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Economic-ecological assessment of multi-crop small-scale model farms in the Republic of Armenia (piloting results from Gegharqunik region)

Meruzhan Galstyan[1], Andreas Meliqyan[1], Hovik Sayadyan[2*], Aghvan Sahakyan[1], Narek Sahakyan[1], Hamlet Martirosyan[1], Valeri Aleqsanyan[3], Inna Hakobjanyan[1]

[1]Armenian National Agrarian University, Yerevan, Armenia; [2]Department of Geography and Geology, Yerevan State University, Yerevan, Armenia; [3]Ecologo-noospehirc Research Center of National Academy of Sciences (NAS) of RA

***Corresponding author:** Hovik Sayadyan, PhD, Yerevan State University, Alex Manukyan 1, 0025 Yerevan, Armenia

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ABSTRACT

Background: Biogenic elements such as nitrogen (N), phosphorus (P), and potassium (K) are major pollutants of Lake Sevan's water, causing eutrophication and deterioration of water quality. Untreated wastewater, sewage, agriculture, fish farming, and other activities are significant sources of these pollutants. Vegetable cultivation, heavily reliant on mineral fertilizers and chemicals, and livestock breeding contribute substantially to nitrogen pollution in the lake. However, improved vegetable growing practices, including small-scale agriculture using organic fertilizers, natural soil improvers, and eco-friendly bio-liquids as growth stimulants, can enhance the socio-economic conditions for farmers in the Lake Sevan basin. These practices promote environmentally friendly, water-saving land-use methods, reducing nitrogen leaching into the lake.

Objective: This study aims to demonstrate the socio-economic and environmental benefits of applying innovative agro-technology to small-scale farming in the Lake Sevan watershed (Gegharkunik region). Specifically, the study objectives are to determine the quality characteristics of crops grown in small-scale farms and compare these quality indicators between yields obtained through the proposed technology and traditional cultivation methods.

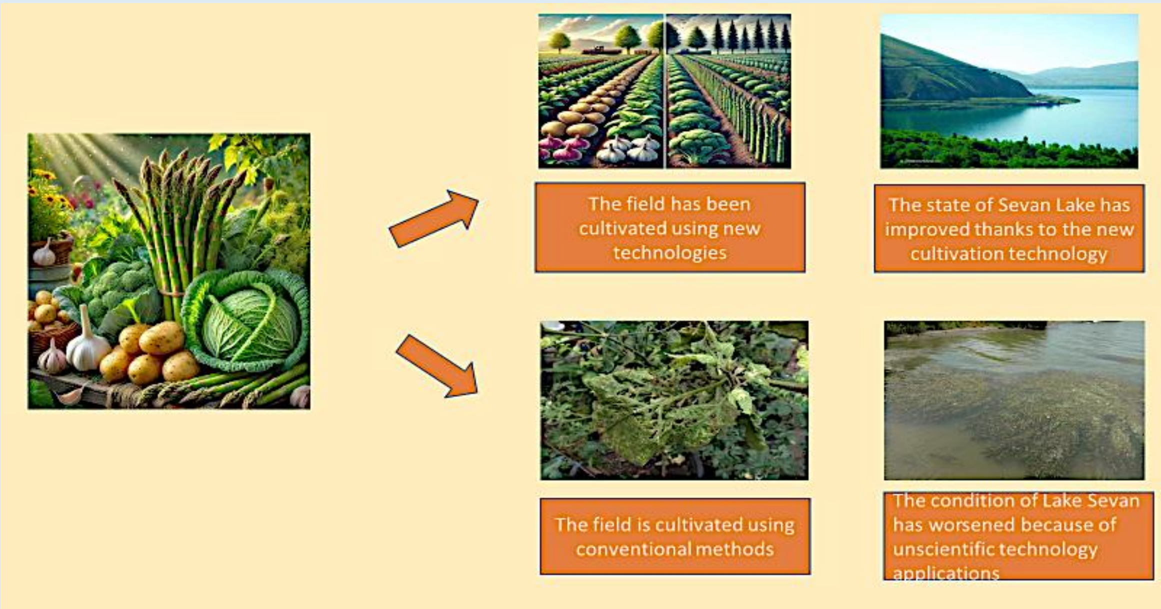
Methods: Field trials of multi-crop systems were conducted on 0.25 ha land plots in four variations across four different locations in the Lake Sevan watershed. The trials were evaluated for various parameters. Nitrate content, dry matter, starch, vitamin C, and sugar levels were determined in potatoes, cabbage, broccoli, beets, and green beans, while fat content was measured in green beans and green peas.

Results: Economic efficiency calculations revealed that utilizing the proposed innovative agro-technology in a multi-crop small-scale farm (0.25 ha) yielded a 20-25% increase compared to traditional cultivation with synthetic fertilizers, accompanied by notable environmental benefits.

Conclusions: The study demonstrates that small-scale agricultural practices employing the proposed agro-technology have significant socioeconomic and environmental impacts on local farmers.

Keywords: Cultivation of non-traditional crops, organic farming, small-scale farming, activities, economic and ecological evaluation, and food quality characteristics.

Graphical abstract: Functional properties, organic and conventional farming, ecology of Sevan



INTRODUCTION

Human economic activities, particularly the unsustainable use of natural resources, have numerous negative effects on the environment [1]. These activities disrupt the natural balance, degrade biota and their habitats, and create unpredictability in natural and social systems [2-3].

In Armenia, rapid privatization of agricultural production and land in 1997 led to a significant decline in agricultural productivity. Typically, a single farmer's land comprises of 4-5 small, scattered plots, making effective cultivation challenging. This fragmentation increases material and energy consumption per unit of land, contradicting efficient agricultural management principles. Poor road conditions and difficult access to remote plots often result in uncultivated lands [4].

Post-privatization factors, including small farms and other agricultural management issues, contributed to decreased cultivated land productivity and farmers' incomes [5-6.]. Therefore, studies focusing on stable agricultural systems, secure rural employment, poverty elimination, and farm prosperity are crucial and timely. These studies align with strategic plans enhancing agricultural efficiency in the republic.

The objective of this study was to establish small-scale, multi-crop farms within the ecological context of Lake Sevan, evaluating their economic and ecological efficiency and replicating successful examples in other communities within the Gegharkunik region and the republic with similar agro-climatic conditions. To achieve this, research was conducted to investigate the potential of such farms. Small-scale, multi-crop model farms were created in the Lake Sevan basin on 0.25-hectare plots to assess the productivity of cultivated crops, and qualitative and quantitative indicators of harvested produce.

To ensure year-round employment for farm workers, 5-7 species of traditional and cash crops were selected. This approach allowed observation of optimal crop combinations, ensuring economically viable and ecologically sustainable harvest. To enhance soil fertility and promote eco-friendly practices, legumes (beans, peas, and chickpeas) were incorporated into crop selection [7, 8]. Legumes are known for nitrogen fixation through symbiosis with Rhizobium bacteria, enhancing soil fertility [9].

Additionally, crops like beans, chickpeas, potatoes, garlic, and lettuce (salad) are rich in bioactive compounds. These naturally occurring chemical compounds in plants affect biological processes, including antioxidants, flavonoids, and phenolic acids. They improve soil health, promote plant resilience, and offer benefits for human health. These bioactive compounds contribute positively to sustainable agricultural practices by enhancing soil and crop productivity [10-14].

Recent studies in functional food science highlight the role of bioactive compounds in enhancing crop yield and quality, providing insights into sustainable farming practices [15-16].

MATERIALS AND METHODS

Small-scale farm organization (2023-2024): Included the following steps: identification of farmers, crop selection, land preparation and input acquisition, fertilization and monitoring, quality assessment.

Quality Indicators Assessment: Quality indicators, including nitrates, dry matter, starch, vitamin C, and sugars were determined in potatoes, cabbage, broccoli, beets, and green beans, while fat content was measured in green beans and peas. These measurements followed established methods. Crop yield and dry matter content served as key quality indicators. The dry matter content was analyzed using the thermogravimetric method [17], while sugar content was determined through Bertrand's method [18]. Vitamin C content was measured using UV spectrophotometry [19], and nitrate content was determined through the Griess reagent method [20]. Starch content was analyzed using the enzymatic colorimetric method [21].

Region Selection: Gavar, Martuni, and Vardenis communities were selected based on population size, agricultural engagement, the geography of the 28 rivers and streams flowing into Lake Sevan.

Crop Selection and Fertilization: Crop selection for each farm on climatic conditions, ensuring employment for farm workers and improving socio-economic conditions through high-quality harvests. Fertilization for potatoes, cabbage, brussels sprouts, cauliflower, broccoli, etc. was organized based on nutritional needs. Farmers received ¼ on the recommended amount of biohumus, zeolite, and bentonite the organic mix (2 t of Organomix, 400kg of biohumus, 375 kg each of zeolite, bentonite, and approximately 5 L of bioliquid. These were applied during primary soil cultivation, while the bioliquid was used for foliar feeding.

Methodological Approaches: Stakeholder participation in agriculture research and piloting is also crucial in determining the level of sustainability [22].

Field Trials: Field trials are conducted on farmers' fields and involve experimental plot design, data collection, and analysis to assess the performance of new crop varieties, fertilizers, and other agricultural inputs [23].

RESULTS AND DISCUSSION

The results and detailed analyses for the 2023-2024 period are organized by farm (see Tables 1, 2, 3, and 4). Each table presents the harvest quantities, expenses incurred, gross income, and net profit per dram spent for crops cultivated using traditional methods, compared to those utilizing new agro-technology.

At Vanik Gevorgyan's farm in the Sarukhan administrative area of Gavar, seven crops were grown: potatoes, green peas, green beans, broccoli, lettuce, garlic, and various leafy vegetables (see Table 1). The yields per hectare were as follows: potatoes—500 centners, green peas—32.0 centners, broccoli—400 centners, green beans—100 centners, garlic—140 centners, lettuce—120 centners, and leafy vegetables—100 centners. For 0.25-hectare area, the net income was 4.39 AMD per AMD spent, compared to 3.96 AMD per AMD spent using traditional methods. Additionally, fields cultivated with the new agro-technology required two fewer irrigation cycles, averaging 1,500 m³ per hectare, highlighting its advantages.

During 2021-2022, the new agro-technology was implemented on 22.5 hectares of potato and cabbage fields for 223 farmers. Compared to traditional methods using equivalent mineral fertilizers, potato and cabbage yields increased by 1.5 to 2.0 times, while nitrate content in the final harvest decreased by 50%. Studies demonstrate that optimized agricultural practices, such as precision nitrogen dosing and plant density management, significantly increase potato yields compared to traditional methods. For instance, close plant spacing, and nitrogen optimization led to higher tuber yields due to increased foliage cover and photosynthetic efficiency, reflecting a general trend that innovative agro-technologies can boost crop yields by enhancing plant nutrient uptake and growth conditions [25].

T nitrate content in the final harvest decreased by 50%, aligning with findings that biofertilizers like Biohumus and Biosok reduce nitrate levels in crops while maintaining high yields. These biofertilizers improve soil health and nutrient cycling [26].

Under irrigated agricultural conditions, this technology enabled farmers to save 1,300 m³/ha of irrigation water in potato fields and 1,900-2,000 m³/ha in cabbage fields, compared to traditional cultivation methods. The soils on these farms are primarily riverbed alluvial soils, characterized by a humus content of 4.02-4.28%, a pH range of 6.9-7.1, and low levels of easily hydrolysable nitrogen (4.8 mg per 100 g of soil). Available phosphorus is moderate (8.2-8.9 mg per 100 g of soil), while exchangeable potassium levels are adequate (34-37 mg per 100 g of soil).

Research on irrigation management in potato cultivation supports these findings. Deficit irrigation (10-30% water reduction) improves water-use efficiency without compromising yields. Studies, such as Shrestha et al. (2023) [27], indicate optimized irrigation strategies save 1,300-2,000 m³/ha water, meanwhile maintaining soil quality and crop yields. Soil properties (humus content, pH balance, and nutrient levels) play a critical role in promoting healthy crop growth under water-efficient management practices.

Further analysis of the yield, labor, and expenses associated with the new agro-technology provides insights into three additional farms. In Vardenik administrative area, farmer Artush Khachatryan cultivated five crops on a 0.25-ha plot using the new agro-technology, achieving the following yields: potatoes—425.0 centners/ha, broccoli—225.0 centners, kohlrabi—300 centners, green beans—80.0 centners, and strawberries—33.3 centners. Despite a 6-7-day delay in the initial irrigation due to late repairs, resulting in a 20-25% reduction in yield compared to other farms. Khachatryan realized an average profit of 3.2 AMD per AMD spent, compared to 3.0 AMD per AMD spent by farmers using traditional methods under similar conditions (see Table 2). Notably, Khachatryan successfully introduced asparagus, demonstrating high adaptability to local soil and climate, with plans for future expansion of asparagus cultivation.

In the Artsvanist administrative area, farmer Arayik Gharibyan cultivated six crops using the new agro-technology, achieving the following yields: potatoes—440.0 centners/ha, green beans—86.0 centners, broccoli—560.0 centners, table beets—490.0 centners, garlic—200.0 centners, and leafy vegetables—110.0 centners (see Table 3). Gharibyan's implementation yielded: 4.3 AMD profit per AMD spent on fertilizers, soil improvers (zeolite and bentonite), bio-liquid growth promoters, seeds, planting materials, seedlings, and irrigation water. Compared to 3.1 AMD of profit per AMD spent using traditional methods.

Hayk Grigoryan's farm in **Tsvoak**, Vardenis community exemplifies efficient small-scale multi-crop farming with automated drip irrigation. This resulted in higher yields and net income compared to three Sarukhan, Vardenik, and Artsvanist smallholder farms. According to Table 4, the yields at Hayk Grigoryan's farm were as follows: potatoes—500.0 centners/ha, cabbage—800.0 centers, broccoli—600.0 centners (from three harvests), and cauliflower—700.0 centners per hectare. The farm earned a gross profit of 2,657,00 AMD from the o.25-hectare plot. For every AMD spent on inputs, including sowing, planting, fertilizing, irrigation, seeds, seedlings, and soil improvers, the farm achieved a net profit 3.9 AMD—0.8 AMD higher than traditional cultivation methods.

Table 5 summarizes the results from the four small-scale multi-crops demonstrating that 0.25-hectare operations utilizing the new cultivation technology are both economically and ecologically efficient. These examples illustrate the viability of this approach under similar conditions in the Gegharkunik region and beyond.

Laboratory studies compared crop quality from multi-crop technology and traditional cultivation methods (Table 6). Two-year research results indicate that crops grown using innovative technology, featuring organic fertilizers (organomix, biohumus), bioliquid stimulants, and natural minerals (zeolite, bentonite), exhibited higher levels of dry matter, starch, vitamin C, and sugars compared to those cultivated with traditional mineral fertilizers. Furthermore, green beans and peas grown with the new technology showed higher crude protein and fat content than those grown using traditional methods [28].

Table 1. Comparative Assessment of Yield, Costs, and Income of Crops Cultivated by Farmer Vanik Gevorgyan in the Sarukhan Administrative Area: New Agro-Technology vs. Traditional Methods (Average 2023-2024)

No	Crop name	Cultivation via new agro-technology				The resulting product average price, AMD	Cultivated in traditional way			A comparative assessment of cultivation with new agro-technology versus traditional				
		Actual area, m2	Actual yield, centner*	Total expenses incurred (water, sowing, tillage)	Actual received gross income, thousand AMD**		Actual yield, centner	Total expenses incurred in thous. AMD	Gross income thous. AMD	The additional crop, centner	Additional cost		Additional income	
											thous. AMD	%	thous. AMD	%
1	Potato	1000	50.0	249.6	650	130	23.0	163.0	299.0	27.0	86.6	34.8	351.0	54.0
2	Green peas	200	0.64	29.0	25.0	400	0.45	20.0	18.0	0.19	9.0	31.0	7.0	28.0
3	Broccoli	800	32.0	205.0	1440	450	22.5	186.0	1012.5	9.5	19.0	9.3	327.5	22.7
4	Green beans	100	2.0	30.0	50.0	250	1.2	20.0	3.0	0.8	10.0	33.3	20.0	40.0
5	Salad (lettuce)	150	1.2	20.0	84.0	700	1.0	16.0	70.0	0.2	4.0	20.0	14.0	16.7
6	Garlic	50	2.1	32.0	210.0	1000	1.6	24.0	160.0	0.5	8.0	25.0	50.0	23.8
7	Leaf vegetables	2500	0.5	6,0	50.0	1000	0.5	5.0	50.0	-	1.0	16.7	-	-
	Total			571.6	2509.0			434.0	1639.5		137.6	24.1	769.5	30.7

*Centner- 1 centner= 100kg; **AMD- Armenian Dram (local currency, 1 US$= 390 AMD, September

Table 2. Comparative Yield, Costs, and Income of Crops Cultivated Using New Agro-Technology vs. Traditional Methods by Farmer Artush Khachatryan in Vardenik (2023-2024), highlighting higher yields and improved efficiency with the new technology

N	Crop name	Cultivation via a new agro-technology				The resulting product average price, AMD**	Cultivated in traditional way			A comparative assessment of cultivation with new agro-technology versus traditional				
		Actual area, m2	Actual area, m2	Actual yield, centner*	Actual yield, centner		Actual yield, centner	Total expenses incurred in thous.. AMD	Gross income, thous. AMD	The additional crop, centner	Additional cost		Additional income	
											Thous AMD	%	thous. AMD	%
1	Potato	1050	45.0	252.0	585.0	130.0	26.7	165.0	347.1	18.3	87.0	34.5	237.9	40.7
2	Broccoli	800	18.0	205.0	900.0	500.0	12.4	192.0	620.0	5.6	13.0	6.4	280	31.1
3	Kohlrabi	100	3.0	20.0	150.0	500.0	2.0	16.0	100.0	1.0	4.0	20.0	50.0	33.3
4	Strawberry	300	1.0	56.0	100.0	1000.0	0.7	46.0	70.0	0.3	10.0	17.9	30.0	30.0
5	Green beans	250	2.0	37.5	60.0	300.0	1.2	30.0	36.0	0.8	7.5	20.0	25.0	40.0
	Total	2500		570.5	1795.0			449	1173.0		121.5	19.8	621.0	34.6

*Centner- 1 centner=100kg; **AMD- Armenian Dram (local currency, 1 US$= 390 AMD, September 2024)

Table 3. Comparison of Yields, Costs, and Income: New Agro-Technology vs. Traditional Methods by Farmer Arayik Gharibyan in Artsvanist (2023-2024).

	Name of crops	Cultivated technologically					Cultivated in traditional way			A comparative assessment of cultivation with new agro-technology versus traditional				
		Actual area, m2	Actual area, m2	Actual yield, centner*	Actual yield, centner	The resulting product average price,	Actual yield, center	Total expenses incurred in thous. AMD	Gross income thous. AMD	The additional crop, centner	Additional cost		Additional income	
											Thous AMD	%	Thous AMD	%
1	Potato	1000	44.0	249.6	572.0	130.0	21.9	174.0	284.7	22.1	75.6	30.3	287.3	50.2
2	Green peas	600	5.2	88.0	202.8	390.0	4.0	78.0	156.0	1.2	10.0	11.4	46.8	23.1
3	Table beets	500	24.5	85.0	367.5	150.0	20.0	65.0	300.0	4.5	20.0	23.5	67.5	18.4
4	Broccoli	300	16.8	64.0	873.6	520.0	10.5	60.0	546.0	6.3	4.0	6.3	327.6	37.5
5	Garlic	50	1.0	20.5	100.0	1000	0.8	19.9	80.0	0.2	0.6	2.9	20.0	20.0
6	Leafy vegetables	50	0.55	7.5	55.0	1000	0.4	6.9	40.0	0.15	0.6	8.0	15.0	27.3
	Total	2500		504.6	2170.9			403.8	1406.7		110.8	22.0	729.4	33.6

*Centner- 1 centner=100kg; **AMD- Armenian Dram (local currency, 1 US$= 390 AMD, September 2024)

Table 4. Comparative assessment of yield, costs, and income for crops grown using new agro-technology by Hayk Grigoryan in the Tsovak area vs. traditional methods (2023-2024 average).

No	Crop name	Cultivated technologically				Cultivated with technology	Cultivated in traditional way			A comparative assessment of cultivation with new agro-technology versus traditional				
		Actual area, m2	Actual area, m2	Actual yield, centner*	Actual yield, centner		Actual yield, centner	Total expenses incurred in thous. AMD**	Gross in-come, thous AMD	The additional crop, centner	Additional cost		Additional income	
											Thous AMD	%	Thous AMD	%
1	Potato	1000	50,0	250.0	650.0	130.0	25.0	148,0	325.0	25.0	102.0/40.8	325.0	50.0	And 40.18% compared to the income received by technology
2	Green bean	300	4.5	43.0	135.0	300.0	2.3	29,0	69.0	2.2	14.0/32.6	66.0	48.9	
3	Cabbage	200	16.0	159.6	240.0	150.0	9.1	152,0	136.5	6.9	7.6/4.8	103.5	43.1	
4	Broccoli	400	24.0	103.0	840.0	350.0	12.8	98,0	448.0	11.2	5.0/4.9	392.0	46.7	
5	Garlic	100	0.5	21.0	50.0	1000.0	0.7	19,0	70.0	-0.2	2.0/9.5	-0.2	-2.0	
6	Cauliflower	400	28.0	87.0	700.0	250.0	20.4	78,0	510.0	7.6	9.0/10.4	190.0	27.1	
7	Strawberry	60	0.1	9.0	10.0	1000.0	0.15	8,2	15.0	-0.05	0.8/0.1	-0.05	-5.0	
8	Leafy vegetables	40	0.4	6.5	32.0	800.0	0.2	6,5	16.0	0.2	-/-	16.0	50.0	
	Total	2500		679.1	2657.0			538.7	1589.5		140.4/26.1	1067.5	32.35	

Table 5. Results of the comparative analysis of multi-crop cultivations in 4 different model farms with the 0.25 ha each

No	Crop name	Area, m2	The # of cultivated crops	The factual yield from all cultivated crops, centner*	Expenses incurred, thousand. AMD			Total costs, including plough water, in the actual area, thous. AMD**	Gross in-come, thous. AMD	The average self-cost of one crop unit (kg), AMD	Income against spent 1 AMD	Yields and costs in traditional ways				Average selling price, AMD
					Fertilizers, growth stimulator	Zeo-lite, bentonite	Seed, planting material					Yield, centner	Total expendit ures AMD	Actual received gross income, thous AMD	In-come against spent 1 AMD	
1	Hayk Grigoryan, Tsovak	2500	8	123.5	129.5	45.4	178.6	679.1	2657.0	177.0	3.9	65.7	515.8	1600.8	3.1	497.5
2	Arayik Gharibyan, Artsvanist	2500	6	92.05	129.2	45.3	145.4	514.6	2170.9	90.2	4.2	54.9	420.0	1303.0	3.1	541.7
3	Artush Khachatryan, Vardenik	2500	5	69.0	128.1	45.2	182.5	570.5	1795.0	148.0	3.2	49.8	498.0	1491.0	3.0	486.0
4	Vanik Gevorgyan, Sarukhan	2500	7	88.4	129.0	45.1	173.0	671.6	2509.0	140.7	4.4	60.5	465.8	1844.6	3.9	568.6

*Centner- 1 centner=100kg; **AMD- Armenian Dram (local currency, 1 US$= 390 AMD, September 2024)

Table 6. The quality characteristics of the crops obtained by the farmers with the multi-crop technology and the traditional method of cultivation were subjected to laboratory studies.

No	Crop name	Nitrate's MAC, mg/kg	Cultivation by innovative technology							Cultivation by traditional cultivation						
			Nitrate mg/kg	Dry matter, %	Starch, %	Vita-min C, mg%	Raw protein %	Total sugar %	Fat, %	Nitrates, mg/kg	Dry matter %	Starch, %	Vitamin, C, mg%	Raw protein %	Total sugar %	Fat, %
1	Potato	250	80-90	23.2	19.0	10.6	Non deter.	8.4	N/A	190-200	21.0	16.0	8.9	N/A	7.0	N/A
2	Head(ordinary) cabbage	1200	500-600	19.6	N/A	12.4	N/A	6.2	N/A	950-1000	18.4	N/A	10,0	N/A	5.2	N/A
3	Broccoli	1000	350	20.4	N/A	11.5	N/A	7.4	N/A	800	20.0	N/A	10,4	N/A	7.0	N/A
4	Table beet	300	115-120	19.8	8.0	9.4	N/A	12.0	N/A	200	18.0	6.8	7.0	N/A	11.0	N/A
5	Grean been	200	90-100	21.0	N/A	N/A	24.2	9.0	36.4	140	20.2	N/A	N/A	20.1	6.9	35.7
6	Grean peas	200	80-90	18.0	N/A	N/A	18.6	10.2	30.0	120	19.0	N/A	N/A	16.9	9.8	31.0
7	Leafy vegetables	500	300	19.4	N/A	13.8	16.0	8.4	N/A	450	18.2	N/A	14.0	14.0	8.4	N/A

The studies further revealed that nitrate content in crops grown with traditional mineral fertilizers often approached or exceeded the maximum allowable concentrations (MAC). This trend is attributed to reduced mineral fertilizer usage, particularly nitrogen-based ones, driven by rising costs due to global challenges like the Ukraine war, which impacted imports. In contrast, crops cultivated with the proposed technology organic fertilizer technology demonstrated nitrate levels 40-50% below the MAC (Figures 1 and 2).

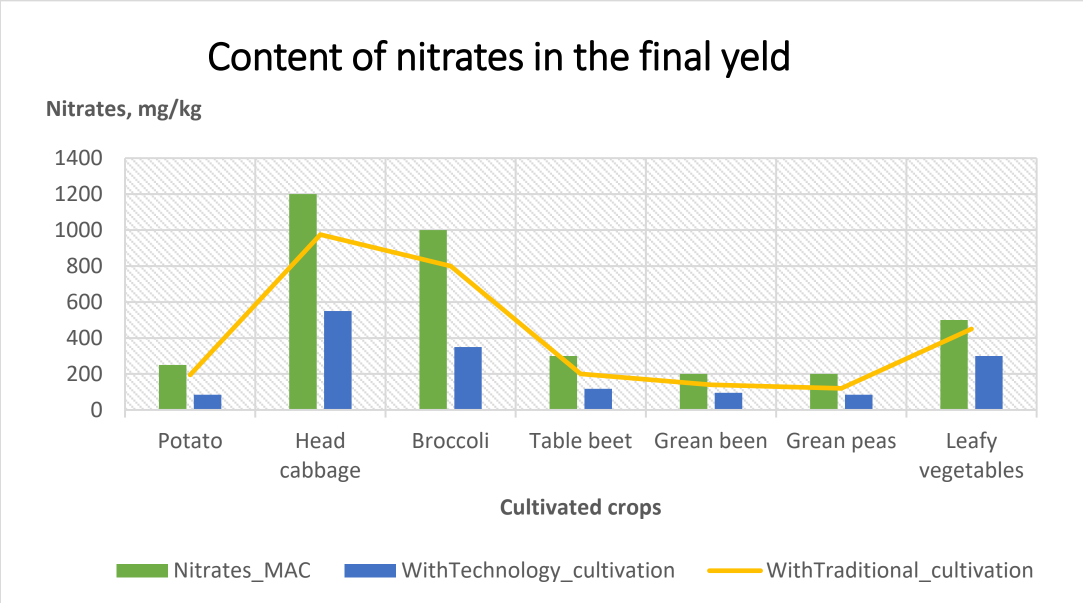


Figure 1. The content of nitrates in the yield with technology and traditional cultivation, against the MAC (mg/kg) in different crops

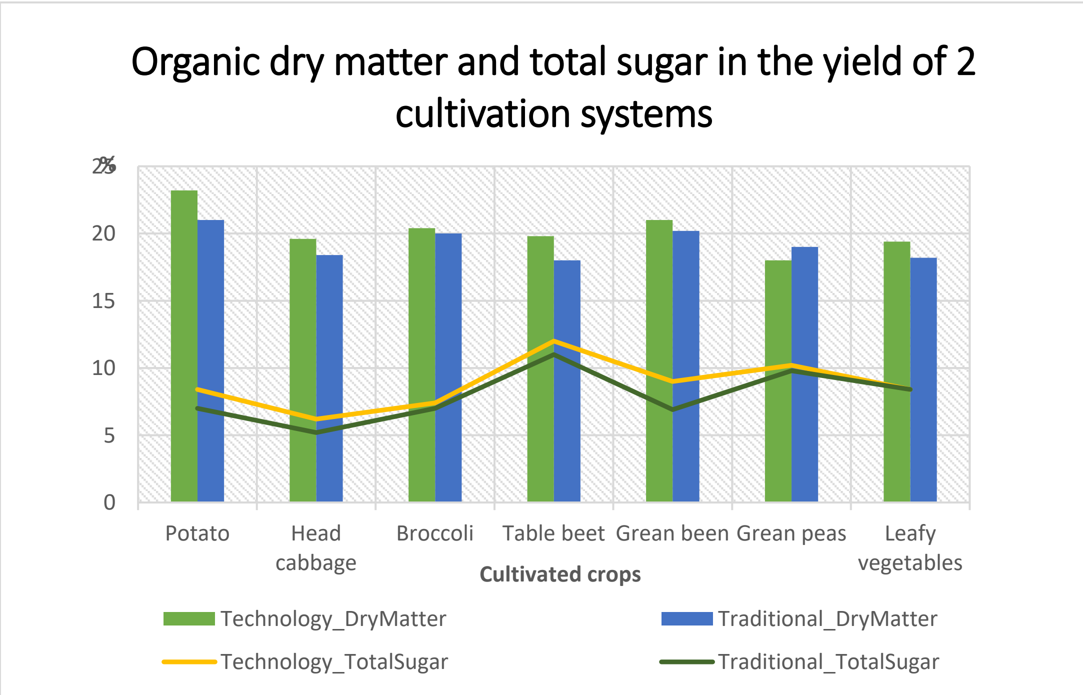


Figure 2. The content of organic dry matter and total sugar in the yield of 2 cultivation systems- with the proposed technology and in tradition ways (values in %)

The implementation of new agrotechnologies in small-scale farming has demonstrated significant benefits, including improved crop yield and quality, and reduced nitrate levels, which are critical for consumer health. Research highlights precision agriculture, automated irrigation, and advanced tools (UAVs, IoT) enable better resource management and crop diversification. Enhancing sustainability and productivity in smallholder systems contributes to food security and profitability [29].

Organic fertilizers and soil improvers benefit the environment by reducing chemical runoff and promotes sustainable agricultural practices [30]. Introducing crops like asparagus showcases adaptability and potential for diversifying production to meet market demands. This diversification can provide additional income streams for farmers and reduce the risk of crop failure [31].

CONCLUSION

The agro-technological innovations in model multi-crop farms around Lake Sevan have yielded remarkable outcomes: enhanced crop yields, economic returns, and water conservation. These new methods more than doubled the yields of region-specific crops such as potatoes, cabbage, and broccoli. Economic analysis confirmed increased net profits, while substantial water savings contributed to ongoing efforts to restore Lake Sevan's ecological balance. Furthermore, crops cultivated with the updated techniques exhibited lower nitrate levels and superior nutritional quality, aligning with higher agricultural standards compared to traditional practices.

Overall, integrating innovative agro-technologies into small-scale farming can contribute significantly to improving the socio-economic conditions of farmers, promoting environmental sustainability, and enhancing food security in the Lake Sevan basin and potentially beyond.

Recommendation: Based on two years of successful operation across four small-scale multi-crop farms, this model should be widely adopted. It has proven to be economically viable, increasing employment opportunities and contributing to socio-economic improvements in Gegharkunik Marz and similar regions.

Competing interest: There are no conflicts of interest to declare.

Author contribution: MG, AM, HS and IH designed the study, implemented field trials and wrote the manuscript, AS, NS, HM and VA monitored the field trials, performed analyses and revised the manuscript. All authors have read and approved the final manuscript.

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