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Assessing the sustainability of agricultural growth in Azerbaijan from an ecological perspective

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Abstract

Agricultural production in Azerbaijan has expanded rapidly over recent decades, raising concerns about the long-term sustainability of soil and water resources. This study aims to evaluate the sustainability of Azerbaijan's current agricultural growth model from a ecological perspective. The analysis focuses on national-level agricultural production systems during the period 1995-2024. Secondary data from FAO, the State Statistical Committee of Azerbaijan and international databases were analyzed using descriptive and comparative statistical methods to assess trends in land use, irrigation, nutrient balances, agrochemical inputs and climate-related indicators. The results show that agricultural output increased more than ninefold since 2000, while over 36% of agricultural soils are affected by erosion and salinization, nitrogen removals exceed 380 kg ha, irrigation accounts for about 34.5% of renewable freshwater withdrawals, and agriculture contributes more than 53% to national water stress. At the same time, nitrous oxide emissions from crop production have more than doubled and methane emissions from livestock increased by about 70%, indicating rising climate pressure. These findings suggest that current growth is driven mainly by land expansion and input intensification rather than ecological efficiency. The study recommends promoting water-saving irrigation technologies, balanced nutrient management, soil conservation practices and climate-smart agriculture to improve environmental quality and long-term sustainability.

Keywords*: ecological sustainability; agriculture; soil resources; water use; Azerbaijan*

Introduction

In recent times, agricultural expansion and intensification have emerged as significant contributors to environmental pressure on soil and water resources globally. Higher dependence on irrigation, mineral fertilizers, and agrochemicals has helped increase agricultural productivity, but at the same time, it has also contributed to faster rates of soil degradation, nutrient imbalance, water contamination, and greenhouse gas emissions (Andrade et al., 2022; Biswas et al., 2014; Sharma et al., 2024). Soil is considered one of the fundamental and non-renewable resources for agricultural activities, and its degradation is seen to limit ecosystem services such as nutrient cycles, water retention, and biological activity.(Angeli Minaya Loconi et al., 2025) Soil erosion, salinization, loss of organic matter, and nutrient mining are seen to reduce soil fertility, while excessive fertilizer and pesticide application is likely to affect soil biota and pollute surface and groundwater resources. Moreover, inefficient irrigation practices are likely to increase water stress and promote secondary salinization, thereby exacerbating land degradation. Climate change is a multiplicative stress factor that can worsen these problems. Changes in temperature, precipitation, and increased occurrences of extreme weather conditions can impact crop growth, irrigation, and nutrient balance (Ortega Montoya and Tejeda González, 2022). Simultaneously, agricultural practices are known to be major contributors to methane (CH_4) and nitrous oxide (N_2O) emissions. The interrelationship between agricultural intensification and climate change can create feedbacks that enhance soil-water system vulnerability. In Azerbaijan, agriculture plays an important role in food security and rural development, and agri-

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cultural output has grown substantially over the last decades.(Nesirov et al., 2024) However, the degree to which this growth is sustainable in terms of soil and water resources has not been sufficiently explored. The existing research has been concentrated mainly on the economic performance and output of agriculture, while research on the bio-ecological aspects of soil, water, and climate pressures is lacking. The main purpose of the current research is to assess the sustainability of the existing agricultural growth pattern in Azerbaijan from a bio-ecological perspective, focusing on the long-term dynamics of land use, irrigation dependency, nutrient balances of the soil, agrochemicals, and climate-related variables. It is expected that the research will provide scientific support for the development of environmentally friendly agricultural practices.

Materials and Methods

This research is based on secondary data available from various national and international official statistics. Secondary data on agricultural production data, data on agricultural land use, agricultural mechanization, input use data, environmental data, ecological indicators on soil resources, water use data, nutrient balance data, data on application of various agrochemicals, climate data, as well as additional data from the World Bank database regarding macroeconomic indicators for the selected countries, are available from the Food and Agriculture Organization of the United Nations (FAO) official statistics portal as well as from the official portal of the World Statistical Committee of the Republic of Azerbaijan. The period of analysis extends from 1995 to 2024 Azerbaijan's agricultural development is in its post-transition period. It will be possible to analyze trends in structures and in bio-ecology during this time. Descriptive statistical analysis was applied to examine temporal trends in agricultural production, land use, irrigation, fertilizer and pesticide application, and climate-related indicators. Comparative analysis was used to identify structural changes over time and to relate agricultural growth patterns to corresponding ecological pressures. The study does not aim to establish causal relationships but rather to assess sustainability implications by linking observed production growth trends with environmental pressure indicators. This approach is consistent with macro-level sustainnability assessments, where long-term statistical evidence is used to identify potential risks to soil and water resources and to evaluate the compatibility of current development trajectories with ecological sustainability principles. The analysis may be subject to some limitations: the data may be based on national aggregation that does not allow for regional differences in the quality of soils, water availability, as well as farming practices. Secondly, the findings were based on indirect estimations; that is, direct data on the quality of soils or water were not measured directly. The analysis, however, allows us to use data based on reliable sources; this will be useful in establishing trends in national-scale evaluation in terms of ecological sustainability.

Results and Discussion

Agricultural growth and pressure on soil resources

The course of agricultural development in Azerbaijan is characterized as follows: during the last three decades, Azerbaijan experienced rapid development in this sphere. The statistical data show that during the period ranging from 2000 to 2024, there was a growing trend in the development of this sector: its output increased 9.4 times in terms of physical output, with its share of GDP diminishing by 10.5%. Crop cultivation, mainly crops like cereals, legumes, and beetroot/sugar beet crops, has seen exponential growth. For example, in 1995, cereal and legume crops were harvested from 921.4 thousand tons, but by 2024, the yield had grown to 3278.1 thousand tons, a 3.6 times increase. Also, beetroot/sugar beet crops registered a nearly 8.7 times increase. Similar increases are seen in crops like sunflower with a 43 times increase potatoes with a 6 times increase, and melons/gourds with an 11.7 times increase. The increasing rate of land occupancy has a strong chance of affecting soil resources and consequently increasing land erosion.

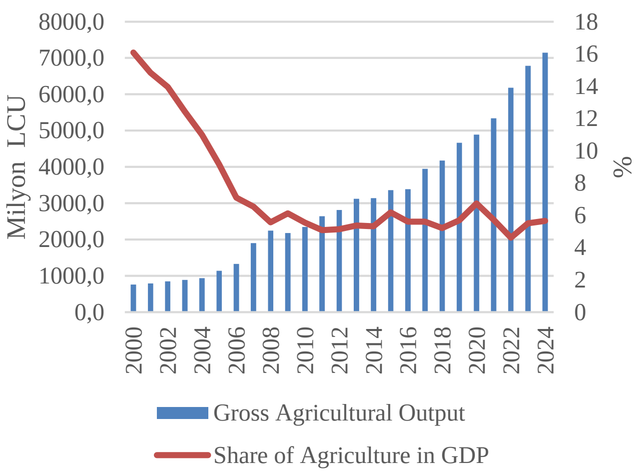

Figure 1. *Actual agricultural production volume in Azerbaijan Source: Compiled by the author based on World Bank data.*

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Table 1. *Production volume of crop products in Azerbaijan (thousand tons***)**

Crop products	1995	2000	2005	2010	2015	2020	2024
Cereals and pulses	921.4	1540.2	2126.7	2000.5	2999.4	3257.1	3278.1
Cotton	274.1	91.5	196.6	38.2	35.2	336.8	310.8
Tobacco	11.7	17.3	7.1	3.2	3.5	6.9	6.5
Sugar beet	28.1	46.7	36.6	251.9	184.3	233.8	244.2
Sunflower for seed	0.7	3.7	16.1	15.5	18.4	23.9	30.2
Potatoes	155-5	469.0	1083.1	953.7	839.8	1037.6	927.4
Vegetables	424.1	780.8	1127.3	1189.5	1275.3	1738.9	1838.9
Melons and gourds (və ya Garden crops)	41.9	261.0	363.8	433.6	484.5	448.1	490.6
Grapes	308.7	76.9	79.7	129.5	157.1	208.0	308.7

Source: Compiled based on data from the State Statistical Committee of the Republic of Azerbaijan.

Livestock production has increased in the same manner. Meat production (in live weight) has risen from 184.3 thousand tons in 1995 to 659.0 thousand tons in 2024, while egg production has multiplied five-fold (Table 2). These advances in livestock production add more pressure to the pasture and fodder areas because permanent areas of meadow and pasture lands were 2453.3 thousand ha in 1995 but fell to 2414.4 thousand ha in 2023 (Table 4). Decrease in grazing areas can contribute to increased risk of soil deterioration by over-grazing the lands. Mechanization has also led to increased pressure on agricultural activities. This is evident from the fact that, over the past three decades, the number of tractors increased from 33,174 units in the year 1995 to 40,771 units in the year 2024. Similarly, the number of plows, cultivators, and seeders has increased 2 to 4 times over the period from 2010 to 2024.

Table 2. *Production volume of livestock products in Azerbaijan*

No	Product	Unit of measurement	1995	2000	2005	2010	2015	2020	2024
1	Meat (live weight)	thousand tons	184.3	258.9	335.0	425.9	515.6	591.1	659.0
2	Meat (slaughtered weight)	thousand tons	109.4	153.6	198.0	244.9	298.6	346.0	386.3
3	Milk	thousand tons	826.5	1031.1	1251.8	1535.8	1924.5	2192.5	2298.5
4	Eggs	million units	455.8	542.6	874.6	1178.6	1552.9	1906.2	2300.8
5	Wool (physical weight)	thousand tons	9.0	10.9	13.1	15.6	17.0	16.1	14.8
6	Cocoon	tons	1100.0	66.6	78.0	6.0	0.2	446.6	239.4

Source: Compiled based on data from the State Statistical Committee of the Republic of Azerbaijan.

Table 3. *Status of the machine and tractor park in Azerbaijan (in units)*

Machinery	1995	1999	2005	2010	2015	2020	2024
Tractors	33174	29500	14887	21258	12262	34954	40771
Ploughs	8770	6477	3019	3344	570	4519	6212
Cultivators	4512	4180	1009	939	49	1277	1751
Grain and seed drills	6702	4897	1412	1844	185	3233	4322
Mowers	2088	1296	1056	873	90	1312	1798
Balers	3269	1984	903	1501	476	1512	2135
Combines	8240	6183	1502	2594	1063	4245	3874
Machines	5955	1098	362	765	111	1717	3086

Source: Compiled based on data from the State Statistical Committee of the Republic of Azerbaijan

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Table 4. *Indicators for the sustainable use of land resources in Azerbaijan (thousand ha.).* Source: Compiled based on FAO data.

Indicator	1995	2000	2005	2010	2015	2020	2021	2022	2023
Total land area of the country	8660.0	8660.0	8660.0	8660.0	8660.0	8660.0	8660.0	8660.0	8660.0
Agricultural land	4489.1	4740.4	4758.6	4766.8	4769.8	4780.1	4780.6	4780.5	4779.6
Arable land	1726.3	1825.6	1843.2	1884.1	1937.7	2084.3	2089	2091.9	2091.7
Cropland (Sown area)	2035.8	2062.4	2064.7	2111.5	2174.7	2357	2363	2365.5	2365.1
Permanent meadows and pastures	2453.3	2678	2693.9	2655.3	2595.1	2423	2417.5	2415	2414.4
Land area equipped for irrigation	1444	1430	1433	1425	1434.5	1480.2	1484.9	1484.9	1485
Actually irrigated agricultural area	-	-	1430	1405.1	1431	1464.9	1469.3	1469.3	1464
Actually irrigated cropland	-	-	1378	1357.8	1374.2	1421.8	1425.9	1425.9	1420.6
Actually irrigated permanent meadows and pastures	-	-	52	47.3	44.3	43.1	43.4	43.4	43.4
Certified organic agricultural area	-	-	-	18.1	20.32	20.77	20.77	20.77	114.03
Certified organic arable land	-	-	-	1.7	-	-	-	-	-
Certified organic permanent meadows and pastures	-	-	-	16.4	-	-	-	-	-
Area under organic farming	-	-	20.3	21.51	37.63	38.08	38.08	38.08	114.83

Irrigation practices and management remain essential in sustaining ecological practices. The total area equipped for irrigation has remained stagnant, while irrigated lands do not cover all arable lands (Table 4), hence indicating inefficient utilization of water resources, leading to salinization of soils through erosion caused by climate variations. (Fikrətzadə & Əliyev, 2022). Nutrient management also faces challenges. When analyzing nutrients, N, P, and K, imbalances show an increase in nutrient extraction compared to those input, mainly because of increased farming (Table 5). Extraction of N has doubled from 1995 to 2023, however, fertilizers containing minerals vary in amount. The same applies to P and K, in which a significant amount of nutrients is removed from the soil through harvested crops. These imbalances might affect soil fertility and sustainability. (Andrade et al., 2022; Biswas et al., 2014). In addition to this, chemical inputs such as mineral fertilizers and pesticides increase the level of ecological pressure. In the case of fertilizers, their use was at its greatest in 2020 at 152 thousand tons. This was accounted for by the increased intensification of use in cereal crops, vegetables, cotton, and fodder crops (Table 6). In the area of pest management strategies, intensification has also increased from 2010 to the present day. There was a tripling in the use of fungicides, insecticides, and herbicides (Table 7). However, the longterm bio-eco risks include negative impacts on the microbiological condition of the soil and water.(Çeker, 2016). The fertilizer trends described in Table 6 indicate a trend towards more input-intense agricultural practices after 2010, with significant temporal and crop-specific fluctuations. This may indicate limited implementation of balanced, site-specific nutrient management practices, which could lead to increased risks of nutrient loss, soil degradation, and water pollution. The input-intense fertilizer practices are often linked with increased pest and disease pressure, which may lead to increased pesticide use. Therefore, the fertilizer and pesticide trends should be considered as part of the same process. In this regard, the pesticide trends described in Table 7 may be considered as additional information on the ecological implications of the current agricultural practices.

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Table 5. *Dynamics of the nutrient balance indicator in Azerbaijan.* Source: Compiled based on FAO data.

Indicator	1995	2000	2005	2010	2015	2020	2023
Nitrogen per unit area of arable land (kg/ha)							
Atmospheric deposition	42.373	49.358	51.998	55.814	54.606	56.737	58.339
Biological fixation	0.4837	0.4297	0.5726	0.587	0.5987	0.5632	0.5043
Removal by harvest	185.929	200.626	301.013	237.678	313.188	393.428	380.341
Removal of crop residues	73.006	97.983	119.226	94.705	135.776	156.287	158.734
Leaching	2.726	11.859	2.087	18.995	54.527	48.385	37.564
Applied manure	52.797	54.202	6.179	64.638	66.328	55.907	51.524
Mineral fertilizers	167.011	10.182	80.339	69.647	28.747	40.791	29.274
Seeds	13.018	18.628	24.409	23.253	fev.23	2.229	22.131
Volatilization (Evaporation)	65.942	19.315	44.073	37.595	143.684	128.383	97.236
Phosphorus per unit area of arable land (kg/ha)							
Removal by harvest	36.214	39.274	59.771	47.759	62.297	78.523	76.082
Removal of crop residues	14.826	17.666	21.844	16.839	24.761	2.984	30.149
Applied manure	10.248	10.283	11.859	12.879	13.494	11.668	10.875
Mineral fertilizers	18.954	0.4614	0.6787	0.4369	1.938	97.179	46.429
Seeds	0.2477	0.3622	0.4819	0.4546	0.4332	0.4286	0.4238
Potassium per unit area of arable land (kg/ha)							
Removal by harvest	88.457	8.953	143.537	118.209	137.907	187.946	181.981
Removal of crop residues	18.303	251.955	298.419	233.816	33.331	381.193	38.747
Applied manure	5.373	57.478	64.797	66.919	65.311	52.884	48.316
Mineral fertilizers	20.385	0.8049	15.425	12.602	13.915	53.598	36.262
Seeds	0.439	0.7186	11.116	10.686	0.9997	0.9617	0.9222

Table 6. *Volume of mineral fertilizers used in Azerbaijan for the years 1990-2024.* Source: Prepared based on data from the State Statistical Committee of the Republic of Azerbaijan and the agrodata.az statistical portal.

Years	Total, thousand tons	Per hectare of sown area kg	Share of fertilized area in total sown area %	of which:							
				Cereals	Cotton	Tobacco	Potatoes	Vegetables and melons	Forage crops	Orchards	Vineyards
1990	139,3	87	64	92	144	221	131	223	36	70	0
1995	11,4	10	24	10	21	42	150	20	2	1	1
1999	1,3	5	13	5	11	4	0	1	0	0	0
2010	32	18	34	20	25	76	16	37	4	20	15
2015	41	23	58	21	35	72	26	28	9	17	8
2020	152	81	79	88	131	137	87	98	29	73	54
2024	99,7	53	71	60	87	109	78	60	7	63	39

Table 7. *Indicators on pesticide use in the agriculture of Azerbaijan (t.).* Source: Compiled based on FAO data.

Means / Agent	1995	2000	2005	2010	2015	2020	2023
Fungicides and bactericides	95	95	95	159	271	280	280
Herbicides	5	5	5	83	57	59	59
Insecticides	44	44	44	77	159	169	169
Pesticides	149	149	149	334	530	543	543
Rodenticides	5	5	5	15	21	7	7

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A noteworthy progressive change was the significant increase in certified organic farming methods by 2023. While the practice had earlier been minimal, the change should positively impact the conservation of soil fertility, reduction of chemical use, and improvement of biodiversity to increase the overall ecological sustainability of the landscape (Sharma et al., 2024). Thus, in conclusion, as Azerbaijan continually intensifies its agricultural sector, this not only leads to increased economic and food security outcomes but also increases pressure and stress on soil fertility and nutrient cycling systems and its use of water and other resources. Sustainability will thus require optimizing nutrients and soil and irrigation efficiencies as well as increasing organic farming systems to ensure strengthening our soil and its sustainability into the future.

Irrigation dependency and water resource sustainability

The dominant feature of the agricultural sector in Azerbaijan that needs to be tackled is that there exists a considerable level of dependency, as revealed through the use of irrigation against the backdrop of a situation characterized by escalating levels of water stress. Despite the considerable stability of the land that has been put under irrigation, as well as a situation whereby not all of the utilized agricultural land is actually being fully supported by irrigation, there exists a situation whereby there are limited levels of water resources, as well as considerable levels of inefficiency regarding the irrigation infrastructure that already exists. The use of water by the agricultural sector, as revealed through the FAO AQUASTAT indicators, started from 30.4% of total renewable water resources in 1995 but nonetheless exhibited a consistent escalation over the subsequent period, eventually reaching 34.5% by 2021-2022 (table 8). Thus, despite the large proportion of the water usage amount, the efficiency of the irrigation water usage in the agricultural sector is very low and varies between 0.10 $US/m³ and 0.24 $US/m³ over the specific period. This highlights the reality that a large volume of resources is utilized to produce a modest value of output compared to other sectors. At the same time, the proportion of the agricultural sector is constantly increasing its contribution to the total amount of the water stress: from 46.6 % in 1995 to over 53 % in 2022. It is noted that the total amount of the water stress in the country is constantly above 50 %, a clear sign of a traditional sign of high stress conditions. Ineffective irrigation methods have further aggravated the unsustainable developments that effect and influence these processes. Erosion and salinization have developed because of ineffective irrigation methods, including inefficient irrigation water application and outdated and inefficient irrigation water drainage. This particularly affects those regions that have irrigation systems. Estimates have indicated that 36.4% of Azerbaijan's agricultural land is affected and experiencing erosion and salinity, thus becoming less effective and sustainable. However, such is also expected to happen when there is deterioration and devaluation of land due to less efficiency, causing irrigation to rise and further devalue water that is often limited. Overall, the cumulative effect of the combined results strengthens the case that the increase of intensive cultivation in Azerbaijan is strongly related to the increasing dependency on irrigation and the declining sustainability of the country's water resources. As a result of the various impacts discussed here, if there are no substantial developments or innovations pertaining to the efficiency of irrigation techniques or the use of efficient drainage mechanisms for resolving the challenges of water scarcity or other factors like soil degradation, the sustainable development of the entire agricultural ecosystem can still remain an issue for consideration.

Climate change as a multiplying stress factor

Indicators of climate change tend to be instrumental in measuring agricultural sustainability in various ways, especially as they affect agricultural outputs, livestock

Table 8. *Indicators on the use of water resources in Azerbaijan*

Indicator	Unit	1995	2000	2005	2010	2015	2020	2021	2022
Agricultural water withdrawal (as a percentage of total renewable water resources)	%	30.43	28.52	30.12	29.13	30.73	32.32	34.50	34.50
Water-use efficiency in irrigated agriculture	US$/m³	0.10	0.13	0.15	0.20	0.24	0.20	0.17	0.15
Total water-use efficiency	US$/m³	0.49	0.96	1.70	3.96	4.07	3.71	3.75	3.97
Contribution of the agricultural sector to water stress	%	46.60	43.68	46.12	44.60	47.05	49.49	52.82	53.06
Total water stress	%	61.69	48.53	52.11	48.44	51.62	53.89	57.27	57.53

Source: Compiled based on FAO AQUASTAT data.

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production, or energy resources' consumption patterns. On the other hand, it has been clearly ascertained that increases in greenhouse gases are a significant indicator of sustainable agriculture due to their contribution to intensification processes as they affect environmental constraints as well as agriculture in general. Based on the assessments of the FAO, it has been ascertained that Azerbaijan's agricultural processes are subject to fluctuating patterns of GHG emissions in a complex manner. In crop production, fluctuations in methane (CH_4) emissions were seen from 1995 to 2023 (Figure 2). Emissions were seen to increase from 1.02 kt in 1995 to 1.87 kt in 2000. Then, year after year, it started to decrease until 2020, when it increased to 1.57 kt. It was even seen to increase to 1.51 kt in 2023. On the other hand, there was an increased rate in nitrous oxide (N_2O) emissions from crop production (Fig. 2). It increased from 0.98 kt in 1995 to more than 2.6 kt within the period of 2015-2020. By 2023, this increased by more than twice that of the 1990s. Such an increase has been strongly linked to the rise of fertilization rates and alterations in the balance of the soil-water relationship, thus implying that there has been an increased tendency towards climate externalities following productivity-oriented intensification strategies. Keeping in mind the high global warming potential of the observed N2O emissions, the mentioned trends also represent an important risk for the climate protocols as well as the productivity of the soils. A similar trend has also been observed for the livestock population (Fig. 3). Methane emissions related to livestock population growth increased steadily from 1995 and reached nearly 70% by the year 2015. A small decrease was observed from 2015 onwards but main-tained higher levels compared to the 1990s. Enteric fermentation and manure management represent the.overall main emission related to these sectors. A similar trend has also been observed for the overall increase in nitrous oxide emissions related to livestock, although to a lesser extent (Fig. 3). Nitrous oxide emissions related to the livestock population growth increased mainly from the overall processes of manure storage and land applications related to nitrification and denitrifyca--tion.(Gurbuz et al., 2021) It has also been observed that an increase in output levels was not accompanied by a decrease in emission intensity on a per-unit output level for the livestock population, showing a low level of climate efficiency. Temperature changes form another sounding climate stress component. Research into the causes of changes in temperature fluctuations month by month between 1995 and 2024 identified trends in temperature increases. These increases have profound variations during the major development phases. Specifically: in 2024, the rise in temperature in the months of April and June was noted to be as high as 4.5 °C and 3.39 °C, respectively. These raise the heat stress for crops. Temperature increases have observable effects on crops by accelerating the phases in the development cycle. They have profound impacts on evapotranspiration losses. They also have devastating effects on the balance in the moisture content in the soil. They account for some damages due to pests because of the premature tendencies to flower. Overall, these findings indicate that climate change can be considered multipliers for the existing natural pressures on water availability, soils quality, and agricultural intensification-promoting strategies. These combined effects of temperature increase, GHG emissions, and resource-intensive production methods decrease the resilience of agro-ecological systems and thus the sustainnability risk for the agricultural landscape in Azerbaijan in the long term (Fig. 4)..

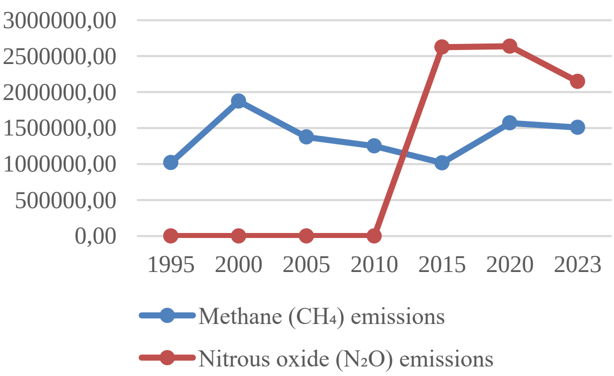

Figure 2. *Greenhouse gas emissions in crop production*
Source: Compiled based on FAO data.

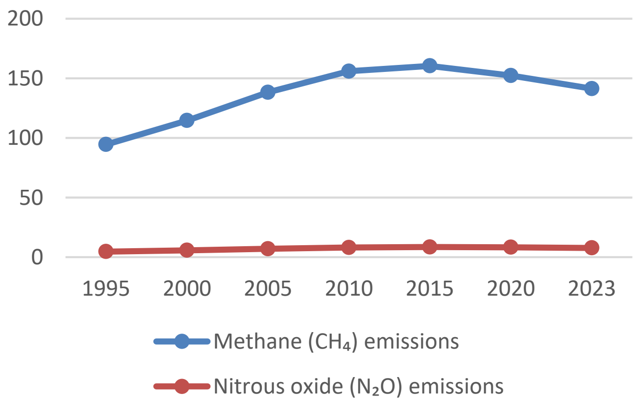

Figure 3. *Greenhouse gas emissions in livestock production*
Source: Compiled based on FAO data.

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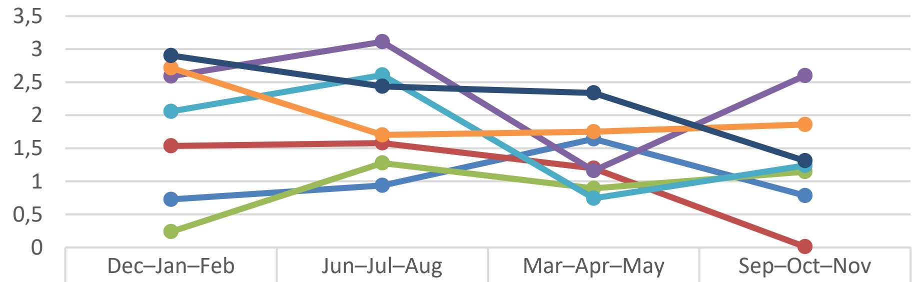

	Dec–Jan–Feb	Jun–Jul–Aug	Mar–Apr–May	Sep–Oct–Nov
1995	0,726	0,937	1,641	0,784
2000	1,535	1,579	1,197	0,01
2005	0,238	1,276	0,893	1,146
2010	2,591	3,111	1,16	2,599
2015	2,057	2,607	0,742	1,239
2020	2,715	1,701	1,749	1,858
2024	2,901	2,436	2,337	1,31

Figure 4
Monthly temperature fluctuations in Azerbaijan
Source: Compiled based on FAO data.

Conclusions

The results indicate that agricultural output has increased by over ten times since 2000, accompanied by a three- to four-fold expansion in major crop and livestock products. However, the improvements have been realized through land expansion and rising irrigation and input use dependence rather than ecological efficiency improvements. The soil-related indicators show that there are significant sustainability constraints, as more than 36% of agricultural soils are impacted by erosion and salinization processes, and nutrient balance analysis shows that the removal of nitrogen, phosphorus, and potassium in the form of harvested biomass and crop residues is increasingly outpacing the input of these nutrients in the form of fertilizers, manure, and biological sources. For nitrogen, crop removals exceeded 380 kg ha^{-1} in 2023, while the input of nitrogen in the form of mineral fertilizers was less than 30 kg ha^{-1}, showing the potential for nutrient mining and a reduction in soil fertility. Water resource indicators also show the structural vulnerability that exists. Currently, agriculture uses approximately 34.5% of total renewable water resources and contributes more than 53% to national water stress; however, irrigation water use efficiency is low (0.10-0.24 US$ m^{-3}). These are characteristics of a highly irrigation-dependent growth pattern with increasing water scarcity. Inefficient irrigation and drainage systems have resulted in secondary soil salinization, which further emphasizes the interlinked degradation of soil and water resources. Climate change plays the role of a multiplying stressor in these processes. Emissions of nitrous oxide from crop cultiva-tion have increased by more than twice their value in the mid-1990s, and methane emissions from livestock have risen by 70% by 2015, which implies that increa-sing crop and animal production have not been accompanied by decreased emission intensity. In addition, temperature anomalies higher than 4 °C in crucial months of the growing season enhance heat stress and evapotranspiration loss, thereby weakening the resilience of agro-ecosystems. Overall, the evidence points to a ecologically constrained pattern of agricultural growth that is not likely to be sustained in the long term. From a policy point of view, the key actions that could be taken include: (i) widespread use of water-saving irrigation technologies and improvement of existing drainage systems; (ii) use of balanced and site-specific nutrient management, including mineral and organic fertilizers; (iii) expansion of soil conservation tillage, crop rotation, and residue retention; (iv) promotion of climate-resilient livestock and crop production systems to mitigate methane and nitrous oxide emissions; and (v) incorporation of ecological indicators into national agricultural planning and policy processes.

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