productivity indicators. WR_i denotes crop water requirement (m^3 ha^{-1}). For GEWP and NEWP, GR_i, ha and NP_i, ha denote gross revenue and net profit per hectare (IRR ha^{-1}), respectively. PWP is reported in kg m^{-3}, while GEWP and NEWP are reported in IRR m^{-3}.

A computational model has been developed to analyse the economic performance of the current cropping pattern in the Ardabil, Nir, and Sareyn counties, which collectively make up the agricultural zone of the Baliqlu Chay river basin. Five primary crops grown in each region were evaluated; they include potato, wheat, barley, alfalfa, and canola. The economic metrics for each crop-region pair were calculated using the government-guaranteed purchase prices for the agricultural year 2022-2023, as set by the Iranian government. The economic metrics for each crop-region pair were calculated using the Python programming language and the Pandas library, which were employed for data management, automation, and ensuring consistency and accuracy in the calculations of gross revenue, labor cost, input cost, and net profit (McKinney et al., 2012; Chupilko et al., 2025). The economic metrics evaluated for each crop-region pair included four major economic metrics in addition to irrigation water costs, as well as three water productivity indicators (PWP, GEWP, and NEWP) to quantify water-use efficiency. Irrigation water costs are classified based on how the water is supplied and delivered, and this classification is based on the Ministry of Agriculture-Jihad's data as compared to the FAO CROPWAT model's calculation of crop irrigation water requirements within Ardabil Province. Groundwater supply sources were charged a flat volumetric rate of approximately 400 IRR per m^3 (Crop Year 2022-2023). While the charge for semi-modern (dam-fed) delivery systems was set at 2 per cent of the crop's gross revenue, for traditional systems it was set at 1 per cent of the crop's gross revenue (Plan and Budget Organization, 2024).

3. Results and Discussion

Table 3 shows a series of economic parameters related to gross revenue (GR_i), irrigation water, labor, and input costs (IC_i), total cost, and per-hectare and total net profit (NP_i) for the five major crops of potato, wheat, barley, alfalfa, and canola in the three counties of Ardabil, Nir, and Sareyn.

Table 3. Economic performance indicators of main crops in the Baliqlu Chay river basin by county (values in billion IRR)

Region	Crop	Gross revenue (GR_i)	Irrigation water cost	Labor cost (LC_i)	Input cost (IC_i)	Net profit per hectare	Total net profit (NP_i)
Ardabil	Potato	39572.90	34.87	4625.66	4491.95	2.10	30420.42
	Wheat	16601.46	332.03	675.08	1113.33	0.64	14481.02
	Barley	3375.53	67.51	277.98	332.64	0.24	2697.40
	Alfalfa	730.87	14.62	0.00	168.10	0.21	548.15
	Canola	103.95	0.33	6.13	9.33	0.37	88.16
Nir	Potato	758.88	0.58	0	1.23	3.17	757.08
	Wheat	1439.95	2.35	43.55	90.44	0.57	1303.61
	Barley	281.70	0.57	11.48	1.58	0.35	268.08
	Alfalfa	21.20	0.10	0.28	0.06	0.44	20.76
Sareyn	Potato	157.38	0.13	8.13	0.06	2.75	149.06
	Wheat	1121.66	11.22	57.54	123.08	0.34	929.82
	Barley	502.14	5.02	56.67	58.73	0.19	381.72
	Alfalfa	632.09	6.32	81.21	45.26	0.38	499.29
	Canola	17.39	0.08	1.18	0.53	0.28	15.61

These parameters will form the basis for comparing economic performance and the role of production factors in the productivity of water and labor in different parts of the basin. In general, potato shows the net profit (per hectare) in all three counties. The total net profit of potatoes in Ardabil County reaches about 30,420 billion IRR, several times higher than that of other crops. This crop shows the highest economic return per unit area, with a net profit of 2.10 billion IRR ha^{-1}, though the irrigation water cost is the highest among all crops, estimated at about 34.87 billion IRR, and the input cost is 4,491.95 billion IRR. Nir County had a very similar economic performance to that of Ardabil County. Its net profit reached 3.17 billion IRR ha^{-1}, which is the highest value among regions and thus indicates that potato production in this region is very efficient in terms of managing inputs and production costs. Potatoes in Sareyn County generate an acceptable net profit of approximately 2.75 billion IRR ha^{-1} despite the smaller scale of production, indicating a significant potential for the region. Although wheat crop profitability is less than potato for all three counties, it is still important in regard to sustainability and the management of economic risk. With regard to Ardabil County, the net profit of wheat is 0.64 billion IRR per hectare with a total net profit estimate of approximately 14,481 billion IRR. The estimated net profit per hectare in Nir County is 0.57 billion IRR per hectare; however, because of the relatively low labor (43.55 billion IRR) and irrigation (2.35 billion IRR) costs in Nir County, it indicates that Nir County's wheat production has been comparatively financially efficient in terms of the low availability of water within that region. In Seryan County, even though both the water and input costs are considerably higher, the net profit per hectare is 0.34 billion IRR, suggesting that the relatively stable level of profitability associated with wheat production.

Barley and alfalfa rank lower in economic terms across all areas. The net profit per hectare of barley varies from 0.19 to 0.35 billion IRR, and its total net profit accounts for only a small fraction of the value produced by potato or wheat. However, due to their low water and input requirements, these crops can play a supportive role in maintaining the resilience of the cropping pattern under water-stress conditions.

Although the net profit of alfalfa cultivation in Nir is relatively acceptable, amounting to 0.44 billion IRR ha^{-1}, it would be less profitable in the other regions, oscillating between 0.21 and 0.38

billion IRR ha⁻¹. From an agricultural policy standpoint, the cultivation of alfalfa is justified in high-livestock-carrying capacity areas, while in an entirely economic view, it will be of secondary priority. Canola also records the lowest net profit among the studied crops, hovering at approximately 0.28-0.37 billion IRR ha⁻¹, which is most likely due to its high input prices and relatively modest yields.

3.1. Water productivity indicators (PWP, GEWP, NEWP)

Table 4 summarizes physical water productivity (PWP), gross economic water productivity (GEWP), and net economic water productivity (NEWP) for the major crops in each county.

Table 4. Water productivity indicators (PWP, GEWP, NEWP) of main crops in the Baliqlu Chay river basin by county

Region	Crop	WR (m^3 ha^{-1})	Yield (t ha^{-1})	GR (billion IRR ha^{-1})	PWP (kg m^{-3})	GEWP (thousand IRR m^{-3})	NEWP (thousand IRR m^{-3})
Ardabil	Potato	6030	30.17	2.738	5.003	454.0	348.3
	Wheat	2560	4.92	0.738	1.922	288.2	250.0
	Barley	1860	3.01	0.304	1.618	163.2	129.0
	Alfalfa	5540	6.00	0.285	1.083	51.4	37.9
	Canola	3500	1.42	0.441	0.406	126.0	105.7
Nir	Potato	6030	35.00	3.176	5.804	526.7	525.7
	Wheat	2560	4.19	0.628	1.637	245.4	222.7
	Barley	1860	3.65	0.368	1.962	197.9	188.2
	Alfalfa	5540	9.50	0.451	1.715	81.4	79.4
Sareyn	Potato	6030	32.00	2.904	5.307	481.5	456.1
	Wheat	2560	2.73	0.409	1.066	159.9	132.8
	Barley	1860	2.46	0.248	1.323	133.4	102.2
	Alfalfa	5540	10.00	0.475	1.805	85.7	68.6
	Canola	3500	1.00	0.310	0.286	88.7	80.0

Note: Economic water productivity values are reported as thousand IRR per m³ for readability

PWP indicates the amount of crop produced per unit of water (80 kg/m3), while GEWP and NEWP represent gross revenue and net profit generated per unit of water consumed (IRR/m3). These indicators quantify water-use efficiency within the existing cropping pattern and enable comparison of economic returns against water demand.

Figure 2 shows the highest physical water productivity across counties (about 5.00-5.80 kg/m3) and also the highest NEWP, particularly in Nir (approximately 526 thousand IRR/m3).

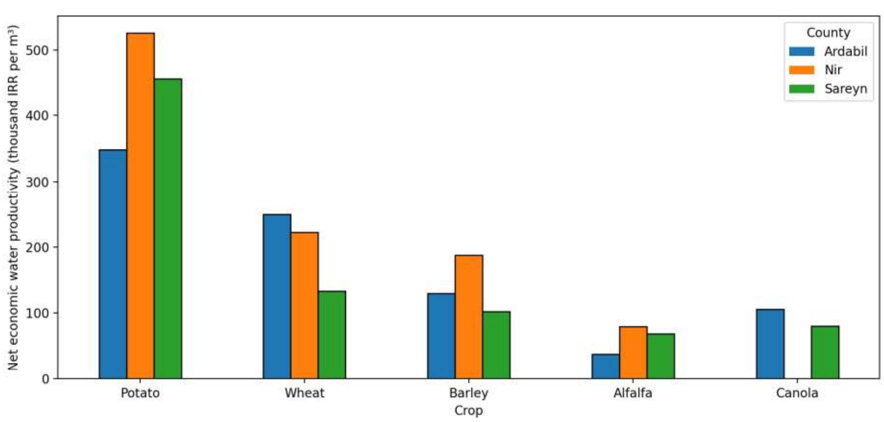
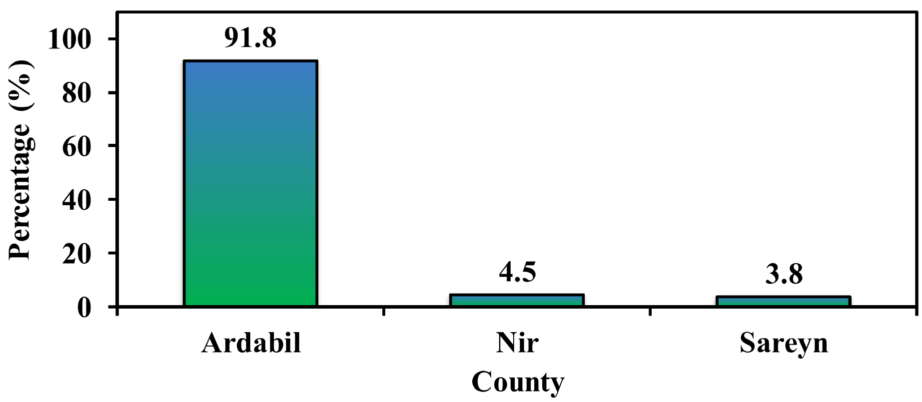


Figure 2. Net economic water productivity (NEWP) by crop and county

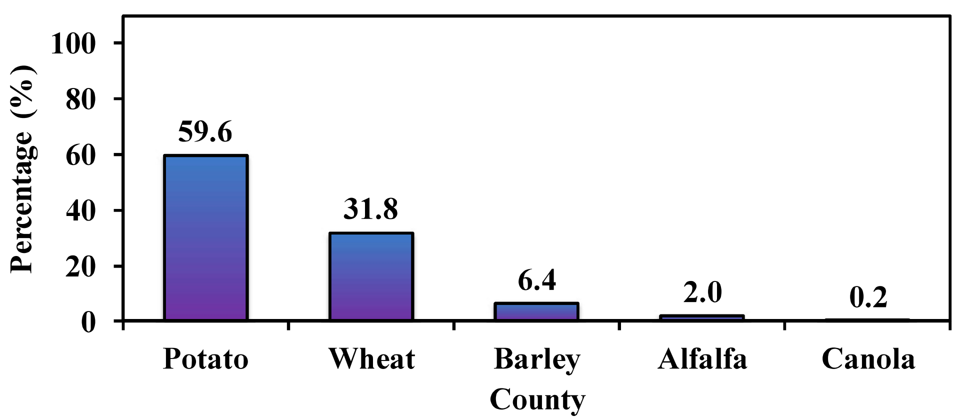
Wheat provides a more moderate but relatively stable NEWP (about 133-250 thousand IRR/m3) with substantially lower water requirements than potato. Barley generally exhibits intermediate values, while alfalfa and canola show lower net returns per unit water in most cases. The results confirm that the current pattern is highly profitable where potato dominates, but it can intensify pressure on water resources; therefore, NEWP and PWP should be jointly considered in basin-level policy discussions.

3.2. Share of net income by county and crop

Figure 3 shows the distribution of net agricultural income across counties (Ardabil, Nir, and Sareyn) as well as by crop production area.



a)



b)

Figure 3. Share of net income by agricultural crop and by the counties of Ardabil, Nir, and Sareyn

Ardabil has a dominant position (91.8% of total net agricultural income) within the regional agricultural economy. Nir (4.5%) has a smaller share of net agricultural income than Ardabil, while Sareyn has the smallest share (3.8%). The concentration of net agricultural income in Ardabil reflects its relatively high levels of agricultural activity and/or productivity (compared with Nir and Sareyn) associated with the production of high-value agricultural commodities (potato and wheat). This disparity indicates an inequity in agricultural profitability from one county to the next and suggests the importance of establishing farm policies targeted toward improving farm income and creating necessary infrastructure in counties like Nir (Fig. 3a).

There is a notable difference among the crops in their contribution to net income. While potato covers only about 24.4% of the total cultivated area in the Baliqlu Chay river basin, it provides 59.6% of the total net income, indicating its high economic value and higher yield (t ha^{-1}). Wheat comes in second place, holding a share of 31.8% in net income. In contrast, barley, alfalfa, and canola contribute only 6.4%, 2%, and 0.2%, respectively, to the total net income (Fig. 3b). These results suggest that economic goals should be combined with environmental functions in agricultural land-use planning. For instance, although alfalfa is relatively less profitable, its role in providing fodder and thereby facilitating soil nitrogen fixation is very important. Therefore, multi-functional land-use planning is needed to achieve an appropriate balance between economic profitability and environmental sustainability.

3.3. Economic–hydrological comparison of major crops

Figure 4 compares the net income and irrigation water requirement for major field crops.

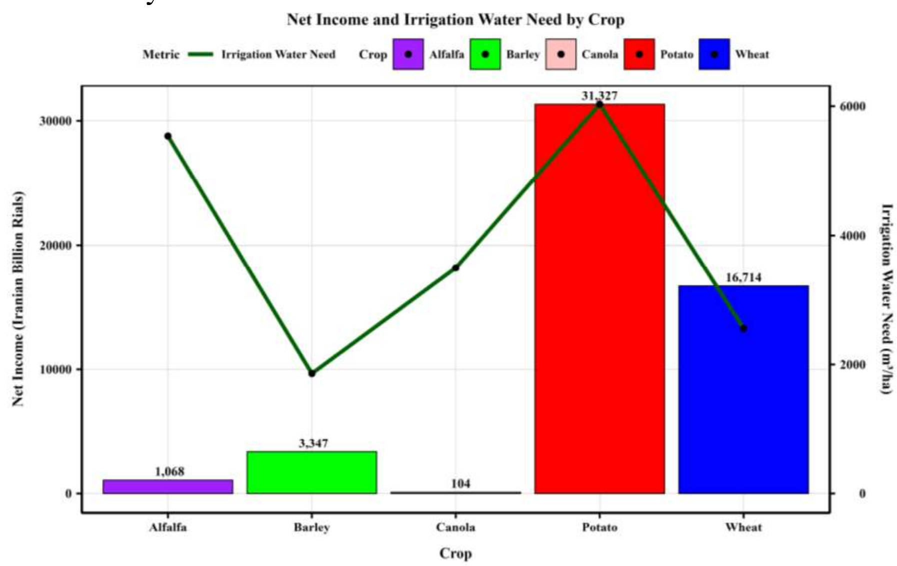


Figure 4. Comparison of net income and irrigation water requirement for major field crops

Five major field crops, including potato, wheat, barley, alfalfa, and canola, are presented using a combined bar-line chart, where net income (IRR) is illustrated by bars and irrigation water requirement (m^3 ha^{-1}) is shown on a secondary y-axis using a line plot. This graphical representation allows a direct comparison of the economic performance of each crop alongside its irrigation water demand, facilitating an integrated assessment of economic efficiency and water-use implications. According to the results, potato, while having the highest water requirement at about 6,000 m^3 ha^{-1}, also generates the highest net profit on the order of 3×10^{13} IRR, showing a very strong economic performance. However, it exerts massive pressure on water resources. This crop is attractive from a policy viewpoint on water resources if the conditions are favorable in terms of water availability, but it should be carefully evaluated for scenarios where there is a scarcity of water.

By contrast, wheat has a moderate water requirement (ca. 2,500-3,000 m^3 ha^{-1}) on a large cultivated area and provides a remarkable net profit (ca. 1.5×10^{13} IRR), so it is a crop showing a relative balance between economic returns and water productivity. In addition, barley has a more limited water requirement of around 2,000 m^3 ha^{-1} but earns a lower net profit; however, because of its modest water demand, its relative water-use efficiency, expressed by the net profit per unit of water consumed, can be particularly attractive during drought or under severe water-stress conditions. Alfalfa and canola, by contrast, combine low net profits with relatively high water requirements (about 5,000-6,000 m^3 ha^{-1} for alfalfa and about 3,500 m^3 ha^{-1} for canola), placing them lower in the optimal cropping pattern from a joint economic–hydrological point of view, except in cases where additional co-benefits (such as government support, soil-improvement functions, or livestock feeding value) favor their inclusion.

3.4. Analysis of net income versus number of labor days per hectare

Figure 5 shows the net income for different crops in the three counties: Ardabil, Nir, and Sareyn. The bar charts show the net income earned (in Iranian Billion Rials) from each crop: Alfalfa, Barley, Canola, Potato, and Wheat, in the respective regions, which expresses the vast variability in the income earned from each crop per county.

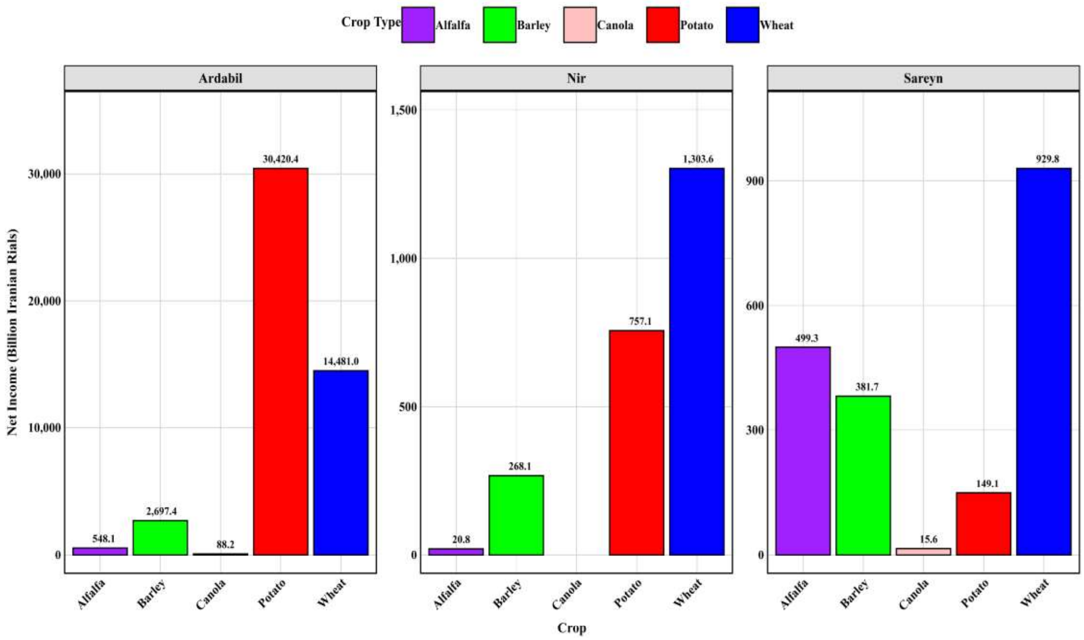


Figure 5. The net income for different crops in the three counties

The results show that potatoes in the Ardabil region have the highest net profit among the crops studied. This indicates that potato production is a high-value activity with strong potential for job creation and significant economic returns. The larger cultivated area of potatoes in Ardabil likely contributes to their higher net profit; however, our analysis shows that this high profitability is not solely due to the cultivated area but also to higher water-use efficiency. The combination of strong economic performance and high-water productivity makes potatoes a high-value crop in the region.

Figure 6 below shows the labor days required by various crops in each county. It is evident from these bar graph representations that each crop has varying labor days as far as Nir, Ardabil, and Sareyn are concerned, with Potato taking the highest number of labor days in each case.

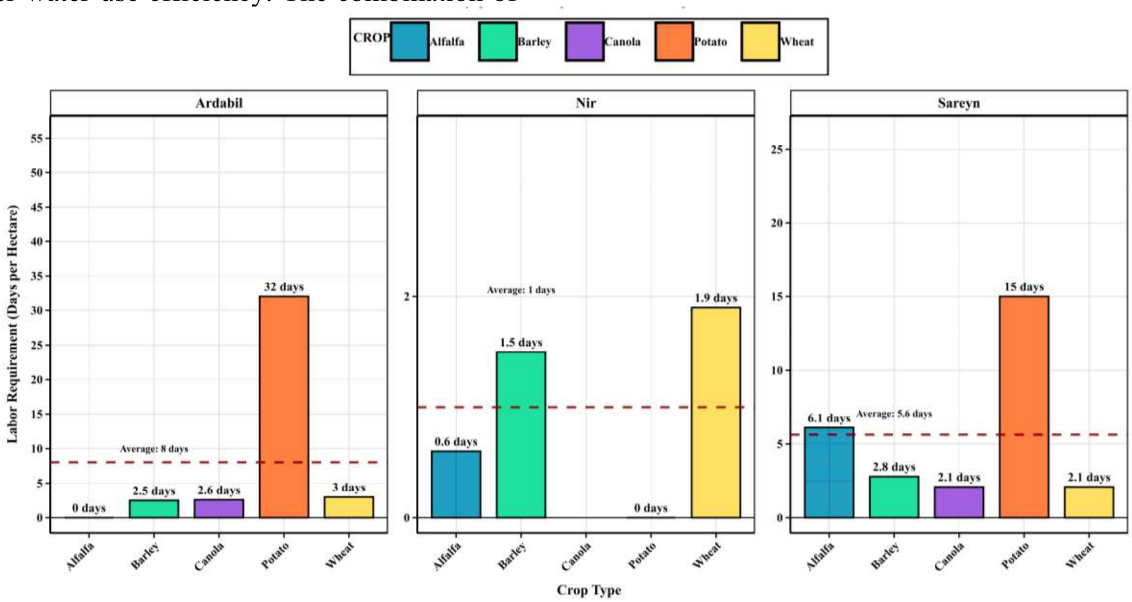


Figure 6. The labor days per unit area for different crops in the three counties

The wheat in the Nir region produces moderate net profits but requires very little labor to produce (under 2 days per person). This pattern reflects the high degree of mechanization and labor productivity in wheat production, such that a considerable economic return is obtained per unit of labor employed. Barley and canola have lower net profits in all three regions and are within the 0-5 person-days ha^{-1} range of labor. In contrast, alfalfa, with its requirement of about 15 person-days ha^{-1} of labor in Sareyn, along with low net profit, reflects a very labor-intensive crop with no high economic returns; hence, its cultivation is justifiable mainly in conditions where there is a need for improvement of the soil, livestock feed, or ecosystem stability. Overall, the dispersion pattern of the data shows that the relationship between labor input and net profit is nonlinear and is dependent on crop type and local conditions. In other words, increasing labor does not necessarily lead to higher profit, except for crops with high economic value (such as potatoes). This analysis points out that cropping-pattern policies in different regions should be planned on the basis of labor-efficient indicators, i.e., net profit per person-day, so as to ensure an optimal mix of employment generation, productivity, and profitability. To summarize, the results of this study underscore the importance of understanding crop profitability, resource management, and water use efficiency in shaping optimal cropping patterns that contribute to regional economic stability and environmental sustainability. The analysis shows the concentration of agricultural profits in specific regions, such as Ardabil, where approximately 92% of the net agricultural income is generated. This concentration emphasizes the need for targeted policies tailored to local conditions. Supporting this view, Rodríguez-Pose & Hardy (2015) argue that regional policies play a crucial role in addressing economic disparities, ensuring that agricultural practices are optimized for the maximum economic benefit. Similarly, research by Fallahi & Gholinezhad (2016) underscores the significance of such localized policy measures. The results also stress the critical role of mechanization and effective management in determining crop priorities, particularly for crops like wheat, which demand less labor, especially in regions like Nir. This aligns with the conclusions of Sabzevari et al. (2020), who identified labor efficiency as a key determinant in selecting crops. Additionally, the results confirm the necessity of integrating environmental factors and climate change considerations into crop priority decisions. As noted by Azizi et al. (2022), crops such as barley, which thrive under dry climatic conditions, could offer higher returns, suggesting that adaptability to climate change can be a valuable trait in crop selection. Moreover, the study echoes the conclusions of Sedighkia et al. (2023), advocating for a balanced approach in land allocation and environmental flow management. Our research similarly suggests that optimizing crop allocation involves more than a mere redistribution of land. The impact of climate change, particularly on water resources, is a critical factor that must be addressed in any comprehensive agricultural planning strategy. In conclusion, agricultural policies must be informed by localized data, incorporating competitive advantages. A comprehensive policy approach should recognize the multifunctionality of agricultural land, acknowledging that crops like alfalfa, although less financially valuable, provide significant ecological and economic benefits.

4. Conclusions

An objective of this research work is to carry out the economic analysis and optimize the cropping pattern for the Baliqlu Chay river basin. The results show that there is a large variation in the economic return and efficient use of resources for different crops and geographical areas. The economically valuable crops like potatoes, requiring higher water and labor inputs, give the highest economic return if resources are utilized efficiently, mainly in the Ardabil and Nir areas. The crops with lower economic returns, like barley and canola oil, should ideally be grown in combinations with other crops because of water or economic limitations. The potatoes give the highest average net return per hectare in the Ardabil, Nir, and Sareyn areas. Alfalfa and canola crops, which are less profitable and less water-intensive, could potentially increase crop sustainability in water-limited environments. The above results are consistent with previous studies that place a strong emphasis on optimizing economics in a context related to resource limitations and take into consideration factors related to environmental impacts associated with crop management decisions. Besides profitability, water-use efficiency has also been analyzed considering both physical and economic water productivity indicators, such as PWP, GEWP, and NEWP. It follows from the analysis that potatoes have the highest physical and economic water productivity, yielding substantial economic returns per unit of used water, though they create the highest stress on water resources due to high crop water requirements. Wheat, being a crop with average water requirements, presents a more balanced profile that ensures economic feasibility and contributes to food security at the regional level. Alfalfa and canola generally have lower economic water productivities, and their inclusion within the cropping system should be justified by other benefits than net economic returns per unit of water used, such as providing feed for livestock, improving the quality of the soil, and serving as a hedge against agricultural risks.

Author Contributions:

Seyedsaeid Nabavi: Conceptualization, methodology, formal analysis and investigation, visualization, resources, writing, original draft preparation.

Arash Malekian: Conceptualization, supervision, formal analysis and investigation, writing, review, and editing.

Naser Mashhadi: Data curation, resources, formal analysis and investigation, writing, review, and editing.

Khaled Ahmadaali: Methodology, software, formal analysis and investigation, visualization, writing, review, and editing.

Raoof Mostafazadeh: Resources, field investigation, data curation, writing, review, and editing.

Ali Shahbazi: Validation, visualization, writing, review, and editing.

Authors' Conflicts of Interest:

The authors of this article declared no conflict of interest regarding the authorship or publication of this article.

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