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RESEARCH ARTICLE

Analysis of Factors Affecting Farmers' Decisions to Get Agricultural Insurance: The Case of Oltu District of Erzurum Province

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ABSTRACT

This study aims to examine the socio-economic factors influencing the decision to purchase agricultural insurance among farmers in the Oltu district of Erzurum Province. Primary data obtained from a total of 150 surveys applied in Oltu district were used in the research. The analysis, based on the probit model, identifies key variables affecting the likelihood of purchasing insurance and explores their relationships. The findings are consistent with previous literature. The results show that an increase in household size raises the likelihood of purchasing insurance, as risk-sharing within families may enhance the need for insurance. Non-agricultural activities reduce the need for insurance, as income from these activities allows farmers to manage risks more easily. The increase in land ownership slightly reduces the demand for insurance, although the effect is weaker. Farmers with larger landholdings tend to have more resources and better risk management, thus reducing their insurance needs. An increase in livestock count significantly raises the likelihood of purchasing insurance. Farmers engaged in livestock farming are more inclined to insure their assets, as livestock represent high-risk assets. Tractor ownership also increases the likelihood of purchasing insurance, although the effect is borderline. Tractor owners generally operate larger farms, thus increasing their insurance needs. The model's validity was confirmed through a Chi-Square test, which rejected the independence hypothesis, showing that the probit model is reliable. The study suggested strategies to increase insurance use, such as supporting small businesses, applying insurance incentives to small farmers, developing livestock insurance policies, and improving access to agricultural machinery.

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1. Introduction

The agricultural sector has an important place in the world economy and is a vital sector for many countries. However, agriculture is a sector that carries great risks, especially due to external factors. These risks include climate change, natural disasters, pests, diseases and market fluctuations. These factors threaten farmers' production processes and income. Therefore, agricultural insurance is a financial security tool that protects farmers against these risks. Agricultural insurance helps farmers maintain production continuity by providing coverage against losses caused by natural disasters or other external factors. However, there are a number of factors that affect the spread of agricultural insurance. Factors such as trust in the insurance sector, economic conditions, government support, farmers' knowledge levels and the quality of service provided by insurance companies can directly affect the decision to purchase insurance.

Agricultural insurance plays a major role in enabling farmers to cope with the adverse situations they encounter. With the development of technology and the diversification of insurance products, agricultural insurance has now become

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accessible to more farmers. However, insurance rates in developing countries such as Türkiye are still low. The reasons for this situation are many. The difficulties farmers experience in covering the costs of insurance policies, insufficient information about the insurance system and lack of trust prevent agricultural insurance from spreading to a wider segment. Agricultural insurance not only covers the losses of the producer, but is also of great importance in terms of ensuring stability in the agricultural sector, supporting rural development and increasing economic security. However, more incentives and awareness-raising efforts are needed for agricultural insurance to become widespread.

The support provided by the state for agricultural insurance plays a major role in making these insurances more widespread. In Türkiye, state-supported insurance systems such as the Agricultural Insurance Pool (TARSİM) encourage farmers to take out insurance. In order to secure the risks threatening the agricultural sector in Türkiye, it was considered to put an insurance mechanism into effect and for this purpose, the "Agricultural Insurance Law" numbered 5363 was enacted on 14/06/2005 and the Agricultural Insurance Pool (TARSİM) was established. Agricultural insurance is a mechanism that provides confidence that the damages will be covered in the event of damage to animals and products within the scope of agriculture (Altınözü, 2007). Crop insurance and animal life insurance applications were initiated as of June 1, 2006. As of 2022, the amount of insurance created through insurance practices in Türkiye will be 296.1 billion liras, approximately 49% of this amount is plant product insurance, 26% is cattle life insurance, 14% is greenhouse insurance, 8% is small cattle life insurance, 2% is poultry life insurance, 1% is beekeeping insurance and 0.27% is aquaculture life insurance. According to the results of the same year, 86% of the 3 million policies made in Türkiye are plant product insurance, 9% is cattle life insurance, 3% is small cattle life insurance, 1% is greenhouse insurance, 0.40% is beekeeping insurance, 0.10% is poultry life insurance and 0.01% is aquaculture life insurance (Tarsim, 2023).

Agricultural insurance is an important tool that protects farmers against the risks they face. However, accessibility of policies alone is not enough for agricultural insurance to become more widespread. Factors such as economic conditions, government incentives, services provided by insurance companies, farmers' trust in the insurance system and their level of knowledge are among the elements that directly affect the decision to purchase insurance. Strengthening these elements will enable agricultural insurance to become more effective and widespread. Agricultural insurance is of critical importance not only for farmers but also for the sustainability of the agricultural sector in general.

In this study, the effects and levels of the factors that are effective in the decision of farmers to have agricultural insurance in Oltu district were tried to be revealed in line with the data obtained from the surveys conducted with the producers in Oltu district of Erzurum province. Political suggestions were made based on the findings obtained.

2. Materials and Methods

The study protocol was approved by the Atatürk University, Faculty of Agriculture Ethical Committee with the decision number 2025/1 in session 2025/12.

2.1. Materials

The main material of the research consists of primary data obtained from face-to-face interviews with farmers who have agricultural insurance and those who do not have agricultural insurance in the neighborhoods of Oltu district of Erzurum province. In addition, secondary data obtained from published articles, reports, postgraduate theses, national and international publications such as the Ministry of Agriculture and Forestry, TARSİM and statistics were also used.

Since the number of businesses that have insurance in Oltu district is 75, all of them were included in the scope of the research. The total number of surveys applied was 150, 75 of which were from those who had agricultural insurance and 75 from those who did not have agricultural insurance, and Microsoft Excel and NLogit programs were used in the transcription and analysis of the survey data.

2.2. Methods

Oltu District in Erzurum Province, which has microclimate features and has higher plant and animal production diversity compared to other districts, was selected as the study area.

The main population of the research consists of all farmers who have and do not have agricultural insurance in the villages of Oltu district of Erzurum province. The number of enterprises to be surveyed was determined as 150 in total, including all enterprises that have agricultural insurance in Oltu district (75) and 75 enterprises that do not have agricultural insurance.

The data obtained in the study were transformed into supporting variables in reaching the points related to the purpose of the study. The socio-economic characteristics of the farmers were presented with means and percentages.

In the study, the chi-square test was used to test whether the difference between the observed frequencies and the expected frequencies was statistically significant in order to reveal the relationship between some socio-economic business characteristics and insurance (Aşkan & Dağdemir, 2015).

In the study, the probit model was used as an econometric model to determine the factors that affect farmers' agricultural insurance. Probit Model; is a model type in which the dependent variable has a qualitative character and the positive result takes the value 1 and the negative result takes the value

0, and the probability of the dependent variable being positive or negative is calculated. NLogit program was used in the implementation of the model.

3. Results and Discussion

3.1. Socio-Economic Characteristics of Enterprises

Demographic characteristics of the producers were examined in terms of marital status and it was determined that 98% of the producers were married. While 57.3% of the producers who had agricultural insurance were between the ages of 36-50, 44% of the producers who did not have agricultural insurance were between the ages of 36-50.

According to the education distribution of the producers, 25.3% of the producers who have agricultural insurance are middle school graduates and 41.3% are high school graduates. 30.7% of the producers who do not have agricultural insurance are middle school graduates and 29.3% are high school graduates. The study titled Investigation of the Perceptions of Cotton Producers Towards Climate Change and Agricultural Insurance: The Example of Aydın Province also stated that 50% are primary school graduates, 18% are middle school graduates, 22% are high school graduates, 5% have an associate degree, and 1% have a postgraduate degree. The researchers reported that there is a positive relationship between the adoption and implementation of innovations, including insurance in agriculture, and the level of education, that is, it is easier for people with a higher level of education to adopt and implement innovations and new technologies (Şengün & Özden, 2022). However, in the research titled Factors Affecting Farmers' Decisions to Have Agricultural Insurance: Adana Province Example, no relationship was found between having agricultural insurance, which can be considered an innovation in Turkish agriculture, and education level (Ünal, 2017).

According to the residence preferences of the producers, the residence preference of the producers who have agricultural insurance is village/neighborhood at a rate of 80%, while this rate is 77.3% for those who do not have agricultural insurance.

Social security status of producers: 90.7% of producers who have agricultural insurance have social security and 55.8% are subject to a retirement fund. 96% of producers who do not have agricultural insurance have social security and 86.1% are subject to a retirement fund.

It was examined whether the producers had any job or source of income other than agricultural activities and accordingly, it was determined that 40% of the producers who had agricultural insurance were engaged in activities other than agriculture and that this activity was public labor with a rate of 53.3%. It was determined that 78.7% of the producers who did not have agricultural insurance were engaged in activities other than agriculture.

According to the equipment and machinery assets of the producers per farm, it was determined that 0.56 of the producers who had agricultural insurance had tractors, 0.50 had trailers, 0.50 had ploughs, 0.25 had baler machines, 18 had combine harvesters, 0.01 had spraying machines and 0.02 had other equipment and machinery assets. It was determined that 0.29 of the producers who did not have agricultural insurance had tractors, 0.2 had trailers, 0.13 had ploughs, 0.05 had baler machines, 0.01 had no combine harvesters or spraying machines and 0.02 had other equipment and machinery assets.

According to the land assets per farm of the producers, the total property land assets of those who have insurance are determined as 25.4 da, the total rental land assets are 6.7 da, and the total land assets processed by partners are 1.4 da, while the total property land assets of the producers who do not have agricultural insurance are determined as 24.2 da, the total rental land assets are 4.7 da, and the total land assets processed by partners are 0.16 da. While the number of land plots per farm of the producers who have agricultural insurance is 4.6 da, this number is 3.9 da for the producers who do not have agricultural insurance. In the research conducted on the silage corn producing enterprises in Pasinler district of Erzurum province, the average property land is determined as 116.64 da, the average amount of rented land is 4.44 da, and the average amount of land kept by partners is 0.76 da. The average number of parcels in the study is calculated as 9.10 (Tuvanç & Dağdemir, 2009).

The number of cattle per farm of producers with agricultural insurance is 49.9 and that of producers without agricultural insurance is 10.2.

When the workforce of the enterprises is examined in terms of male business unit, it is understood that the enterprises that have insurance have more workforce capacity. While the total workforce of the enterprises that have insurance is at the level of 4.43, it is 4.19 in the enterprises that do not have insurance.

One of the factors that has the greatest impact on the investment decisions of enterprises and their adoption of new technologies is undoubtedly the annual income level. In this study, the income level and composition of the enterprises examined were examined. The annual total income of the producers who have agricultural insurance from plant production was determined as 24080 TL, the income from animal production as 349560 TL and the income from non-agricultural activities as 58997.3 TL. In the income distribution of the producers who have agricultural insurance, 6.3% of the income from plant production, 80.1% of the income from animal production and 13.6% of the income from non-agricultural activities constituted.

The annual total income of producers who do not have agricultural insurance from plant production is determined as 41653.3 TL, income from animal production is determined as

50920 TL and income from non-agricultural activities is determined as 187227.1 TL. Income distribution of producers who do not have agricultural insurance consists of 14.9% income from plant production, 18.2% income from animal production and 66.9% income from non-agricultural activities.

3.2. Analysis of Factors Affecting Insurance

The chi-square test results used in the analysis of the factors affecting the agricultural insurance behavior of the enterprises examined are given in Tables 1 and 2.

As a result of the chi-square analysis conducted on the relationship between farmers' agricultural insurance and their age, the X^2 value was determined as 13.37438 and the p-value as 0.00389. This low p-value indicates that there is a significant relationship between age groups and insurance. While the rate of those who have insurance is low in the young age group, the middle age group (36-50 years) is the group with the highest rate of those who have insurance. The rate of insurance decreases in the age groups of 51 and above. A significant relationship was found between age and insurance. While young farmers are more reluctant to have insurance, the rate of farmers in the middle age group is higher. Velandia et al. (2009) stated that young farmers are less inclined to have insurance. Young farmers tend to see insurance costs as high and perceive risk as lower. Adjabui et al. (2019) stated that age is an important factor affecting the demand for insurance and that farmers in the middle age group are generally more likely to have insurance. Akintunde (2015) stated that the age factor is an important factor affecting insurance decisions and that farmers, especially those between the ages of 35-50, have higher rates of insurance. However, there are also studies stating that insurance and age have a negative correlation with increasing age. This result is probably due to increasing financial liabilities with increasing age (Adjabui et al., 2019; Budhathoki et al., 2019).

According to the chi-square analysis results between agricultural insurance and the education level of the producers, the X^2 Value is 8.00575 and the p-value is 0.15592. This high p-value shows that there is no significant relationship between education level and insurance. However, while the rate of insurance is higher among high school graduates, the rate of insurance is lower among university graduates. This may indicate that the level of education does not have a direct effect, but there are differences in some groups. Aina et al. (2018) state that as the level of education increases, the rate of insurance increases. Educated farmers can better understand the benefits of insurance products and risk management. Akintunde (2015) states that as the level of education increases, the probability of farmers to have insurance increases and educated farmers have more information about insurance products. On the other hand, there are also studies stating that an increase in education decreases the tendency to have insurance (Arshad et al., 2016; Kwadzo et al., 2013).

An examination was made between the producers' residence in the district center or neighborhood (village) and their insurance behaviors and as a result of the chi-square analysis, the X^2 Value was found as 0.15890 and the p-value as 0.92362. Since the calculated p-value is very high, there is no significant relationship between the place of residence and insurance. Fahad and Jing (2018) emphasize that the insurance rates of farmers in rural areas are low and that farmers in rural areas are less willing to get insurance and that insurance awareness should be increased. Since a clear definition of the exact boundaries of the rural-urban distinction in Türkiye cannot be revealed statistically and in real terms, it is necessary to take into account the fact that producers determined to reside in the district center will not fully reveal their urban behavior patterns when evaluating this parameter.

In the chi-square analysis between the producer's social security and agricultural insurance behavior, the X^2 Value was determined as 1.71429 and the p-value as 0.19043. The p-value does not show a significant relationship. However, the rate of insurance among those with social security appears to be higher.

The relationship between whether farmers have non-agricultural income activities and whether they have insurance was also questioned and as a result of chi-square analysis, X^2 Value: 23.23632 and p-value was found as 0.00000. P-value is very small and statistically significant. This result shows that non-agricultural activities are an important factor affecting the decision to have insurance. The insurance rate of enterprises with non-agricultural activities is much lower. The fact that the producer has a non-agricultural income-generating activity causes them not to see agriculture as their main occupation and stands as an obstacle to professionalization in agriculture. Abebe and Bogale (2014) stated that non-agricultural activities can affect the insurance needs of farmers because these activities can diversify farmers' incomes and reduce the need for insurance. Ali (2013) stated that the demand for agricultural insurance of farmers with non-agricultural activities generally decreases. Singh (2017) stated that non-agricultural activities diversify farmers' incomes and therefore reduce the demand for agricultural insurance. Some studies have stated that non-agricultural activities do not reduce the demand for insurance, on the contrary, these activities support farmers' decision to buy insurance (Adjabui et al., 2019; Arshad et al., 2016; Gulseven, 2020).

The presence of a tractor in a business is important in terms of showing that agricultural production is adopted as a basic profession. As a result of the chi-square analysis between this significant variable and insurance behavior, the X^2 Value was determined as 10.90116 and the p-value as 0.00096. The p value found as a result of the analysis is statistically significant, meaning it can be said that owning a tractor is a factor affecting the decision to have insurance. The insurance rate of businesses owning tractors is much higher. Ali (2013) stated that farmers owning tractors have more modern agricultural techniques and therefore are more likely to have insurance.

Farmers' land assets and insurance behavior were questioned and as a result of the analysis, X^2 Value was determined as 48.42003 and p-value as 0.99719. According to the analysis results, there is no statistically significant relationship between land assets and insurance. In other words, there is no significant difference between land assets and insurance. In the literature, there are studies stating that the amount of enterprise land decreases the tendency to buy agricultural insurance (Madaki et al., 2023; Musonda, 2012; Nyaaba et al., 2019), while there are studies stating that it increases it (Başer et al., 2023; Budhathoki et al., 2019; Chand et al., 2016; Dahal et al., 2022; Danso-Abbeam et al., 2014). It was emphasized that large land holdings are a factor that increases the possibility of farmers to make insurance, that the risks farmers face increase with large land holdings, that insurance is common in large land holdings because large land holdings generally carry more risks and that farmers try to manage these risks with insurance. In this study, the absence of a significant relationship between land holdings and making insurance is generally inconsistent with the literature findings. This result shows that the average land size in the examined enterprises is due to the fact that they are in the status of small enterprises. Because, the average land size in the examined enterprises is 33.5 acres in the enterprises that make insurance and 29.06 acres in the enterprises that do not make insurance.

It is observed that the number of land plots is not a factor affecting the decision to buy insurance among the businesses that do and do not buy insurance. There are mixed findings in the literature on whether the number of land plots affects the insurance decision. It is suggested that farms with a large number of plots are more inclined to buy insurance because they need more risk management. However, the fact that such farms have more dispersed and diversified production may also balance the need for insurance (Sadati et al., 2010). On the other hand, farms with large single plots of land may have a higher need for insurance because it is thought that such businesses are more vulnerable to risks, especially natural disasters. However, the fact that there is no significant difference between insurance and the number of land plots in the study indicates that this factor does not play a decisive role in the insurance decision.

One of the factors that will encourage a farm to have agricultural insurance is the livestock presence in the farm. In order to determine this relationship, the relationship between the farm's livestock presence and insurance behavior was examined. As a result of the chi-square analysis, it was determined that the livestock presence of the farms that had insurance was higher than those that did not have insurance and this difference was significant ($X^2 = 143.58$, $p = 0.00010$*). The livestock presence is an important factor in agricultural insurance. Animal production is a high-cost sector for farmers and livestock insurance is an effective way to manage these risks. Livestock insurance helps farmers reduce the financial risks associated with livestock losses due to various reasons such as illness, accident or natural disaster. This protection allows farmers to have a more stable income. Insurance payments cover economic losses in the event of livestock losses and ensure that the financial stability of the household is maintained. This stability allows for better planning and investment on the farm. Farmers aim to ease the financial burden arising from any loss by insuring their livestock, especially their cattle, and many studies have determined that there is a positive correlation between livestock ownership and the tendency to purchase insurance (Dong et al., 2020; Ghazanfar et al., 2015; Madaki et al., 2023; Mehmood et al., 2022; Nugrahaini et al., 2021; Subedi & Kattel, 2022). However, insuring cattle may be a barrier for some farmers due to high insurance premiums and management difficulties (Abebe & Bogale, 2014; Akintunde, 2015). The research confirms that cattle ownership is an important factor in insurance participation.

The chi-square test result between the labor force of the enterprise and insurance behavior shows that there is no significant difference ($\chi^2 = 8.17654$, $p = 0.31728$). This reveals that the total labor force (total of female and male labor force) does not have a significant effect on the decision to buy insurance. Labor force has been examined as a factor affecting insurance decisions, especially in the agricultural sector. The literature generally associates the effect of labor force on insurance decisions with the economic power and agricultural production capacity of farmers. Studies have addressed the aspects of the labor force potential in enterprises that can positively or negatively affect insurance decisions. It has been stated that farms with more labor force tend to buy insurance. However, this tendency is generally seen in large enterprises and high-income farmers (Liu et al., 2021; Madaki et al., 2023; Mehmood et al., 2022; Shang & Xiong, 2021). In small-scale farms, the workforce may often be insufficient to generate income levels that can pay insurance premiums. The impact of total workforce availability on insurance decisions largely depends on farmers' economic situation and agricultural production capacity. A large workforce may lead to an increase in the decision to purchase insurance in large farms, but in small farms, the workforce has no significant impact on insurance (Mensah et al., 2023; Nugrahaini et al., 2021; Nyaaba et al., 2019).

According to the chi-square analysis between the annual income level of the enterprise and insurance, annual income is higher in enterprises that have insurance, and this difference is significant ($X^2 = 35.10$, $p = 0.00003$*). Income level is one of the primary factors affecting participation in agricultural insurance. High-income farms are more likely to have insurance because they have greater risks. Studies show that high-income farmers are more comfortable paying insurance premiums and therefore more likely to have insurance (Budhathoki et al., 2019; İkikat Tümer et al., 2019; Kurniaty et al., 2021; Mensah et al., 2023; Nugrahaini et al., 2021). In addition, it is observed that lower-income farmers have higher rates of not having insurance due to their sensitivity to insurance costs (Ellis, 2016; Mehmood et al., 2022). The findings of this study are consistent with the literature as they show that high-income businesses are more likely to purchase insurance.

The effect of factors related to agricultural insurance is not limited to economic factors; socio-cultural, structural and political factors also shape this decision. The results obtained are parallel to the findings of many studies in the literature. Factors such as age, non-agricultural activities, and tractors show a significant relationship with insurance. Especially non-agricultural activities and tractor ownership are important factors affecting the rate of insurance. Characteristics such as marital status, educational status, place of residence and social security do not have a significant effect on the decision to insure.

Table 1. Analysis of the distribution of some socio-economic characteristics of enterprises.

Business Features		Insurance		Non-Insurance		Chi-square Test	
		Frequency	Percentage	Frequency	Percentage	X^2	P
Age	25-35	5	6.7	0	0	13.37438	0.00389*
	36-50	43	57.3	33	44.0		
	51-65	24	32.0	32	42.7		
	>65	3	4.0	10	13.3		
Education	Literate	1	1.3	0	0	8.00575	0.15592
	Primary School	18	24.0	14	18.7		
	Secondary School	19	25.3	23	30.7		
	High school	31	41.3	22	29.3		
	University	6	8.1	16	21.3		
Residence	Town	15	20.0	17	22.7	0.15890	0.92362
	Neighborhood (Village)	60	80.0	58	77.3		
Social Security	Yes	68	90.7	72	96.0	1.71429	0.19043
	No	7	9.3	3	4.0		
Non-Agricultural Activity	Yes	30	40.0	59	78.7	23.23632	0.00000*
	No	45	60.0	16	21.3		
Tractor ownership	Yes	42	56.0	21	28.0	10.90116	0.00096*
	No	33	44.0	54	72.0		

Table 2. Analysis of some technical indicators of enterprises.

Business Features		Insurance	Non-Insurance	Chi-square Test	
				X^2	P
Land ownership (da)	Possession	25.4	24.2	48.42003	0.99719
	Rent	6.7	4.7		
	Partnership	1.4	0.16		
Number of Land Pieces	Number	4.6	3.9	19.84085	0.92062
Total Cattle Assets	Number	49.9	10.2	143.58478	0.00010*
Labor Force (EİB)	Female	1.05	1.10	8.17654	0.31728
	Male	3.38	3.09		
Total Annual Income	TL	432 637.3	279 800.4	35.09770	0.00003*

3.3. Econometric Model Results

The most appropriate model was chosen by trying different model combinations from the existing data set. Table 3 provides the definitions and statistical indicators of the variables used in the econometric model. The variables used in the model, such as the number of family members, total land assets and number of cattle, are continuous variables, while the variables for non-agricultural activities and the presence of tractors in the enterprise are binary variables. The mean of the variable for the number of family members used in the econometric model is 4.77, the mean for total land assets is 31.05 and the mean for cattle assets is 30.1. In the enterprises examined, 40% of the entrepreneurs have non-agricultural activities and 42% have tractors.

Table 3. Statistical summary and description of variables.

Variables	Definition	Average	Standard Error
X1	Number of family members, continuously variable	4.77	1.353
X2	Non-agricultural activity, binary variable, yes:1; no: 0	0.40	0.492
X3	Land ownership, continuously variable	31.05	49.835
X4	Number of cattle	30.1	30.498
X5	Tractor ownership, yes:1; no:0	0.42	0.496

The probit model results and marginal effects, which attempt to determine the factors affecting farmers' insurance, are presented in Tables 4 and 5. The probit model created was found to be significant at the 1% level. When the probit model results and marginal effects are evaluated together, several important factors that affect farmers' insurance probabilities stand out. The constant term, non-agricultural activity and the number of cattle variables from the model coefficients were found to be significant at the 1% level, while the number of family members, total land assets and the presence of a tractor in the farm were found to be significant at the 10% level.

According to the probit model results, the probability of making agricultural insurance increases as the number of family members increases, the producer's cattle stock increases and the producer's tractor is found. The farmer's non-agricultural activity and the increase in land stock decrease the probability of making agricultural insurance.

Table 4. Probit model results.

Variables	Coefficients	Standard Error	P-value
Sabit	-2.60291***	0.58182	0.0000
X1	0.20501*	0.10709	0.0556
X2	-1.06151***	0.31729	0.0008
X3	-0.00466*	0.00245	0.0567
X4	0.04391***	0.00657	0.0000
X5	0.55201*	0.33279	0.0972
Logarithmic Likelihood Function	-51.52202		
Restricted Logarithmic Likelihood Function	-103.97208		
Chi-Square (5 d.f.)	104.90011		
Significance Level	0.0000		

*10% significance level, ** 5% significance level, *** 1% significance level.

According to the results of the marginal effects of the variables related to the probit model on taking out agricultural insurance; the marginal effects of the variables of non-agricultural activities and the number of cattle are significant at the 1% level, the marginal effect of the variable of the number of family members is significant at the 5% level, and the total land assets are significant at the 10% level. If the number of family members increases by one unit among the variables in the model, the probability of the producer taking out agricultural insurance increases by 4.02%. It can be said that risk sharing among family members supports insurance decisions. The effect of family structure on insurance has generally been reported with a positive relationship in previous studies. It has been stated that the family structures of farmers have an important place in the decision-making processes (Oduniyi et al., 2020). Solidarity and risk sharing, especially among family members, can increase the demand for insurance.

According to the model results, the existence of a producer's non-agricultural activity reduces the probability of making agricultural insurance by 24.3%. It is frequently emphasized in the literature that non-agricultural activities have a negative effect on farmers' insurance decisions. It is observed that farmers feel less need for insurance with the income they earn from non-agricultural activities (Abebe & Bogale, 2014; Singh, 2017). This finding shows that farmers' risk management and income diversification can reduce insurance demand.

The increase in the farmer's land holdings decreases the probability of insurance by a very low level of 0.1%. Since the p-value is slightly above 5%, this effect is at the statistically significant limit. Each decare increase in land holdings decreases the probability of insurance by 0.091%. This situation shows that large-scale enterprises have lower insurance requirements because they have more resources. The effect of land size on insurance demand is summarized in the literature as farmers can better manage their own internal risks and their insurance needs decrease when they have larger land holdings.

Increasing the producer's cattle stock by one unit increases the probability of making agricultural insurance by 0.9%. This effect is quite strong and statistically significant. Each additional cattle increases the probability of making insurance by 0.86%. This is consistent with the literature that farmers engaged in animal husbandry have higher insurance rates. Farmers engaged in animal husbandry generally have higher insurance demands. Because cattle are high-risk assets, this may lead farmers to make insurance (Madaki et al., 2023; Mehmood et al., 2022; Nugrahaini et al., 2021). These findings indicate that farmers engaged in animal husbandry are more inclined to manage their risks through insurance.

Having a tractor increases the probability of having insurance, but the p-value is at the limit of significance. Having a tractor in an agricultural enterprise increases the probability of having insurance by 11.7%. The effect of tractor presence on insurance is related to farmers adopting modern agricultural practices. Having a tractor generally increases the insurance requirements of farmers and leads to larger farms.

Table 5. Marginal effects.

Variables	Marginal Effect	Standard Error	P-value
X1	0.04017**	0.02021	0.0469
X2	-0.24351***	0.07286	0.0008
X3	-0.00091*	0.00047	0.0501
X4	0.00860***	0.00076	0.0000
X5	0.11663	0.07334	0.1118

*10% significance level, ** 5% significance level, *** 1% significance level.

4. Conclusion

This study aimed to examine the factors affecting the decisions of farmers to have insurance in agricultural enterprises in Oltu District of Erzurum Province. The probit model analysis shed light on various socio-economic characteristics affecting the decisions of farmers to have insurance. The research findings are generally consistent with previous studies when compared with the literature.

The fact that the number of family members increases the probability of getting insurance shows that farmers attach more importance to family solidarity and risk sharing. This finding is parallel to studies in the literature indicating that family structure has a significant effect on farmers' insurance preferences. Risk sharing among family members may increase farmers' need for insurance. Farmers tend to manage risks collectively, especially when there are more individuals in family businesses.

The negative impact of non-agricultural activities on insurance is consistent with the literature. The presence of non-agricultural income sources reduces the need for farmers to have insurance. Since farmers can manage their own risks more easily with the income they earn from non-agricultural activities, their need for agricultural insurance decreases. This finding is an important factor that shows how farmers' risk diversification affects their insurance needs. Considering that non-agricultural activities have a negative impact on insurance, agricultural insurance awareness campaigns should be expanded to include non-agricultural activities.

The fact that an increase in land holdings reduces the need for insurance is a finding consistent with the literature. It is emphasized in the literature that farmers with large land holdings generally tend to have less insurance because these farmers have more resources and risk management capacity. This shows that farmers can better manage their own internal risks with large land holdings and the demand for insurance decreases as a result. However, these findings also reveal that insurance incentives should be increased for small-scale farmers. Since small farmers may have difficulty managing their risks, special insurance policies and incentives should be developed for this group.

The increase in the number of cattle is an important factor that increases the probability of insurance. Farmers engaged in livestock want to secure their high-risk assets with insurance. This finding is consistent with previous studies. The high tendency of farmers to insure their cattle indicates their willingness to manage risks more effectively. In this context, the development of insurance policies specific to the livestock sector and the expansion of cattle insurance coverage may increase the tendency to purchase insurance.

The fact that the presence of a tractor increases the possibility of insurance can be interpreted as farmers increasing their insurance needs by having more modern and large-scale businesses. Tractor use is an important element that increases farmers' agricultural productivity and also indicates that farmers may face more risks.

In light of the research findings, the following recommendations can be made to increase the use of agricultural insurance:

1. Training programs should be organized to increase knowledge and awareness of different demographic and socio-economic farmer groups.

2. Taking Non-Agricultural Activities into Account: Considering that non-agricultural activities reduce insurance

demand, awareness campaigns should be organized for farmers about the effects of non-agricultural income on insurance.

3. Incentives for Small Farmers: The observation that insurance demands of farmers with small lands are low indicates that more affordable insurance policies and supports should be provided for farmers in this group. Additional insurance premium support can be provided especially for low-income farmers.

4. Developing Livestock Insurance: Developing special livestock insurance policies for farmers engaged in livestock farming will increase insurance usage. In addition, it should be supported with risk-reducing measures such as animal health insurance and vaccinations.

5. The presence of agricultural machinery such as tractors increases the demand for insurance. Therefore, increasing the level of agricultural mechanization of enterprises and facilitating the acquisition of agricultural machinery can further increase the use of insurance.

6. Developing insurance programs for farmer groups and implementing them with appropriate policies can increase the level of adoption due to responsibility sharing.

Compliance with Ethical Standards

The study protocol was approved by the Atatürk University, Faculty of Agriculture Ethical Committee with the decision number 2025/1 in session 2025/12.

Conflict of Interest

The authors declare no conflict of interest.

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RESEARCH ARTICLE

Assessment of Nutritional Characteristics and Mineral Composition of Badara Plateau Pasture, Çamlıhemşin, Rize, Türkiye

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ABSTRACT

This two-year study (2023–2024) aimed to evaluate the forage quality and nutritional composition of the Badara Plateau pasture, a high-altitude rangeland located in the Çamlıhemşin district of Rize Province, in northeastern Türkiye. Plant samples were systematically collected from twelve distinct sites during July of each year, coinciding with peak biomass production. The samples were analyzed for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent protein (ADP) and key macro minerals (P, K, Ca, Mg) using Near-Infrared Reflectance Spectroscopy (NIRS). In addition, several derived nutritional parameters were calculated, including digestible dry matter (DDM), dry matter intake (DMI), relative feed value (RFV), digestible energy (DE), and metabolizable energy (ME). The average dry matter yield was 92.04 kg da^{-1}. The average CP content was 16.14%, reflecting a high nutritional quality of the forage. Fiber content, represented by ADF (31.99%) and NDF (66.08%) values, indicated moderate digestibility and intake potential. The mineral analysis revealed adequate levels of essential macro elements, with balanced Ca/P (5.21) and K/(Ca+Mg) (0.91) ratios. Overall, the findings of this study offer critical insights into the nutritive value and potential carrying capacity of the Badara Plateau rangeland and can inform the development of sustainable grazing strategies for comparable alpine ecosystems in the region.

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1. Introduction

The economic sustainability of livestock production closely tied to feed costs, a substantial component of operational expenditure, which constitute a major proportion of total production costs. Among feed resources, natural and cultivated pastures represent the most cost-effective source of roughage and are fundamental to the sustainability of livestock systems, supplying approximately 70% of the global roughage requirements for ruminants (Lund, 2007). However, the combined effects of rapid global population growth, intensifying climate change, and economic volatility are exerting increasing pressure on the availability and quality of forage derived from these critical ecosystems. Furthermore, the conversion of pasturelands to alternative land uses and the widespread incidence of overgrazing are severely undermining both the productivity and ecological resilience of these rangelands.

Overgrazing stands as a main cause of pasture degradation, particularly in arid and semi-arid regions (Holechek et al., 2011; Snyman, 2005). This degradation manifests in several detrimental ways, including reduced pasture productivity, deterioration of soil physical and chemical properties (Beukes

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& Cowling, 2003), and increased vulnerability to soil erosion. Moreover, overgrazing intensifies the spread of unpalatable and invasive plant species, diminishes overall vegetative cover, and ultimately results in substantial reductions in aboveground biomass production. (Çomaklı et al., 2012; Tongway et al., 2003). These consequences not only detrimentally affect the productivity and sustainability of livestock systems, but also have far-reaching ecological implications, including the loss of biodiversity and the degradation of essential ecosystem services.

Both the quantity and quality of roughage derived from pastures are key determinants of the efficiency and sustainability of livestock production systems (Heitschmidt et al., 1995). As such, ecologically responsible pasture management practices are essential to maintain and enhance the functionality of these ecosystems. Protecting existing pasture ecosystems and implementing effective rehabilitation strategies in vulnerable areas are critical for ensuring long-term productivity and ecosystem health. Achieving these objectives requires a comprehensive assessment of current pasture conditions and the underlying factors contributing to their degradation. A detailed characterization of pasture vegetation is an essential prerequisite for developing and implementing any effective rehabilitation strategy. Therefore, a thorough evaluation of botanical composition, yield, and quality characteristics of different pasture sections is crucial before initiating any rehabilitation interventions, especially in areas exhibiting spatial heterogeneity in soil properties, topography, and plant cover. Such an evidence-based approach enables the formulation and application of site-specific, targeted rehabilitation strategies, thereby enhancing their effectiveness and contributing to the broader objective of sustainable pasture management (Alay et al., 2016; Çınar et al., 2014).

The nutritional value of feed derived from both natural pastures and cultivated forage crops is closely linked to overall forage quality. This encompasses key attributes such as palatability, animal intake, digestibility, the presence of anti-nutritional compounds (e.g., toxins), chemical and morphological composition, and energy and protein content. Furthermore, various environmental factors, including climatic conditions (temperature and precipitation), seasonal variations, the relative proportions of grasses and legumes, altitude, and aspect, can significantly influence forage quality (Kaya, 2008; Kirilov, 2001). A comprehensive understanding of these complex interactions is essential for optimizing livestock nutrition, promoting sustainable pasture utilization, and ensuring the long-term viability of grazing systems.

This study aims to evaluate the livestock carrying capacity and nutritional potential of Badara Plateau pasture, located within the Çamlıhemşin district of Rize province in the Eastern Black Sea Region of Türkiye, by comprehensively analyzing the nutritional value and mineral composition of its constituent vegetation. This research will contribute to enhanced livestock production and the long-term conservation of this valuable resource, providing a model for sustainable pasture management in similar high-altitude ecosystems.

2. Materials and Methods

This research was conducted in Badara Plateau pasture, located in the Çamlıhemşin district of Rize province, within the Eastern Black Sea Region of Türkiye, an area recognized for its remarkable natural beauty and rich biodiversity. The research site is positioned at an approximate altitude of 1850 meters above sea level, approximately 30 km from the district center. The grazing period in Rize province generally starts on May 15 and ends on October 31. The geographical location of the study area is illustrated in Figure 1. Representative photographs of the site's characteristic features, including topography, vegetation cover, and dominant plant communities, are presented in Figure 2, providing a visual representation of the study environment.

Soil samples collected from Badara Plateau were analyzed to determine key soil properties. The analysis revealed the following characteristics: The soil texture was classified as clay loam with a saturation percentage of 75.9%. The soil exhibited a strongly acidic reaction with a pH of 4.48. The total salt content was low (0.14%), indicating a low salinity level. The lime content was also low (0.11%). The organic matter content was found to be 3.27%, which is considered sufficient. Available phosphorus (P_2O_5) and potassium (K_2O) levels were 11.24 kg da^{-1} and 62.45 kg da^{-1}, respectively, both indicating sufficient levels. Rize province, where the study area is located, experiences a temperate climate characterized by substantial precipitation. Analysis of long-term meteorological data obtained from the Turkish State Meteorological Service (MGM) indicates an average annual temperature of 14.5 °C and a high annual precipitation total of 2300 mm (T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı, 2025).

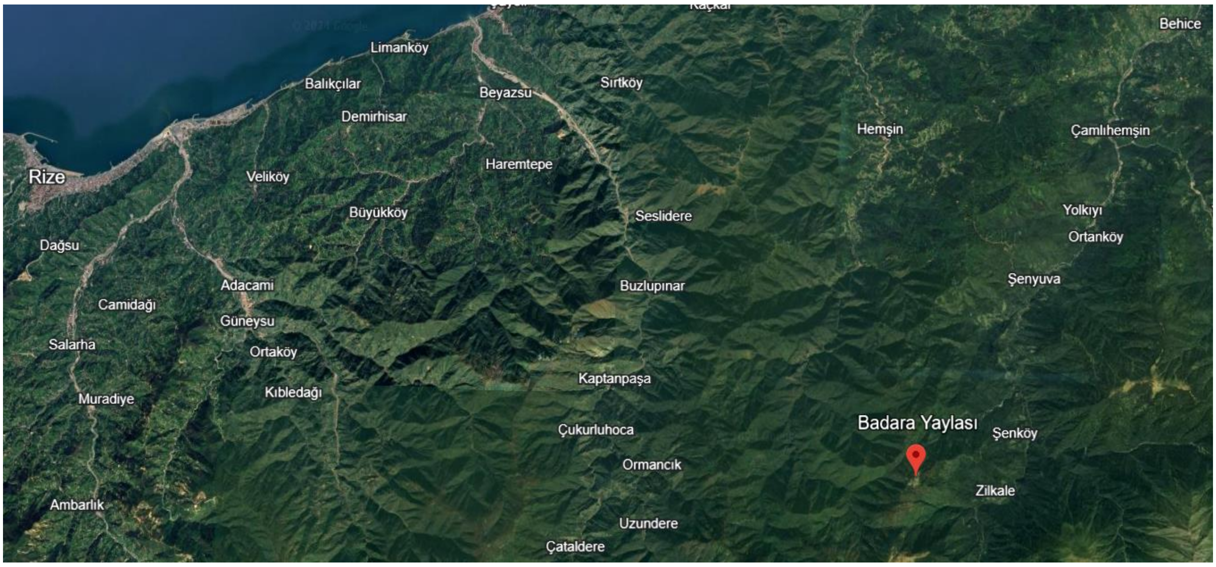

Figure 1. Location of the study area on the map (Google Earth).

Figure 2. Some photos taken from the study area.

In order to determine the nutrient quality values, plant material was collected from twelve different points in the open grazing area of Badara Plateau pasture in July 2023 and 2024, coinciding with the peak period of biomass production. At each sample point, vegetation was harvested at ground level using 50 × 50 cm quadrats to ensure representative sampling. Immediately after harvesting, fresh weights were measured *in situ* using a portable precision balance to minimize moisture loss. Samples were then oven-dried at 70 °C for 48 hours to achieve a constant dry weight, which was subsequently used to calculate yield per unit area (kg da^{-1}). The dried plant material was ground and homogenized using a mill equipped with a 1 mm sieve for subsequent chemical analyses.

The concentrations of crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent protein (ADP), and the minerals phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined using Near-Infrared Reflectance Spectroscopy (NIRS) with a Foss NIR Systems Model 6500 Win ISI II v1.5 instrument. NIRS was selected for its rapid, non-destructive, and cost-effective analysis of multiple constituents, enabling efficient processing of a large number of samples.

Several key nutritional parameters were calculated based on ADF and NDF values using established equations. Digestible dry matter (DDM) was calculated using the equation: DDM = 88.9 – (0.779 × %ADF) (Oddy et al., 1983). Dry matter intake (DMI) was estimated using the equation: DMI = 120 / (%NDF) (Sheaffer et al., 1995). Relative feed value (RFV) was calculated as: RFV = (DDM × DMI) / 1.29 (Sheaffer et al., 1995). Digestible energy (DE) was estimated using the equation: DE = 0.27 + 0.0428 × (%DDM) (Fonnesbeck et al., 1984), and metabolizable energy (ME) was calculated as: ME = 0.821 × DE (Mcal kg^{-1}) (Khalil et al., 1986). These calculated parameters provide valuable estimates of forage quality and potential animal performance.

Furthermore, the ratios of Ca/P and K/(Ca+Mg) were calculated to assess the balance of macro elements, which is crucial for animal health and metabolic functions (İ. Aydın & Uzun, 2002; Polat & Bayraklı, 2019). Maintaining appropriate mineral ratios is essential for preventing nutritional imbalances and optimizing animal productivity.

Descriptive statistical analyses were performed on the collected data for all examined parameters using JMP statistical software. Descriptive statistics, including means, standard deviations, and ranges for each parameter, were calculated.

3. Results and Discussion

Table 1 presents the summary of the nutrient composition of grass samples collected from Badara Plateau pasture over the two-year study period (2023–2024). These data provide a comprehensive evaluation of the pasture's nutritional quality and reveal potential year-to-year differences in nutrient concentrations.

Table 1. Nutrient content and quality of Badara Plateau pasture: analysis of fresh and dry yield, fiber, protein, and mineral composition (average±standard deviation).

Features Analyzed	1.Year	2.Year	Average
Fresh Yield (FY) (kg da^{-1})	408.00±17.10	364.00±16.86	386.00
Dry Yield (DY) (kg da^{-1})	104.00±9.97	80.08±6.18	92.04
Crude Protein (CP) (%)	16.29±0.82	15.99±0.48	16.14
Acid Detergent Fiber (ADF) (%)	33.15±3.05	30.83±1.44	31.99
Neutral Detergent Fiber (NDF) (%)	64.91±3.76	67.25±5.70	66.08
Acid Detergent Protein (ADP) (%)	1.24±0.06	1.19±0.04	1.22
Digestible Dry Matter (DDM)	63.08±2.37	64.88±1.12	63.98
Dry Matter Intake (DMI)	1.85±0.16	1.78±0.11	1.82
Relative Feed Value (RFV)	90.40±9.01	89.75±9.73	90.07
Digestible Energy (DE) (Mcal kg^{-1})	2.97±0.10	3.05±0.08	3.01
Metabolic Energy (ME) (Mcal kg^{-1})	2.44±0.04	2.50±0.08	2.47
Phosphorus (P) (%)	0.34±0.05	0.29±0.02	0.32
Potassium (K) (%)	1.78±0.21	1.49±0.13	1.64
Calcium (Ca) (%)	1.56±0.25	1.69±0.39	1.63
Magnesium (Mg) (%)	0.16±0.04	0.19±0.07	0.18
Ca/P	4.59±0.13	5.83±1.22	5.21
K/(Ca+Mg)	1.03±0.07	0.79±0.04	0.91

Table 1 summarizes the nutritional composition of forage samples collected from the Badara Plateau pasture during the 2023 (1st year) and 2024 (2nd year) growing seasons. The average fresh yield (FY) across both years was 386.00 kg da^{-1}, with values of 408.00±17.10 kg da^{-1} and 364±16.86 kg da^{-1} for the first and second years, respectively. The average dry yield (DY) was 92.04 kg da^{-1}, with values of 104±9.97 kg da^{-1} in the first year and 80.08±6.18 kg da^{-1} in the second year. The average crude protein (CP) content was 16.14%, with limited interannual variation (16.29±0.82% and 15.99±0.48% for the first and second years, respectively). Acid detergent fiber (ADF) averaged 31.99%, while neutral detergent fiber (NDF) averaged 66.08%. The Acid Detergent Protein (ADP) content of the pasture was found to be 1.22%, indicating a moderate level of protein availability for livestock. Digestible dry matter (DDM) averaged 63.98%, dry matter intake (DMI) averaged

1.82, and relative feed value (RFV) averaged 90.07. Digestible energy (DE) and metabolizable energy (ME) averaged 3.01 Mcal kg^{-1} and 2.47 Mcal kg^{-1}, respectively. Mineral analysis revealed average concentrations of 0.32% for phosphorus (P), 1.64% for potassium (K), 1.63% for calcium (Ca), and 0.18% for magnesium (Mg). The average Ca/P ratio was 5.21, and the average K/(Ca+Mg) ratio was 0.91.

The results indicate that the Badara Plateau pasture exhibits moderate to good nutritional quality. The crude protein (CP) content, averaging 16.14%, suggests adequate protein levels for most grazing livestock. The fiber content, as indicated by ADF (31.99%) and NDF (66.08%), is within acceptable ranges for good forage digestibility and intake. ADP value was found to be 1.22%. ADP indicates a potential limitation in protein availability for livestock, as some proteins can bind to cellulose and lignin and become indigestible, especially if storage methods are inadequate or feed is stored with high moisture content, leading to heating (Yavuz et al., 2009). Furthermore, the calculated values of digestible dry matter (DDM) at 63.98%, dry matter intake (DMI) at 1.82, and relative feed value (RFV) at 90.07 reinforce the overall assessment, suggesting that the pasture is capable of supplying sufficient energy and essential nutrients to support the maintenance and productivity of grazing animals.

The interannual variation in dry yield (DY) is notable, with a a marked decline observed in the second year of the study. This could be attributed to various factors such as differences in precipitation, temperature, or grazing pressure between the two years. Further investigation into these factors could provide valuable insights into pasture management strategies. Although there was a considerable difference in fresh yield between the two years, the crude protein content remained relatively stable between years, indicating consistent protein quality.

The mineral composition analysis indicated adequate concentrations of essential macronutrients, including phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). The Ca/P ratio, averaging 5.21, is within the recommended range for most livestock species, although there was variation between years. The K/(Ca+Mg) ratio, averaging 0.91, also suggests a balanced mineral profile. These balanced mineral ratios are essential for preventing metabolic disorders and ensuring optimal animal health.

This study evaluated the nutritional characteristics of Badara Plateau pasture over two years (2023-2024). The findings, summarized in Table 1, provide important insights into the forage quality and potential carrying capacity of this high-altitude ecosystem. Comparing our results with previous studies conducted in different regions of Türkiye reveals interesting trends and variations.

The average DY observed in Badara Plateau (92.04 kg da^{-1}) was notably lower than the maximum DY reported by Kılıç (2018) in Trabzon (827.3 kg da^{-1}). This substantial difference may be attributed to various factors, including altitudinal variations, differences in soil properties, botanical composition of the pastures, and variations in climatic conditions, particularly precipitation patterns and temperature regimes. The higher altitude and potentially different plant communities in Badara Plateau could have contributed to the lower biomass production.

The average CP content in Badara Plateau pasture (16.14%) is comparable to the findings of Kılıç (2018) (16.6%) and Şahinoğlu (2010) (16.33-18.64%) in Samsun and Nadir (2010) in Tokat (16.48-18.81%). This suggests that Badara Plateau provides a similar protein level to other pastures in these regions. However, studies conducted by Güllap (2010) in Erzurum and Parlak et al. (2015) in Çanakkale reported lower CP values (ranging from 8.26% to 13.18%), indicating the influence of geographical location, specific plant species composition, and environmental factors on protein content. In contrast, A. Aydın and Başbağ (2017)'s study in Karacadağ reported a higher average CP of 19.19%, further highlighting the impact of different ecological conditions on forage quality.

The average ADF (31.99%) and NDF (66.08%) values observed in Badara Plateau are within the ranges reported in some studies but differ from others. Şahinoğlu (2010) reported lower NDF values (46.39-55.21%), suggesting potentially higher intake potential in the pastures they studied. Kılıç (2018) found ADF at 35.7% and NDF at 49.6%, while Nadir (2010) reported considerably lower ADF (24.38-26.84%) and NDF (34.59-36.32%) values. The study of Tutar and Kökten (2019) in Bingöl similarly showed different ADF and NDF rates (34.8-37.4% ADF and 52.5-62.7% NDF), emphasizing the diversity of factors affecting pasture quality. These differences can be attributed to variations in plant maturity at the time of sampling, species composition, and environmental factors. The higher NDF values in Badara Plateau might indicate a more mature stage of plant growth or the presence of plant species with higher fiber content.

The mineral content of Badara Plateau pasture also varied compared to other studies. Phosphorus (P) levels (0.32%) were similar to those reported by A. Aydın and Başbağ (2017) (0.34%). However, potassium (K) levels (1.64%) were lower than those found by Şahinoğlu (2010) (2.32-2.60%) and A. Aydın and Başbağ (2017) (2.42%). Calcium (Ca) content (1.63%) was higher than reported by Şahinoğlu (2010) (0.90-1.33%), while magnesium (Mg) levels (0.18%) were lower than in Şahinoğlu (2010) (0.26-0.36%) and A. Aydın and Başbağ (2017) (0.31%). The Ca/P ratio (5.21) was higher, and the K/(Ca+Mg) ratio (0.91) was generally lower than those reported in other studies. These variations in mineral content likely reflect differences in soil mineral composition, plant species, and environmental conditions.

This study provides valuable data on the nutritional characteristics of Badara Plateau pasture. The variations observed in comparison with previous regional studies underscore the necessity of site-specific evaluations to inform effective and sustainable pasture management strategies. Factors such as; altitude, climate, soil, and botanical composition appear to play significant roles in determining forage quality. These findings contribute to a better understanding of pasture resources in Türkiye and support the development of sustainable grazing practices tailored to the specific conditions of Badara Plateau and similar high-altitude ecosystems.

4. Conclusion

This two-year study (2023–2024) evaluated the nutritional characteristics of Badara Plateau pasture in the Çamlıhemşin district of Rize province, Türkiye. The findings provide valuable insights into the forage quality and potential carrying capacity of this high-altitude ecosystem. The average dry matter yield was 92.04 kg da^{-1}, demonstrating the pasture's capacity for biomass production, although this was lower than some reported yields from other regions, suggesting potential influences of site-specific factors such as altitude (1850 m a.s.l.), soil conditions, and botanical composition. The average crude protein content (16.14%) indicates a good nutritional value for grazing livestock, comparable to other pastures in the region. Fiber content (ADF: 31.99%; NDF: 66.08%) suggests moderate digestibility and intake potential. Calculated nutritional parameters, including DDM (63.98%), DMI (1.82), RFV (90.07), DE (3.01 Mcal kg^{-1}), and ME (2.47 Mcal kg^{-1}), further support the pasture's potential to meet the nutritional requirements of grazing animals. The mineral analysis revealed adequate levels of essential macro elements (P, K, Ca, and Mg), with calculated Ca/P (5.21) and K/(Ca+Mg) (0.91) ratios suggesting a generally balanced mineral profile. However, some interannual variations were observed in yield and mineral content, highlighting the influence of seasonal climatic factors and the importance of continued monitoring. This study contributes to the understanding of pasture resources in the Eastern Black Sea region and provides a basis for developing sustainable grazing management strategies for Badara Plateau and similar high-altitude pastures in Türkiye. Further research should focus on optimizing grazing practices, investigating the impact of climate change on pasture quality, and exploring potential strategies for enhancing forage production and nutritional value.

Compliance with Ethical Standards

This study does not require ethical committee approval.

Conflict of Interest

The author has no conflict of interest to declare.

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RESEARCH ARTICLE

The Effect of Water Renewal Rate and Frequency on the Growth Performance of *Ancistrus multispinis* (Regan, 1912, Pisces, Teleostei) Fry

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ABSTRACT

In this study, the effects of different water renewal rates on the development of *Ancistrus multispinis* fry, a popular aquarium fish species, were examined during the growth phase. For this purpose, five different water renewal programs were applied to *A. multispinis* fry stocked in glass aquariums during the trial period. The water renewal rates in the groups were planned to be 10%, 20%, and 30% daily (d1, d2, and d3) and 30% and 50% weekly (dh3, dh5). The fry, whose total lengths and weights were measured around the 30-35th day after hatching, were placed in trial tanks. At the beginning of the trial, the average total length of the fry was measured at 13.97±0.47 cm, and their average live weight was 0.027±0.05 g. The trial lasted for 90 days. At the end of the trial, it was observed that the fry in the d3 group, which received a 30% daily water renewal, grew better than those in the other groups. In this group, an average total length of 2.75±0.24 cm and an average weight of 0.23±0.05 g were obtained at the end of the trial. In contrast, the growth performance of the other groups was lower compared to the d3 group. Statistical analyses indicated significant differences among the groups. According to the results of the study, it can be stated that regular monitoring of water quality and consideration of periodic water renewal amounts in the rearing process are important in the farming of this fish species. In this regard, this research emphasizes the need to improve existing traditional methods in *A. multispinis* fry rearing and suggests that optimizing water renewal practices can enhance the growth performance of *A. multispinis* fry.

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1. Introduction

Water quality has a critical impact on the growth performance and overall health of fish in aquaculture. The physical and chemical properties of water directly affect the metabolism, growth, and immune system of fish that live in aquatic environments (Obirikorang et al., 2022). Deterioration of water quality in which fish are raised can lead to direct mortality and can also stress the fish, making them more susceptible to infectious diseases. In particular, parameters such as water temperature, dissolved oxygen, pH, ammonia, and nitrate are among the most important factors determining the development and health of fish (Martins et al., 2009; Timmons et al., 2002). Therefore, monitoring and managing water quality is vital for the success of aquaculture systems. Problems arising from water quality in aquaculture are often due to the unsuitability of the water chemistry used and the negative effects of feed and waste on water quality (Kisia & Hughes, 1993). The frequency of water renewals is important in closed-

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loop systems. Over time, the deterioration of water quality can negatively affect the growth performance of fish, reducing survival rates (Obirikorang et al., 2022). Similarly, problems can arise in the development of fish raised in tanks with high stocking densities (Jha & Barat, 2005; Sahoo et al., 2004). Therefore, improving water quality is an important requirement for the healthy development of fish. The more frequently the water in the tank is changed, the more beneficial it is considered to be. However, it is known that there is a limit to the frequency of water renewals. Thus, determining specific water renewal rates for the fish species being cultivated is important. Adequate water renewals help reduce harmful waste accumulation in the tank while also contributing to the maintenance of the water's chemical balance (Kpundeh et al., 2013). Adjusting water renewal rates in closed-loop systems can positively affect the growth rates and health conditions of fish (Zhang et al., 2025). For example, a study on the effects of water renewal rates on growth reported that increasing water renewal rates improved the growth performance of fish and increased resistance to diseases (Kpundeh et al., 2013). This situation demonstrates the importance of regularly implementing water renewal practices in fish farming. *A. multispinis* is a species sensitive to water quality conditions. The fry of this species can grow faster and undergo a healthier development process with increased water renewal rates. In some fish species raised in closed-loop systems, increasing water renewal rates has been reported to enhance the growth performance of fry and increase resistance to diseases (Kpundeh et al., 2013). In this context, the effects of water renewal rates on the growth process of *A. multispinis* fry represent an important research area for the commercial cultivation of this species. Water renewal is a practice that directly maintains the chemical balance of water. Therefore, it positively contributes to better nutrition and increased digestive efficiency in fish (Zhang et al., 2025).

Based on this information, this study observed the effects of water renewal practices, which can have sudden and direct impacts on improving water quality, during the fry rearing phase of the *A. multispinis* species.

2. Materials and Methods

The study protocol was approved by local ethics committee of animal trials of the Çanakkale Onsekiz Mart University in the meeting dated 23.12.2022 with the decision number 2022/12-01.

2.1. The Fish

In this study, newly hatched *A. multispinis* fry that had exhausted their yolk sacs were used. In summary, the effects of different water renewal rates on the development of *A. multispinis* fry were observed. The broodstocks of *A. multispinis* available in our laboratory were used to obtain the fry. Initially, a sufficient number of fry were produced for the experiment. The newly hatched fry of the same age were kept in larval rearing tanks until their yolk sacs were depleted and they began to consume artificial micro-particle feed. Approximately 30-35 days after hatching, the fry, whose total lengths and weights were measured, were placed in trial tanks. To determine the initial length and weight data, 27 samples were measured. According to these measurements, it was found that at the beginning of the trial, the average total length of the fry was 13.97±0.47 cm, and their average live weight was 0.027±0.05 g.

2.2. Experimental Design

The trial lasted for 90 days. The fry used in the experiment were produced from broodstock raised in the same laboratory. After obtaining a sufficient number of fry for the experiment, the trial setups were established. At the beginning of the trial, the live weight and total length measurements of the fry were taken. No anesthetic was applied during the measurements. A total of 5 groups were created (Table 1). The first three groups were designed with daily water renewal rates of 10%, 20%, and 30% (designated as d1, d2, and d3, respectively), while the last two groups were planned with weekly water renewal rates of 30% and 50% (designated as dh3 and dh5, respectively). Each experimental group was replicated three times. At the end of the 90-day trial, live weight and total length measurements were taken. The survival and growth rates between the groups were compared at the end of the trial. All groups were fed with the same brand of commercial fish feed (0.5-0.8 microns, ALLTECH) in the same amounts and meal frequencies. Fish were given 0.01 g of feed per fish per liter, which means 0.05 g of feed per meal for 5 fish in 5 liters and 0.1 g of feed per meal for 10 fish in 5 liters. Water quality parameters were maintained under similar conditions for all groups. In this trial, 20 fry were stocked in aquariums, each with a capacity of 4 L. A total of 300 fry were used in the experiment.

Table 1. Experimental design of the study.

Group	Water renewal Rates	Stock Density	Repetition	Total Number of Fry in the Group (= 3 repetitions)
d1	Daily % 10	20 fry / 4 L	3	60
d2	Daily % 20	20 fry / 4 L	3	60
d3	Daily % 30	20 fry / 4 L	3	60
dh3	Weekly % 30	20 fry / 4 L	3	60
dh5	Weekly % 50	20 fry / 4 L	3	60

2.3. Statistical Analyses

For statistical analyses, ANOVA was used to test the hypothesis regarding the differences among group means. Before this analysis, the assumptions of normality and homogeneity of variances were tested. ANOVA analyses were applied if the assumptions were met. To investigate whether there are differences among the groups, the Kruskal-Wallis test was conducted. The Dunn test was performed to determine which groups had differences.

3. Results

In this study, the development of *A. multispinis* fry was tested under different water renewal frequencies. At the beginning of the experiment, the average length of the fry was 13.97±0.47 cm, and their live weight was 0.027±0.05 g. Based on the data set, five trials were established according to the water renewal. Descriptive statistics and graphs for total length (cm) were obtained from the collected data (Table 2, Figure 1).

Table 2. Descriptive statistics of end-of-trial data for total length (cm) in groups where the effect of water renewal on the growth of *A. multispinis* was measured.

	Experiment	**n**	**min**	**max**	**median**	**iqr**	**mean**	**sd**	**se**	**ci**
1	d1	45	2	3.7	2.7	0.5	2.68	0.373	0.056	0.112
2	d2	45	2	3.6	2.6	0.5	2.709	0.385	0.057	0.116
3	d3	54	1,9	3.7	2.7	0.6	2.752	0.458	0.062	0.125
4	dh3	44	2	3	2.5	0.3	2.527	0.242	0.037	0.074
5	dh5	40	2	3.2	2.6	0.7	2.61	0.359	0.057	0.115

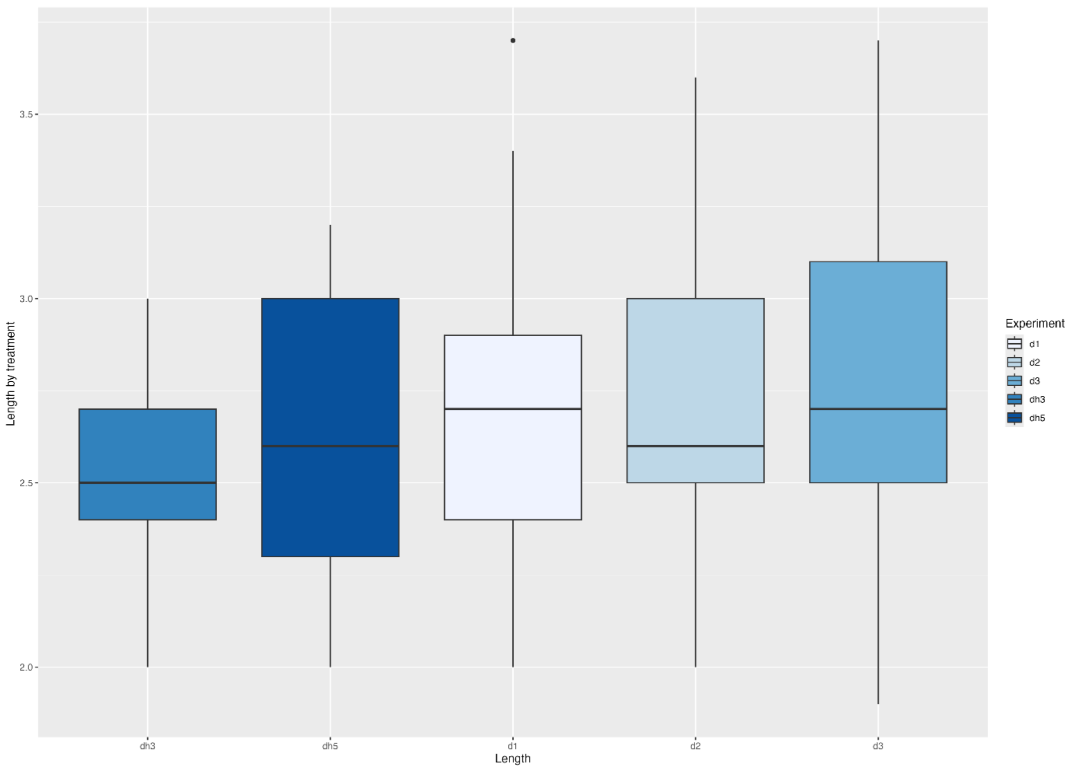

Figure 1. Graph showing the differences in total length (cm) among groups at the end of the water renewal trials. Groups: :Daily water renewal rates of 10%, 20%, and 30% (designated as d1, d2 and d3, respectively), weekly water renewal rates of 30% and 50% (designated as dh3 and dh5, respectively).

To investigate whether there are differences in length among the trials, after determining the suitability of assumption checks, the Kruskal-Wallis test was conducted due to the failure of the assumptions. According to the test results, the null hypothesis stating "there is no difference among the trials" was rejected, and the difference among the trials was found to be statistically significant ($p<0.05$). To identify which trials had differences, the Dunn test was performed. According to the results obtained from the Dunn test, the difference among the trials is statistically significant. Figure 1 is presented to evaluate the differences in total length among the groups.

In this test, statistical comparisons were made between two or more groups. Accordingly, comparisons of some pairs were evaluated using Z, P.unadj (unadjusted p-value), and P.adj (adjusted p-value).

According to this analysis, the differences among the groups are summarized in Table 3.

Table 3. Statistical comparison of total length (cm) among groups at the end of the trial.

	d2	d3	dh3	dh5
d1	O	O	X	O
d2		O	*	O
d3			*	O
dh3				O

O: No significant difference ($p>0.05$); *: Significant difference ($p<0.05$); X: Slight but not significant difference ($p>0.05$).

When evaluating these analysis results overall, only the comparisons between d2-dh3 and d3-dh3 show statistically significant differences. All other comparisons have p-values above 0.05, leading to the conclusion that there is no significant difference.

According to the data obtained at the end of the trial, the descriptive statistics of the groups in terms of live weight (g) are presented in Table 4. Additionally, the differences in live weight among the groups at the end of the trial are shown in Figure 2.

According to the results of the Kruskal-Wallis test, the null hypothesis stating "there is no difference among the trials" was rejected, and the difference among the trials was found to be statistically significant ($p<0.05$). The Dunn test was performed to identify which trials had differences.

Table 4. Descriptive statistics of end-of-trial data for live weight (g) in groups in the water renewal trials.

	Experiment	n	min	max	median	iqr	mean	sd	se	ci
1	d1	45	0.07	0.43	0.18	0.14	0.193	0.081	0.012	0.024
2	d2	45	0.05	0.48	0.19	0.12	0.208	0.097	0.014	0.029
3	d3	54	0.05	0.51	0.215	0.15	0.227	0.104	0.014	0.028
4	dh3	44	0.07	0.32	0.16	0.062	0.165	0.055	0.008	0.017
5	dh5	40	0.06	0.32	0.17	0.13	0.174	0.073	0.011	0.023

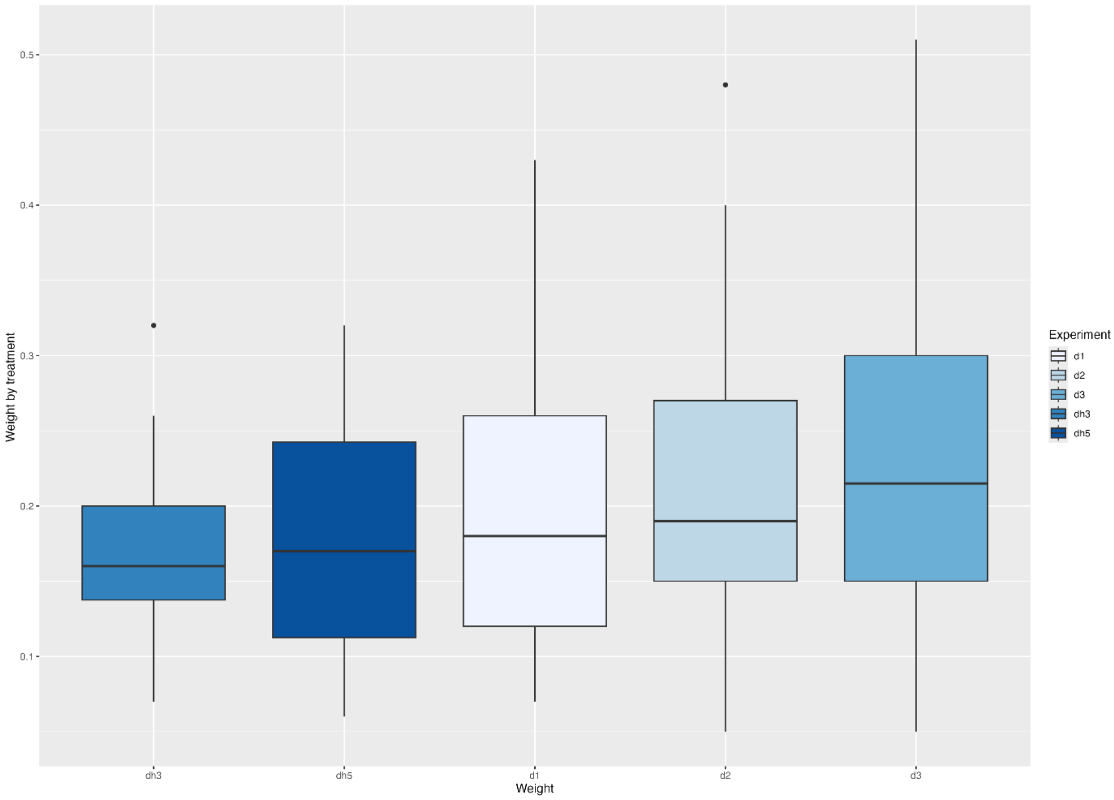

Figure 2. Graph showing the differences in live weight (g) among groups at the end of the water renewal trials. d1: daily 10% water renewal, d2: daily 20% water renewal, d3: daily 30% water renewal, dh3: weekly 30% water renewal, dh5: weekly 50% water renewal.

The evaluation of the data containing statistical comparisons among different groups is as follows (Table 5):

Table 5. Statistical comparison of weight (gr) among groups at the end of the trial.

	d2	d3	dh3	dh5
d1	O	X	X	O
d2		O	*	X
d3			*	O
dh3				O

O: No significant difference (p>0.05); *: Significant difference (p<0.05); X: Slight but not significant difference (p>0.05).

When we make a general assessment based on this data, the comparisons of d2-dh3, d3-dh3, and d3-dh5 show statistically significant differences. In all other comparisons, since the p-values are above 0.05, it can be concluded that there is no significant difference.

The scatter plots (Figure 3) illustrating the relationship between weight and length in *A. multispinis* fry affected by water renewal rates serve as an important observational tool for understanding the results of the trials.

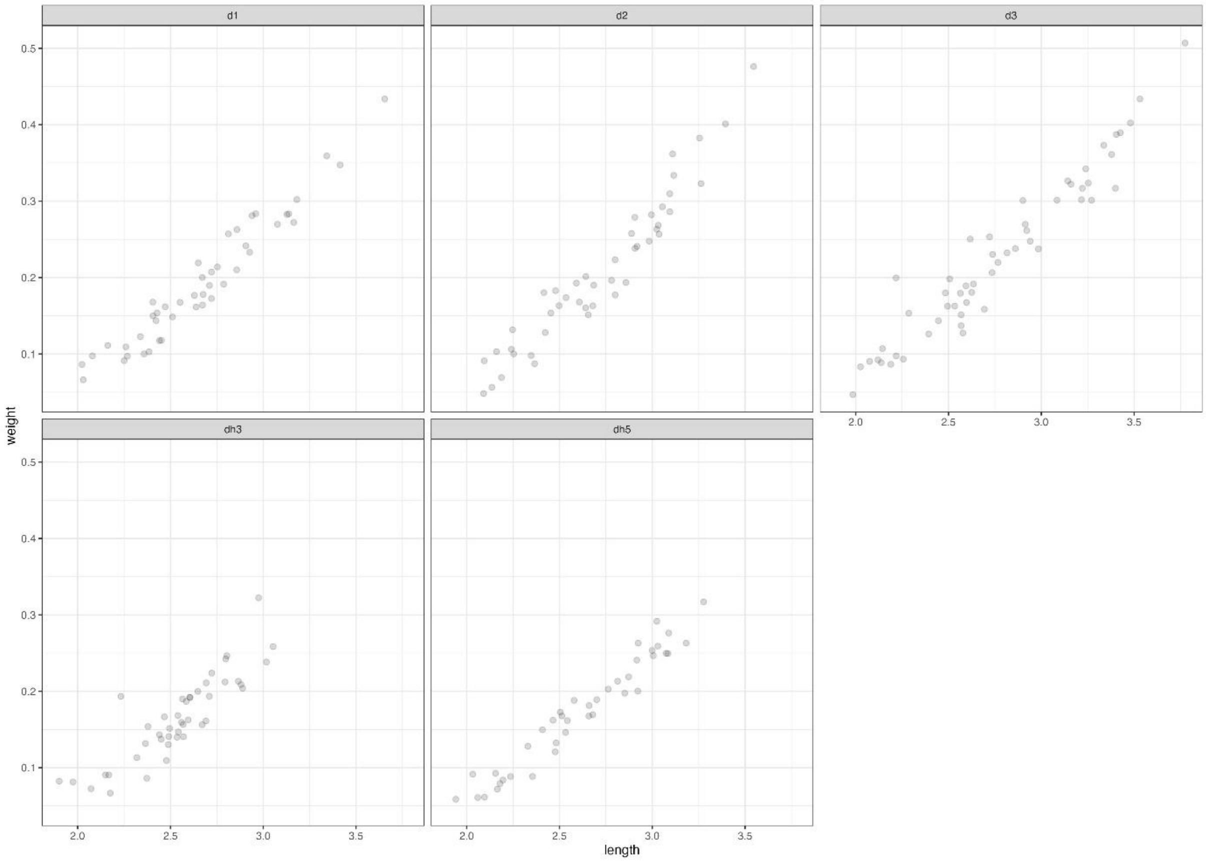

Figure 3. Scatter plots of weight-length graphs from the trials conducted to test the effect of water renewal rates on the growth of *A. multispinis* fry. Weight (=gr), length (= cm). d1: daily 10% water renewal, d2: daily 20% water renewal, d3: daily 30% water renewal, dh3: weekly 30% water renewal, dh5: weekly 50% water renewal.

In all the graphs (Figure 3), a clear positive relationship between length and weight is observed. This indicates that as the length of the *A. multispinis* fry increases, their live weight also increases during the growth process. Generally, individuals with greater total length also have higher live weights. Interpreting these graphs (Figure 3) is crucial to understand which of the water renewal groups (d1, d2, d3, dh3, dh5) exhibited better growth. For example:

- **d3**: This group shows a more pronounced positive trend compared to the others. This suggests that the water renewal rate applied in the d3 group has a slightly more favorable effect on the growth of the fry than the other groups.

- **dh3 and dh5**: The growth trends in these two groups appear less pronounced than in the others. This indicates that the effect of water renewal may vary, and some water renewal rates might be less effective on growth.

Looking at the point distribution in the graphs (Figure 3), it becomes clear how consistent the growth data is for each water renewal group. For instance, in the d1 and d2 groups, the points are more closely clustered, while in the other groups, there is a wider distribution. This suggests that some water renewal groups yield more consistent results in the growth process of the fry. Therefore, the effects of different water renewal rates on the growth of *A. multispinis* fry are clearly observed in these graphs (Figure 3), particularly highlighting the more positive effects of the water renewal rate in the d3 group on growth.

In this experiment, when examining the relationship between water change and the survival rates of fry, no statistical difference was observed between the groups (p=0.872). At the beginning of the experiment, 20 fry were stocked in each replicate tank. The number of fry remaining in each group at the end of the experiment is presented in the table below (Table 6).

Table 6. Descriptive statistics for the number of fry remaining in the groups at the end of the experiment (P = 0.872).

Group	n	min	max	median	iqr	mean	sd	se	ci
d1	3	14	16	15	1	15	1	0,577	2,484
d2	3	13	17	15	2	15	2	1,155	4,968
d3	3	13	16	15	1,5	14,667	1,528	0,882	3,795
dh3	3	11	17	16	3	14,667	3,215	1,856	7,985
dh5	3	11	16	13	2,5	13,333	2,517	1,453	6,252

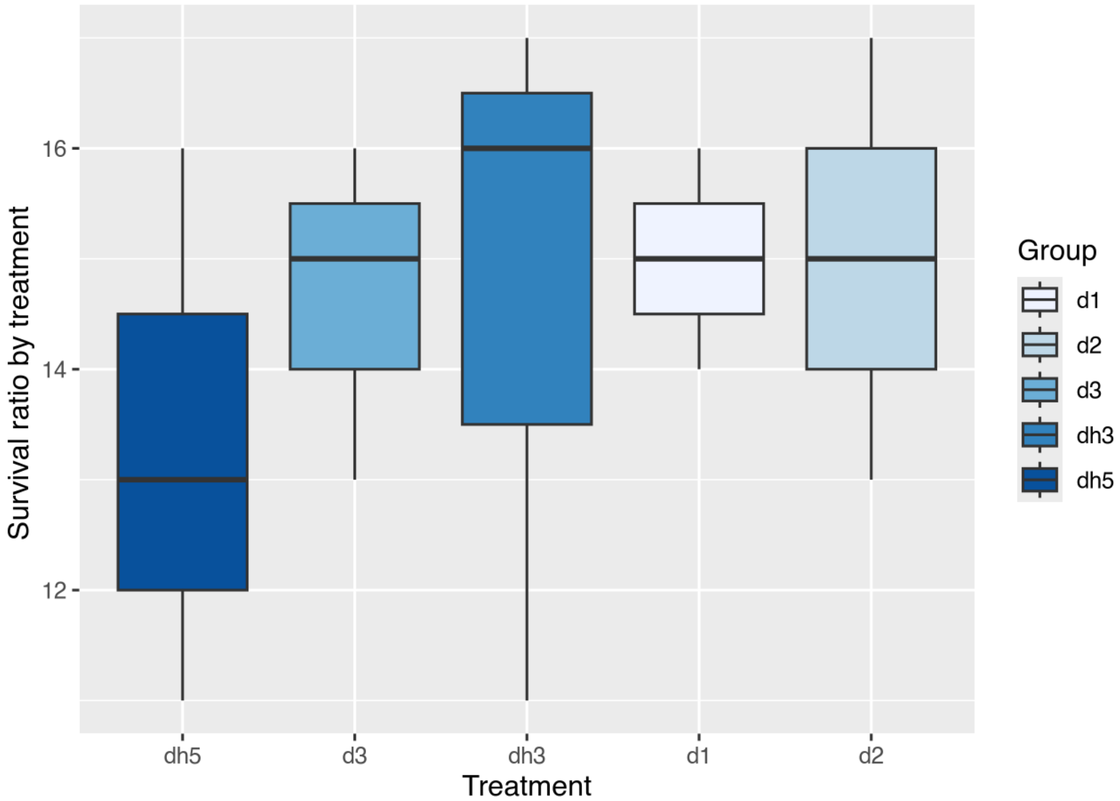

Figure 4. Survival rates in the groups as fry count at the end of the experiment.

The final status of the number of surviving fry at the end of the experiment is shown in Figure 4. Accordingly, the survival rates in the replicate tanks ranged from 55% to 85%. However, when looking at the group averages, the survival rates were found to be 75%, 75%, 73.3%, 73.3%, and 66.65% for groups d1, d2, d3, dh3, and dh5, respectively. Therefore, the statistical analysis (one-way ANOVA) determined that there was no significant difference among the groups in terms of survival rates at the end of the experiment (P = 0.872).

4. Discussion

In this study, the effects of different water renewal rates on the growth of *A. multispinis* juveniles were investigated. The findings indicate that the current breeding practices need to be reviewed and improved. The research results revealed that water renewal rates have a significant impact on the growth of *A. multispinis* juveniles. It was observed that higher water renewal rates enhance the growth performance of the fish and do not negatively affect their survival rates. Water renewal rates were found to be effective in the growth of *A. multispinis* juveniles. Higher water renewal rates positively influenced the health and growth of the fish by improving water quality. A study by Demeke and Tassew (2016) reported that water quality is a primary factor that should be prioritized for healthy fish farming. Additionally, it has been reported that water quality is directly related to growth retardation and increased stress levels in fish. In this context, optimizing water renewal rates could be an effective strategy to enhance the growth performance of *A. multispinis*. Increasing water renewal rates also helps balance the pH level of the water, which is important for the health of the fish (Jana & Sarkar, 2005).

It has been observed that traditional methods commonly used in *A. multispinis* farming in Turkey are not supported by modern scientific findings. It is understood that current producers are reluctant to adopt new methods based on their past experiences. However, this study emphasizes the importance of implementing new methods. Optimizing stock density and water renewal rates can increase production efficiency and provide economic gains.

Among the limitations of traditional methods are factors such as the lack of regular monitoring of water quality and the disregard for stock density. This situation can negatively affect the health of the fish and exacerbate the problems faced by producers. The adoption of modern aquaculture techniques can help overcome these issues. Regular monitoring of water quality and the application of appropriate water renewal rates can positively influence the health and growth of the fish (Timmons & Ebeling, 2010). It is known that water renewal rates are directly related to growth, especially in fish farming conducted in recirculating aquaculture systems. Therefore, the importance of periodic water renewals during the farming process is significant.

In this study, where the effects of water renewal rates on the growth of *A. multispinis* juveniles were observed, statistical differences among the groups were noted based on the collected data. On the other hand, as seen in the figures (Figures 2, 3), the fish in tanks with a daily 30% water renewal (d3) were observed to perform better in terms of length and weight compared to the other groups. At the end of the trial, the total length obtained in this group (2.75±0.24 cm) was greater than that of all the other groups (Table 2). Similarly, the average final live weight of this group (0.23±0.05 g) was also found to be higher than that of the other groups (Table 4).

In this research, based on the values of water renewal rates tested, it was observed that *A. multispinis* juveniles grew better with a daily water renewal rate of 30% (d3 group). In all groups of the water renewal trial, a stocking density of 5 juveniles/L was implemented. It is believed that future trials should observe the effects of a stocking density of 1 juvenile/L with daily 30% water renewals. The simultaneous application of these two techniques may allow for higher performance in growing *A. multispinis* juveniles.

Previous studies have reported that periodic water renewal practices accelerate the growth of fish. For example, a study reported that increasing water renewal rates increased the growth rate of fish by 20% (El-Saidy & Hussein, 2015). Ammonia is a compound that forms as a result of fish waste products and the decomposition of nutrients. High ammonia levels can lead to poisoning and fatal outcomes in fish. Nitrite is produced during the bacterial conversion of ammonia and causes the formation of methemoglobin in fish blood, reducing oxygen-carrying capacity. A study by Bulbul Ali and Mishra (2022) demonstrated that increasing water renewal rates significantly reduced ammonia and nitrite levels. Wendelaar Bonga (1997) showed that higher water renewal rates decreased stress levels in fish and improved their overall health. Another study indicated a correlation between fish stress levels and water renewal protocols (Zhang et al., 2025). Pottinger (2008)'s study found that increasing water renewal rates enhanced fish growth rates by 30%. Furthermore, water renewal rates can also affect the reproductive success of fish. Poor water quality can disrupt reproductive cycles and decrease the survival rates of juvenile fish. Alabaster and Lloyd (2013) found that increasing water renewal rates improved reproductive success by 25%.

In conclusion, the effects of water renewal rates on growth in *A. multispinis* farming are important factors to consider in the cultivation of this species. This study highlights the need to review and improve current farming practices. Future research can contribute to identifying best practices in *A. multispinis* breeding by more comprehensively examining the effects of different water renewal rates. Additionally, developing training programs for producers can encourage the adoption of modern methods and increase efficiency within the industry.

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Compliance with Ethical Standards

The study protocol was approved by local ethics committee of animal trials of the Çanakkale Onsekiz Mart University in the meeting dated 23.12.2022 with the decision number 2022/12-01.

Conflict of Interest

The authors declare that there is no conflict of interest.

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RESEARCH ARTICLE

Artificial Neural Networks Modelling for Nitrate Prediction in Surface Water of Gökırmak River (Türkiye)

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ABSTRACT

This study aimed to develop an artificial neural network (ANN) model to estimate the nitrate content in the surface water of the Gökırmak River. Samplings were carried out during 12 months from six stations between 2020 and 2021. Nitrate content varied between 0.20 and 2.70 mg l^{-1} while the mean value was 1.18 mg l^{-1} during the study period. The developed model consists of two input layers (month and station) and one output layer (nitrate content). Feed-forward backprop was used as the network type. Levenberg-Marquardt (TRAINLM) was used as a training function, LEARNGDM was used as an adaption learning function and mean squared error (MSE) was used as a performance function. The number of neurons was 10 and TANSIG was selected as transfer function. Epoch number adjusted 1000 iterations. ANN model predicted the nitrate content between 0.24 and 2.61 with a mean value of 1.16 mg l^{-1}. The results showed that the best validation performance is 0.61264 at epoch 30. R values are 0.96257 and 0.84231 for training and testing, respectively. R-value was found 0.85352 for all data. In conclusion, this study presents the conception of an artificial neural network (ANN) model designed to predict nitrate concentrations in river water. The developed ANN model provides reasonable results for predicting the nitrate content using only given time and location inputs. More inputs can be included in future studies to ensure higher accuracy in the development of ANN models.

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1. Introduction

Rivers play a vital role in supporting aquatic life and ensuring public health by serving as dependable sources of surface water (John et al., 2014). Recently, human activities such as industrial, urban and agricultural developments, along with natural processes like rainfall, deforestation and seasonal changes, have introduced significant land pollutants into marine environments (Kazi et al., 2009). This decline in water quality strains river habitats, reduces biodiversity and limits

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access to waterways. Therefore, it's crucial to protect freshwater sources and identify the factors impacting water quality in streams (Behmel et al., 2016).

Nitrate has become one of the most concerning and widespread pollutants affecting groundwater and surface water resources worldwide (Shukla & Saxena, 2018). This contamination primarily results from agricultural runoff, industrial discharges and other anthropogenic activities that introduce excessive nitrogen into aquatic ecosystems (Hu et al., 2021; Lawniczak et al., 2016; Wakejo et al., 2022). Ayers and Westcot (1985) notes that the concentration is usually less than 5 mg l^{-1} in most groundwater and surface but some unusual groundwater might contain amounts above 50 mg l^{-1}. While non-polluted natural waters typically contain low levels of nitrate, these human activities have led to elevated concentrations, often surpassing the World Health Organization's safe water quality standard of 50 mg l^{-1} (Davies et al., 2008; WHO, 2003). Excessive nitrate concentrations in surface water can lead to severe environmental and public health concerns (Stamenković et al., 2020). Following pesticides, nitrate is now recognized as the second most prevalent chemical pollutant in surface and groundwater (Back et al., 2018), with concerns stemming from ammonia, nitrite, atmospheric nitrogen and nitrogen in bonded forms (Zhai et al., 2017). A significant environmental consequence of high nitrate levels is eutrophication, where excess nutrients stimulate algal growth, leading to oxygen depletion and hypoxic conditions that threaten aquatic life (EPA, 2020). Therefore, accurate and efficient monitoring of nitrate concentrations is essential for ensuring environmental and public health safety.

Traditional methods for nitrate measurement rely on field sampling and laboratory analysis, which despite their accuracy are labor-intensive, time-consuming and costly (Kumar et al., 2020). As a result, alternative modeling approaches have gained attention for their ability to predict water quality parameters with high accuracy (Isık & Akkan, 2025; Kale, 2020; Palabıyık & Akkan, 2024; Satish et al., 2024; Sonmez et al., 2018; Stylianoudaki et al., 2022).

ANNs are computational models that mimic the learning processes of biological neural networks, allowing them to analyze complex, nonlinear relationships in large datasets (Hrnjica et al., 2021). In water quality modeling, ANNs have been successfully applied to predict various contaminants, including heavy metals, phosphates and nitrates, based on hydrological, meteorological and chemical data (Aguilera et al., 2001; Benzer & Benzer, 2018; Darwishe et al., 2017; Garcet et al.,2006; Halecki et al., 2018; İleri et al., 2014; Kunkel et al., 2010; Mahlknecht et al., 2023; O'Shea & Wade, 2009; Ostad-Ali-Askari et al., 2017; Palani et al., 2008; Peña-Haro et al., 2010; Ransom et al., 2022; Şengörür & Öz, 2002; Singh et al., 2009; Wagh et al., 2017; Yesilnacar et al., 2008). The application of ANNs in nitrate prediction has been explored in different regions and water systems. Stamenković et al. (2020) demonstrated the efficacy of ANNs in forecasting nitrate concentrations, providing valuable insights for environmental management and regulatory decision-making (Stamenković et al., 2020). Similarly, studies by Latif et al. (2020) and Kim et al. (2021) have successfully implemented ANN-based models to predict nitrate variations in reservoirs and river systems, contributing to more proactive water quality control measures.

This study focuses on the implementation of an artificial neural network (ANN) model to forecast nitrate levels as a water quality parameter in the Gökırmak River. The primary objective is to test and develop the ANN model for accurately estimating the nitrate content in the river's surface water. By using ANN, the study aims to enhance the prediction of nitrate concentrations, thereby contributing to effective water quality management in the Gökırmak River.

2. Materials and Methods

2.1. Study Area

Gökırmak River (Figure 1), originating from Ilgaz Mountain in the Kastamonu province, is a major tributary of the Kızılırmak River, which is the longest river entirely within Türkiye's borders. It is stretching over 221 km through Kastamonu, Taşköprü, Hanönü, Boyabat and Durağan before joining the Kızılırmak. Its basin covers an area of approximately 7000 km² (Yildirim et al., 2013). The river basin area experiences a semiarid climate and is heavily agricultural, especially for rice (Dengiz et al., 2015). Fluvial strath terraces along the river contain 3- to 5-meter-thick gravel deposits, mostly well-rounded pebbles (Yildirim et al., 2013). Soil texture varies from sandy loam to clay (Dengiz et al., 2015). Rain falls year-round, and the average annual temperature is 13.7°C. Peak evaporation usually occurs in July (Tanatmış, 2004). Additionally, the river basin is prone to flooding from heavy rain and rapid snowmelt (Baduna Koçyiğit et al., 2017). Arslan et al. (2020) reported a decreasing trend for the streamflow of the river.

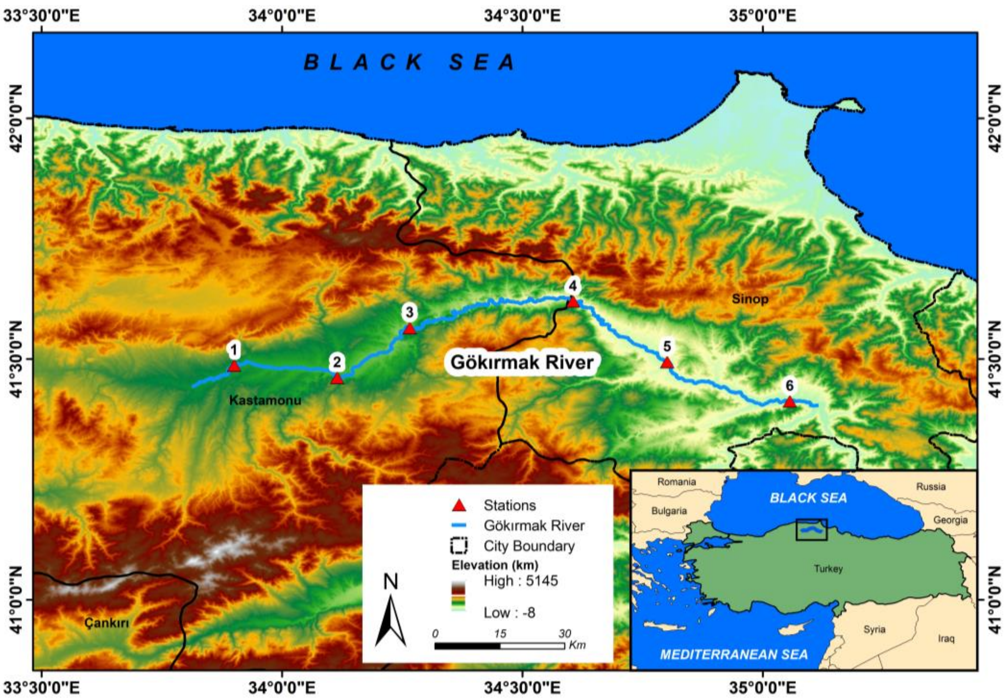

Figure 1. Map of the study area and locations of the sampling stations.

2.2. Data Collection

This study utilized data from the Gökırmak River, encompassing nitrate concentrations, time and location. Samplings were carried out during 12 months from six stations between 2020 and 2021. Nitrate concentrations were measured using spectrophotometric analysis. The sampling plan was designed to cover both seasonal variability and spatial heterogeneity of nitrate concentrations in the Gökırmak River. A total of 72 data points (12 months × 6 stations) were deemed sufficient to detect temporal and spatial patterns in nitrate fluctuations. The selection of stations was based on the river's hydrological characteristics, potential nitrate sources (e.g., agricultural activity), and accessibility. Although no formal statistical power analysis was performed, the sample size aligns with similar studies modeling water quality using ANNs.

2.3. Regression Models

In this study, several machine learning algorithms such as Linear Regression, Decision Tree, Support Vector Regression (SVR), Random Forest, and ANN were implemented to predict nitrate concentration in surface water of Gökırmak River. Linear Regression, Decision Tree, Support Vector Regression (SVR), Random Forest models were developed using the Python scikit-learn library (Pedregosa et al., 2011).

2.3.1. Linear regression

Linear regression is a fundamental statistical technique widely used for modeling the linear relationship between a dependent variable and one or more independent variables assuming linearity (Montgomery et al., 2012). The model is expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \quad (1)$$

where y is the dependent variable (target), $x_1, x_2, \ldots, x_n$ are independent (predictor) variables, β_0 is the intercept, $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients, and ε is the error term representing noise.

While linear regression offers interpretability and computational efficiency, its assumption of linearity limits its ability to model complex nonlinear relationships typically present in environmental datasets.

2.3.2. Decision tree

Decision Tree models are a non-parametric supervised learning method useful for regression tasks by recursively partitioning data into subsets based on feature values to minimize prediction error (Breiman et al., 1984). At each node, the best split is found by:

$$arg \min_{feature,thresold} \sum variance(Y_{partitions}) \quad (2)$$

where Y denotes the target variable in each partition. The prediction at each leaf node corresponds to the mean of target values within that partition.

The resulting tree structure is interpretable and capable of capturing nonlinear patterns. Despite its interpretability and ease of use, single decision trees can suffer from overfitting, particularly with limited data or noisy features, which may affect generalization.

2.3.3. Support vector regression (SVR)

Support Vector Regression is a robust method that aims to find a function within a margin of tolerance to observed data points while controlling model complexity (Smola & Schölkopf, 2004).

$$f(x) = w^T \phi(x) + b \quad (3)$$

where $\phi(x)$ maps input data into a higher-dimensional feature space, w is the weight vector, and b is the bias. The optimization problem minimizes the objective function:

$$\frac{1}{2}\|w\|^2 + C\sum_{i=1}^{n}(\xi_i + \xi_i^*) \quad (4)$$

subject to the constraints:

$$\begin{cases} y_i - f(x_i) \leq \varepsilon + \xi_i \\ f(x_i) - y_i \leq \varepsilon + \xi_i \\ \xi_i \geq 0 \end{cases} \quad (5)$$

Here, ξ_i and ξ_i^* are slack variables allowing deviations beyond ε, and C is the regularization parameter balancing the model complexity and tolerance.

Kernel functions such as the radial basis function (RBF) enable SVR to capture nonlinear relationships effectively. This method offers good performance in modeling complex data but requires careful tuning of hyperparameters (e.g., C, ε, and kernel parameters) to optimize prediction accuracy.

2.3.4. Random forest

Random Forest is an ensemble learning technique that constructs multiple decision trees on random subsets of data and features, then aggregates their predictions to enhance accuracy and reduce overfitting (Breiman, 2001). The regression prediction is obtained by averaging the outputs of individual trees:

$$\hat{y} = \frac{1}{T}\sum_{t=1}^{T} f_t(x) \quad (6)$$

where $f_t(x)$ is the prediction from the t^{th} decision tree.

This method balances accuracy and overfitting control through averaging. It handles nonlinear interactions and high-dimensional data effectively. Hyperparameters such as the number of trees and tree depth were optimized using grid search to maximize performance on nitrate prediction tasks.

2.4. Artificial Neural Network (ANN) Modeling Approach

MATLAB software was used to create ANN model. The "nntool" feature within the Deep Learning Toolbox facilitated the construction and training of our neural network models. For the learning process, we adopted the "Levenberg-Marquardt" algorithm, which is renowned for its efficiency in training feedforward neural networks. To assess the performance of our models, we measured the mean square error (MSE), allowing us to gauge the accuracy of the network predictions.

Determining the exact number of hidden layers and neurons is crucial within these layers in ANN models does not follow a strict rule. Therefore, we relied on a trial-and-error approach to ascertain the optimal network architecture. Through iterative testing, we identified the configuration that yielded the best performance, which was subsequently used in our analysis.

The input layer comprised two key variables: Time (measured in months) and location (specified by station). The output layer was designed to predict nitrate data. To construct the ANN models, we employed a linear activation function in conjunction with a differential descent algorithm. This combination was chosen to optimize the network's ability to learn and generalize from the data. As recommended by Sonmez et al. (2018), the dataset was partitioned into three segments to facilitate machine learning: 70% of the total data served as the training set, 15% was allocated as the test set, and the remaining 15% was utilized for validation purposes. This split ensured a robust evaluation of the model's performance across different data subsets. The learning rate for the model was fixed at 0.01, and the training process was conducted over 1000 iterations. These parameters were selected to balance the speed of convergence with the stability of the learning process, ultimately enhancing the model's predictive accuracy.

2.5. Performance Evaluation Criteria

We employed five distinct performance criteria to evaluate the accuracy of predictions by the artificial neural network model. These metrics are mean squared error (MSE), mean absolute deviation (MAD), mean absolute error (MAE), root mean square error (RMSE), and mean absolute percentage error (MAPE). These criteria were selected to comprehensively assess the deviation or error between the actual and predicted values, ensuring a robust evaluation of the model's predictive capabilities. Each of these measures assesses the extent of error or deviation between actual and predicted values. The accuracy of the model's predictions was calculated separately for the training data, validation data, and the entire dataset. This comprehensive analysis allowed for a nuanced understanding of the model's performance across different segments of the data, ensuring that the model's predictive power was thoroughly evaluated and validated.

2.5.1. Mean absolute deviation (MAD)

Mean absolute deviation (MAD) measures accuracy in the same unit as the data, helping to quantify the error amount. The calculation for MAD is as follows:

$$MAD = \frac{\sum_{t=1}^{n}|y_t - \hat{y}_t|}{n} \quad (7)$$

In this formula, y_t is the actual value, $\hat{y}_t$ is the predicted value, and n is the total number of observations.

2.5.2. Mean squared error (MSE)

Mean squared error (MSE) is a widely used error metric, known for penalizing larger errors more heavily due to squaring. It is calculated by dividing the sum of squared errors by the number of observations:

$$MSE = \frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n} \quad (8)$$

In this equation, n is the number of observations, A_t is the true value, and F_t is the predicted value at observation t.

2.5.3. Root mean square error (RMSE)

The root mean square error (RMSE) evaluates how closely a model's predictions match the actual values, considering the error magnitude. RMSE is derived by taking the square root of the MSE:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}} \quad (9)$$

In this equation, n represents the number of observations, A_t is the true value, and F_t is the predicted value for observation t.

2.5.4. Mean absolute percentage error (MAPE)

Mean absolute percentage error (MAPE) expresses accuracy as a percentage, making it more comprehensible than other metrics. It measures the percentage error:

$$MAPE = \sum_{t=1}^{n} \frac{\left|\frac{y_t - \hat{y}_t}{y_t}\right|}{n} \times 100 \quad (10)$$

In this equation, y_t is the actual value, $\hat{y}_t$ is the forecasted value, and n is the total number of observations.

2.5.5. Mean absolute error (MAE)

Mean absolute error (MAE) calculates the absolute deviation from the original data, without considering the sign. The formula for MAE is:

$$MAE = \frac{1}{n}\left(\sum_{t=1}^{n}|A_t - F_t|\right) \quad (11)$$

In this equation, A_t is the true value, F_t is for the predicted value, and n denotes the number of observations.

3. Results and Discussion

The artificial neural network model developed in the present study achieved a best validation performance of 0.61264 at epoch 30. This metric measures the model's ability to apply what it learned from training data to new, unseen data, ensuring reliable predictions (Stylianoudaki et al., 2022).

Several traditional and ensemble regression models (linear regression, decision tree, support vector, random forest) were tested using the same dataset to benchmark against the ANN model (Table 1). Among these, the random forest regressor showed the best performance (R^2 = 0.544, RMSE = 0.475) and clearly outperformed linear regression, decision trees, and support vector regression (SVR), all of which yielded low or even negative R^2 values. However, the ANN model remained the most effective overall, achieving R^2 = 0.842 with notably lower error metrics (RMSE = 0.386, MAE = 0.116). These findings validate the superiority of ANN models for capturing nonlinear and complex interactions in water quality datasets, particularly in nitrate prediction. The ensemble-based random forest approach may serve as a useful alternative when model interpretability or ensemble insights are prioritized.

Table 2 summarizes the output values of the performance evaluation criteria. The regression coefficients, depicted in the accompanying figure, demonstrate the strength and direction of the relationship between input variables and nitrate concentrations. The R-values, which quantify the correlation between predicted and actual nitrate levels, provide further insight into the model's accuracy. During training, the R-value was calculated as 0.96257, indicating a strong correlation between the actual data and the model's predictions. This high R-value suggests that the ANN efficiently captured the basic patterns in the training dataset. For testing, the R-value was 0.84231, reflecting the model's performance on a separate dataset that was not used during training. While slightly lower than the training R-value, this still represents a strong predictive capability. The validation R-value was determined to be 0.5339, which suggests moderate performance when applied to new, unseen data. This lower R-value indicates that while the model performs well on training and testing datasets, further refinement may be needed to improve generalization. Overall, for all input and output data, the R-value was calculated as 0.85352. This aggregate R-value highlights the model's overall effectiveness in predicting nitrate concentrations across diverse data scenarios. The results of ANN model were illustrated in Figure 2. A comparison of the nitrate (mg/l) data observed in situ and predicted using artificial neural network was also given in Figure 3.

Table 1. Comparison of performance criteria of all models.

Model	R^2	MSE	RMSE	MAE
Linear Regression	-0.093	0.541	0.735	0.597
Decision Tree	0.037	0.476	0.690	0.482
Support Vector	-0.138	0.563	0.750	0.558
Random Forest	0.544	0.226	0.475	0.358
ANN	0.842	0.149*	0.386*	0.116*

Table 2. The output values of performance evaluation criteria of ANN model for testing, training, and whole stage.

Stage	MAD	MSE	RMSE	MAPE	MAE
Training	0.19007806	0.12357852	0.35153737	25.19126661	0.25191267
Testing	0.11156097	0.14880350	0.38575056	11.59280176	0.11592802
Total	0.30163903	0.27238202	0.52190231	36.78406837	0.36784068

Among the performance criteria, MAPE and MAE values indicate that the ANN model maintained a relatively low prediction error, especially in the test stage. The lower MAD and MSE values in the testing set compared to the training set indicate that the model generalizes well, though the validation R-value highlights a potential for improvement in unseen scenarios.

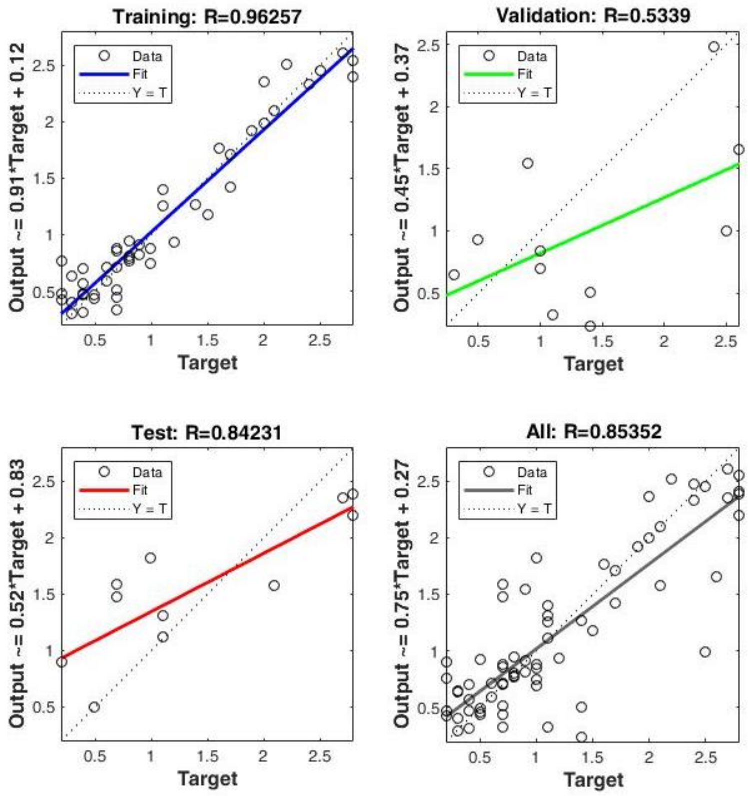

Figure 2. ANN results for predicting nitrate values in Gökırmak River.

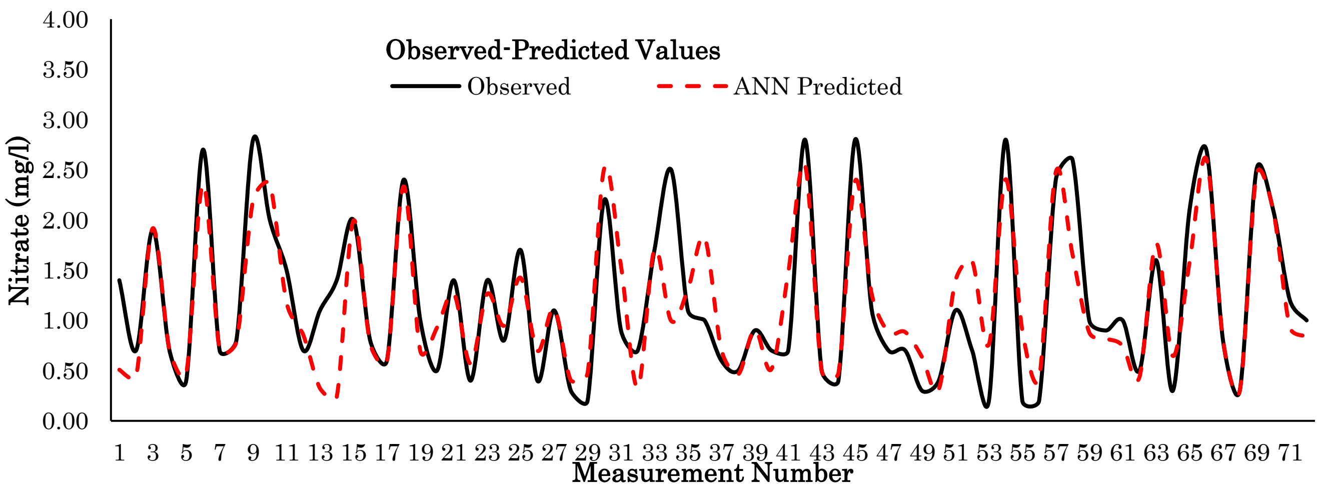

Figure 3. A comparison of the nitrate (mg l^{-1}) data observed in situ and predicted using artificial neural networks.

The results of this study demonstrate that ANN models can effectively predict nitrate concentrations in river systems, with strong correlation coefficients ($R > 0.84$) indicating a high level of accuracy. These findings align with previous research, which has shown that ANNs outperform traditional statistical methods in capturing complex environmental interactions (Suen & Eheart, 2003; Wagh et al., 2018). The findings from the application of artificial neural networks in nitrate prediction underscore the transformative potential of these models in environmental management. One of the major advantages of ANNs is their ability to process large datasets and recognize intricate patterns without requiring predefined relationships among variables (Stylianoudaki et al., 2022). The ability of ANNs to handle large, complex datasets and model nonlinear relationships offers a distinct advantage over traditional predictive methods (Wang et al., 2017). This capability is particularly valuable in river systems, where numerous factors interact to influence nitrate concentrations. This characteristic is particularly beneficial for water quality prediction, where multiple environmental factors, such as land use, temperature, and precipitation, interact in nonlinear ways to influence nitrate dynamics (EPA, 2020). However, the validation performance ($R = 0.5339$) suggests that model generalization remains a challenge. This issue has been noted in other ANN-based studies, where models trained on limited datasets exhibited reduced accuracy when applied to new or unseen conditions (Kumar et al., 2020). One possible explanation for this discrepancy is the absence of additional predictor variables, such as dissolved oxygen, pH, and land-use data, which have been shown to improve nitrate prediction accuracy in similar studies (Benzer & Benzer, 2018; Najah et al., 2013). Likewise, several authors applied ANN to predict nitrate in the surface waters and use different variables to improve the accuracy of the prediction (Halecki et al., 2018; Kim et al., 2021; Latif et al., 2020; Mahlknecht et al., 2023; Meng et al., 2022; Ostad-Ali-Askari et al., 2017; Ransom et al., 2022; Stamenković et al., 2020).

To better assess the performance of the ANN model, it was compared with regression techniques such as linear regression, decision tree regression, support vector and random forest. These models were implemented using the same dataset, and their predictive capabilities were evaluated using the same performance criteria. The ANN model outperformed the others in terms of overall accuracy, particularly in capturing nonlinear relationships. These findings underscore the trade-off between model complexity and interpretability.

Nitrate contamination in water resources fluctuates based on location and season. In densely populated regions with intensive agricultural activities, nitrate pollution tends to be more problematic. Conversely, Wakejo et al. (2022) stated that fertilizers applied to the land can be washed away and seep into the water during periods of heavy rainfall and surface runoff. Therefore, the population may also be considered to improve the precision of the prediction in addition to other variables.

ANNs have been successfully implemented in various global case studies, including in the Danube River, where they provided accurate long-term nitrate predictions (Stamenković et al., 2020), and in South Africa, where neural network-based water quality indices facilitated policy development (Banda & Kumarasamy, 2024). These applications demonstrate the scalability of ANN models in diverse hydrological settings. Additionally, incorporating real-time monitoring data from remote sensing and GIS-based systems could improve model adaptability to changing environmental conditions (Hrnjica et al., 2021).

Despite their potential, ANN models have limitations, including their dependency on large datasets for training and the difficulty of interpreting their internal mechanisms, often referred to as the “black box” problem (Wagh et al., 2018). Another critical consideration in ANN applications is their potential for overfitting. While the model performed well during training and testing, its moderate validation performance suggests that further optimization, such as dropout regularization or ensemble learning, could enhance robustness (Chen et al., 2020). To overcome these challenges, researchers have suggested integrating ANN models with other machine learning approaches, such as decision trees and extreme gradient boosting, to enhance interpretability and predictive accuracy (Najah et al., 2013). Integrating ANNs with hybrid modeling approaches, such as coupling them with physical hydrological models or fuzzy logic systems, could improve interpretability and decision-making applications (Kim et al., 2021; Xu & Liu, 2013). Additionally, interdisciplinary collaboration among hydrologists, data scientists, and policymakers is essential to ensure the practical deployment of ANN models for real-world environmental monitoring (EPA, 2020). By leveraging historical nitrate concentration data, station locations, and time-based variations, the study evaluates the potential of ANNs as a cost-effective and reliable tool for water quality management. Incorporating ANN models into environmental monitoring systems could significantly enhance decision-making processes and contribute to sustainable water resource management.

Future research should focus on refining ANN architectures by incorporating feature selection techniques to identify the most influential parameters affecting nitrate dynamics. Moreover, expanding the dataset by including additional environmental and meteorological variables could further enhance model precision. Ultimately, as noted by Ward et al. (2018), ANN-based approaches represent a transformative tool for water quality management, with the potential to mitigate nitrate pollution and safeguard freshwater resources for future generations.

4. Conclusion

In this study, the Artificial Neural Network (ANN) model demonstrated superior predictive accuracy for estimating nitrate content in surface water compared to traditional methods, such as the Random Forest regressor. The ANN's ability to capture nonlinear relationships and complex patterns within the Gökırmak River dataset contributed to its enhanced performance. However, the ANN approach requires careful tuning and larger computational resources, which may pose challenges in some practical applications. On the other hand, the Random Forest model, while generally easier to implement and interpret, showed comparatively lower predictive accuracy. Its strength lies in robustness and handling of smaller datasets without extensive parameter tuning, making it advantageous when computational simplicity and interpretability are prioritized. Given these findings, the ANN model is recommended for water quality prediction tasks involving nonlinear dynamics and relatively small datasets where predictive accuracy is paramount. For cases where model interpretability and ease of use are more critical, Random Forests remain a viable alternative. Future research should explore hybrid approaches that combine the predictive power of ANNs with the interpretability of ensemble methods, potentially enhancing both accuracy and transparency. Additionally, expanding input parameters and refining model architectures could further improve generalization and practical applicability.

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Compliance with Ethical Standards

Ethical committee approval is not required for this type of study.

Conflict of Interest

The authors declare that they have no conflict of interest.

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RESEARCH ARTICLE

Pre-selection of Imidazolinone-Resistant Canola Plants by Germination and Subsequent Seedling Growth Parameters

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Root length

ABSTRACT

This study aimed to investigate the potential use of the germination test as a model for screening canola plants for herbicide resistance. Imidazoline-resistant (IMI-R) and susceptible (IMI-S) canola hybrids were germinated in various concentrations of imazamox (0, 0.25, 0.50, 1.00, and 2.00 mM) and clopyralid (0, 0.21, 0.43, 0.85, and 1.72 mM). Germination percentage, mean germination time, germination index, shoot length, root length, seedling fresh and dry weight, and dry matter were analyzed. The results indicated that varying concentrations of imazamox and clopyralid had only a limited effect on the germination parameters in canola hybrids. However, seedling growth parameters such as shoot length, root length, and seedling fresh weight were significantly reduced with increasing concentrations of imazamox and clopyralid. Notably, the differences between IMI-R and IMI-S canola hybrids were evident for these parameters. IMI-S canola hybrid exhibited sensitivity to imazamox, while the IMI-R hybrid showed no significant reduction in growth up to 0.50 mM imazamox. Conversely, the shoot length of the IMI-S hybrid was less affected and was longer than that of the IMI-R hybrid under clopyralid treatment. Of the parameters investigated, root length was the most sensitive to imazamox, which can be used to select herbicide resistance. It was concluded that the suitable imazamox concentrations for selecting imazamox-resistant canola plants during the early growth stage were between 0.50 mM and 1.00 mM. Germination parameters were found to be unsuitable criteria for imazamox resistance, while root length, shoot length, and seedling fresh weight should be considered for selection.

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1. Introduction

Vegetable oils are essential nutrients for maintaining a healthy and balanced human diet. The production of edible oils is necessary to meet the demands of both private households and industries (Safdar et al., 2023). Canola (*Brassica napus* L.) is a globally important oilseed crop used for human consumption, a source of protein-rich animal feed, and a renewable resource for biodiesel production (Zhao et al., 2020). Its seeds and meals contain 40-46% high-quality edible oil and 38-40% protein, respectively (Yaman et al., 2024). The sowing area of canola in Türkiye is expanding because of the benefits of winter sowing, high seed yield, and high oil quality.

Canola production is affected by several adverse environmental conditions, such as drought, extreme

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temperatures, salinity, and weeds. It does not cope with the weeds due to its slow growth habits during emergence and early growth stages (Simic et al., 2011). To mitigate the weed hazard, integrated weed management involves a combination of preventative, mechanical, and chemical methods to maximize seed yield and quality of canola (Grozi, 2023). In the conventional production of oilseed canola, registered selective herbicides do not provide satisfactory control of weeds belonging to the *Brassicaceae* family, such as wild mustard, an ancestor of oilseed rapeseed. To solve this problem, herbicide-resistant canola varieties have been developed using Clearfield® technology. This technology utilizes imidazolinone herbicides and imidazolinone-resistant (IMI-R) canola hybrids (Delchev, 2021a; Grozi, 2023; Pfenning et al., 2012) to eradicate both broadleaf and narrowleaf weeds.

Imidazolinone herbicides are known for their high effectiveness at low doses and broad spectrum of weed control, but they also exhibit high persistence in soils (Balabanova, 2022; Breccia et al., 2020). In traditional oilseed canola cultivation practices, the selective herbicides currently in use have not effectively controlled weeds like *Sinapis arvensis* L., *Raphanus raphanistrum* L., *Capsella bursa-pastoris* L., *Descurainia sophia* (L.) and *Thlaspi arvense* L. (Delchev, 2021b). Therefore, hybrid canola varieties resistant to imazamox have been recently developed and registered to control these weeds (Fernández-Martínez et al., 2009; Malidza et al., 2003). Imazamox is a herbicide belonging to the imidazolinone group and inhibits the activity of the enzyme acetohydroxy acid synthase (AHAS), also known as acetolactate synthase (ALS). It is used post-emergence in leguminous crops, IMI-resistant wheat, sunflower, rice, and canola cultivars (Kaya & Kolsarıcı, 2005).

The selection of canola plants resistant to imazamox is the primary breeding objective for effective weed control. Nevertheless, this process is expensive, time-consuming, and labor-intensive because of the difficulties in identifying the resistant parents. Therefore, this study aimed to use germination and early seedling growth parameters in a laboratory setting to develop a simple, rapid, and efficient pre-selection model for imazamox resistance in canola.

2. Materials and Methods

The experiment was conducted at the Seed Science and Technology Laboratory, Department of Field Crops, Eskişehir Osmangazi University in 2024. Two commercial canola hybrids, the imidazolinone-resistant (IMI-R) hybrid KWS Cyrill CL and the imidazolinone-susceptible (IMI-S) hybrid Riccardo KWS, were used in this study.

The seeds of the canola hybrids were germinated at four concentrations of imazamox: 0.25, 0.50, 1.00, and 2.00 mM. These levels were prepared from Intervix® Pro, which contains 40 g of imazamox per liter. Additionally, the seeds were subjected to four clopyralid concentrations of 0.21, 0.43, 0.85, and 1.72 mM, prepared using Phaeton® containing 100 g of clopyralid per liter. This herbicide is registered for standard canola varieties and is used for comparative effects with imazamox. Distilled water was used as the control treatment.

A standard germination test was conducted to identify imazamox-resistant canola plants by comparing the germination and early seedling growth performance of resistant and susceptible canola hybrids. Four sets of fifty seeds from each canola hybrid were placed between three sheets of filter paper with a 20 × 20 cm dimension. A total of 21 mL of the respective solutions was applied to each replicate. Afterward, the filter papers were rolled and inserted into a zipped plastic bag to avoid moisture evaporation. They were incubated at 20°C for 7 days in the dark. Germination was determined by the appearance of a radicle hook (approx. 2 mm), following ISTA (2018) guidelines. On the last day (7^{th} day), five seedlings from each herbicide level were randomly selected to determine root length (RL), shoot length (SL), and seedling fresh weight (SFW). The seedling dry weight (SDW) was determined after drying at 80°C for 24 h.

Germination percentage (GP), mean germination time (MGT) (ISTA, 2018), germination index (GI) (Salehzade et al., 2009), and dry matter (DM) were calculated using the following equations:

$$GP\ (\%) = \frac{Germinated\ seeds\ at\ final\ day}{Total\ seeds} \times 100 \quad (1)$$

$$MGT\ (day) = \frac{\sum Dn}{\sum n} \quad (2)$$

where D is the number of days since the start of the germination test and n is the number of seeds that germinated on day D.

$$GI = \frac{NGS}{DFC1} + \cdots + \frac{NGS}{DFCx} \quad (3)$$

where NGS is the number of germinated seeds, DFC1 is the days of the first count and DFCx is the days of the final count.

$$DM\ (\%) = \frac{SDW}{SFW} \times 100 \quad (4)$$

2.1. Statistical Analysis

The experiment followed a two-factor factorial arrangement within a completely randomized design (CRD), with four replicates. Data were analyzed using the MSTAT-C software(v. 2.10, Michigan State University), and the differences were compared using Duncan's multiple range test at $p < 0.05$ level.

3. Results

A significant interaction between canola hybrids and imazamox concentrations was detected for all measured parameters except germination percentage (Table 1).

Table 1. Analysis of variance and main effects of imazamox concentrations on the investigated characteristics of IMI-S and IMI-R canola hybrids.

Factors	GP (%)	MGT (day)	GI	SL (cm)	RL (cm)	SFW (mg plant^{-1})	SDW (mg plant^{-1})	DM (%)
Hybrids (A)								
IMI-R	93.1^{b}	2.51^{a}	20.3^{b}	5.09^{a}	6.48^{a}	288^{a}	24.1^{a}	8.51^{b}†
IMI-S	97.8^{a}	2.35^{b}	21.9^{a}	3.60^{b}	2.21^{b}	237^{b}	20.6^{b}	8.82^{a}
Imazamox doses (B)								
0 (distilled water)	94.7	2.81^{a}	18.1^{b}	5.25^{a}	7.43^{a}	289^{a}	22.3^{bc}	7.78^{d}
0.25 mM	97.0	2.41^{b}	21.8^{a}	5.01^{b}	5.00^{b}	288^{a}	22.0^{bc}	7.66^{d}
0.50 mM	95.0	2.42^{b}	21.7^{a}	4.43^{c}	4.44^{c}	259^{b}	21.5^{c}	8.27^{c}
1.00 mM	95.5	2.31^{c}	21.9^{a}	3.89^{d}	3.05^{d}	258^{b}	22.5^{b}	8.71^{b}
2.00 mM	95.0	2.19^{d}	22.3^{a}	3.15^{e}	1.80^{e}	216^{c}	23.5^{a}	10.92^{a}
Analysis of variance								
A	**	**	**	**	**	**	**	*
B	*ns*	**	**	**	**	**	**	**
A×B	*ns*	**	**	**	**	**	*	**

*, **: significant at 5% and 1%, *ns*: non-significant, †: Letter(s) connected with the means denote significance levels at p<0.05.

Although the germination percentage of the IMI-S hybrid was higher than that of the IMI-R hybrid, it was not significantly influenced by imazamox concentrations. The mean germination time significantly differed between the hybrids and decreased as imazamox concentration increased. Increasing concentrations of imazamox resulted in a reduction in shoot and root length and seedling fresh weight, whereas the germination index and dry matter content increased.

The germination index was higher in the IMI-S hybrid at all levels of imazamox (Figure 1A). There was a significant difference in shoot and root length between IMI-S and IMI-R canola hybrids at all concentrations of imazamox. The shoot and root length were sensitive to imazamox treatments, as differences between canola hybrids were evident. The shoot length of IMI-S was reduced in the presence of imazamox, while it was significantly lower in the IMI-R hybrid at 1.00 mM (Figure 1C). Imazamox also caused a reduction in root length of the canola hybrids. In the presence of imazamox, the root length of the IMI-S hybrid decreased, but a significant reduction in the IMI-R hybrid was observed at 1.00 mM. The minimum root length of both canola hybrids was obtained at the imazamox dose of 2.00 mM (Figure 1D). Due to the reduction in root and shoot length, the seedling fresh weight also decreased. The IMI-R canola hybrid produced a higher seedling fresh weight than IMI-S, but it was adversely affected at levels higher than 0.50 mM (Figure 1E). There was a significant difference between canola hybrids regarding seedling dry weight in the control. However, imazamox increased the dry weight of the IMI-R canola hybrid and exhibited heavier dry weight at higher concentrations of imazamox. At 2.00 mM imazamox, the IMI-S hybrid had the highest dry matter (Figure 2). However, at 0.50 mM, the dry matter of the IMI-S hybrid significantly decreased. The dry matter of the IMI-R hybrid increased considerably at 0.5 mM imazamox. The effects of imazamox concentrations on seedling growth of two canola hybrids are displayed in Figure 3.

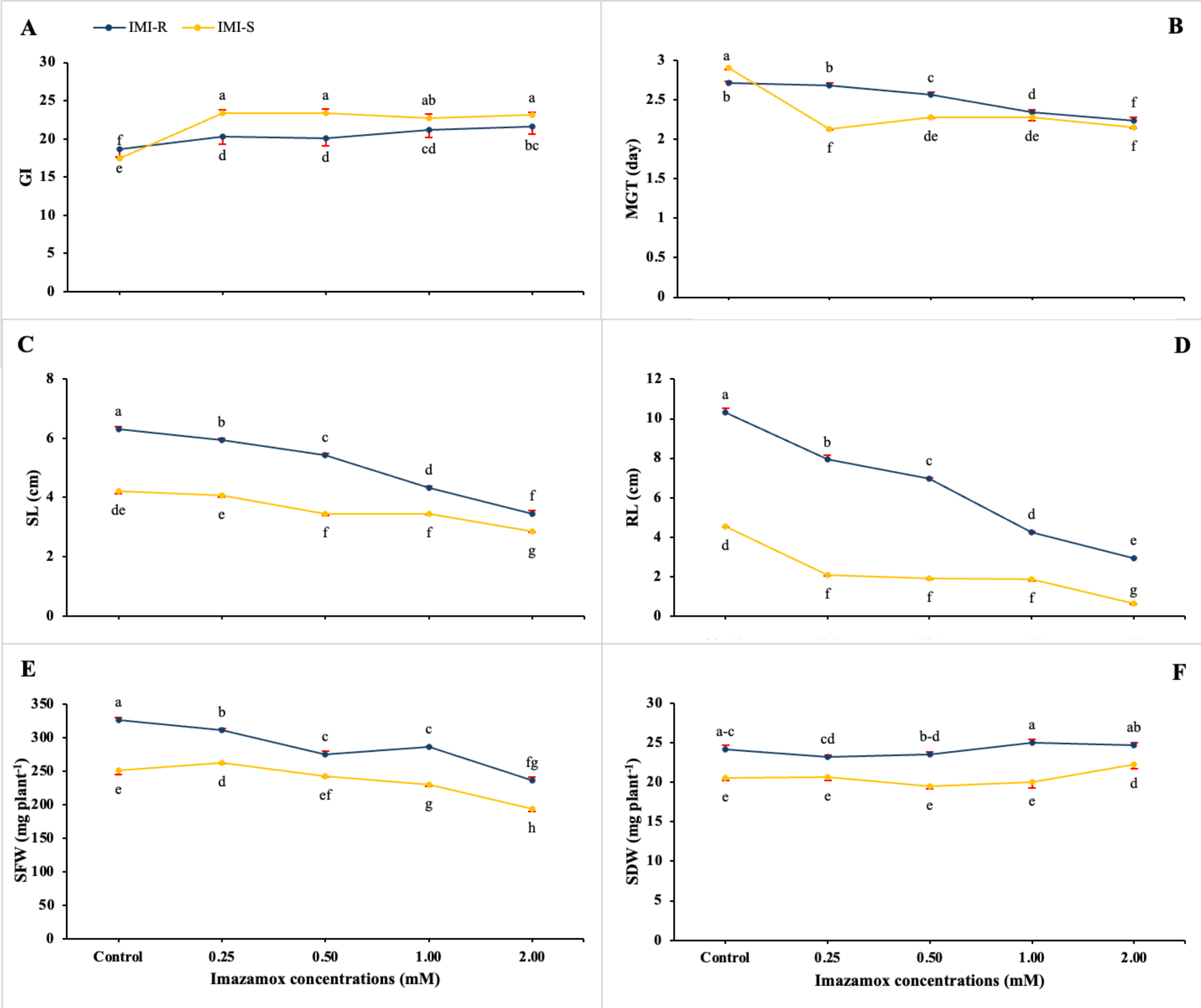

Figure 1. Changes in germination index (GI, A), mean germination time (MGT, B), shoot length (SL, C), and root length (RL, D) of IMI-S and IMI-R canola hybrids under different imazamox concentrations.

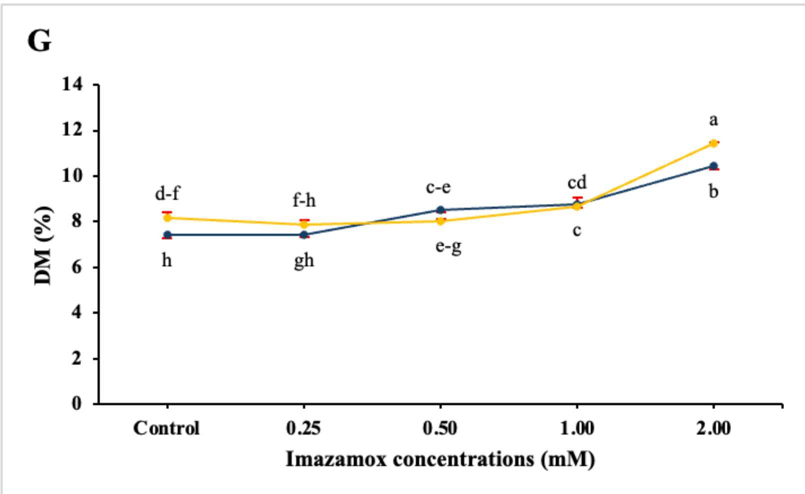

Figure 2. Changes in dry matter (DM, G) of IMI-R and IMI-S canola hybrids under different imazamox concentrations.

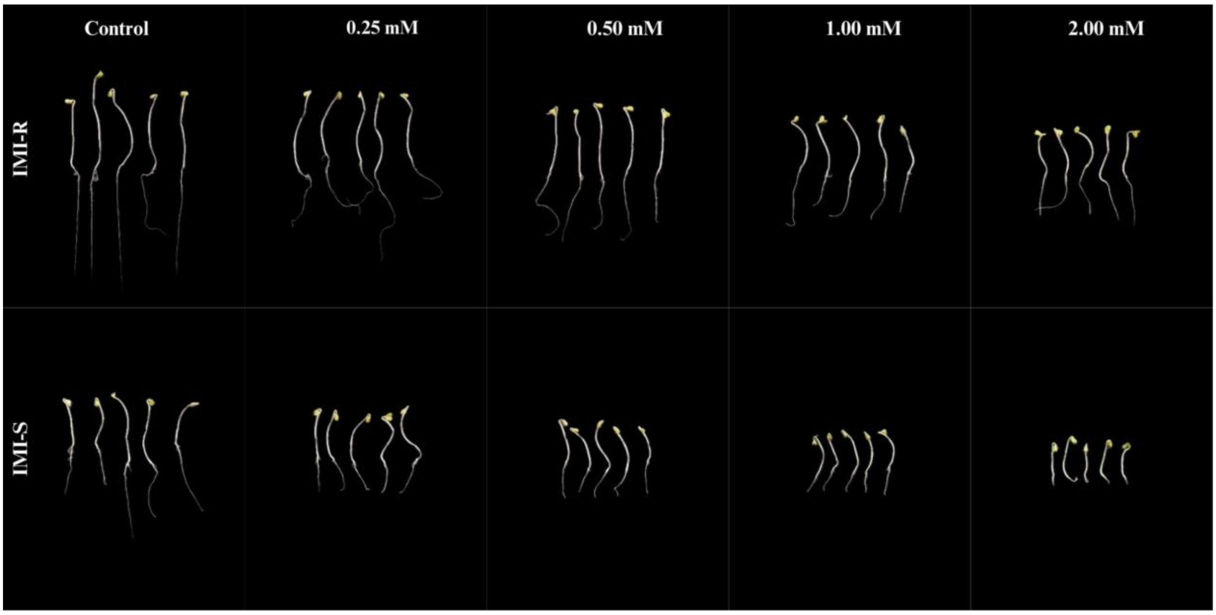

Figure 3. Pictures of seedling growth of IMI-R and IMI-S canola hybrids exposed to various concentrations of imazamox.

Analysis of variance and mean values of canola hybrids and clopyralid concentrations, along with significance levels, were given in Table 2.

Table 2. Analysis of variance and main effects of clopyralid concentrations on the investigated characteristics of IMI-S and IMI-R canola hybrids.

Factors	GP (%)	MGT (day)	GI	SL (cm)	RL (cm)	SFW (mg plant^{-1})	SDW (mg plant^{-1})	DM (%)
Hybrids (A)								
IMI-R	90.2^{b}	2.30	22.6^{a}	4.07^{b}	7.72^{a}	274^{a}	22.9^{a}	8.49^{a}†
IMI-S	96.3^{a}	2.25	22.1^{b}	4.63^{a}	4.35^{b}	246^{b}	17.8^{b}	7.29^{b}
Clopyralid doses (B)								
0 (distilled water)	92.5^{ab}	2.33^{a}	21.5^{bc}	4.90^{ab}	8.33^{a}	286^{a}	20.6	7.14^{c}
0.21 mM	94.7^{a}	2.24^{b}	23.8^{a}	4.99^{a}	6.90^{b}	276^{b}	20.5	7.39^{c}
0.43 mM	93.7^{a}	2.14^{c}	23.5^{a}	4.81^{b}	6.20^{c}	279^{ab}	20.5	7.30^{c}
0.85 mM	95.2^{a}	2.36^{a}	22.1^{b}	3.88^{c}	5.21^{d}	247^{c}	20.3	8.21^{b}
1.70 mM	90.0^{b}	2.31^{ab}	21.1^{c}	3.14^{d}	3.56^{e}	213^{d}	20.0	9.40^{a}
Analysis of variance								
A	**	*ns*	*	**	**	**	**	**
B	**	**	**	**	**	**	*ns*	**
A×B	*	*ns*	**	**	**	**	*ns*	**

*, **: significant at 5% and 1%, *ns*: non-significant, †: Letter(s) connected with the means denote significance levels at p<0.05.

Two-way interactions between canola hybrid and clopyralid concentration were significant for all investigated characteristics except for MGT and seedling dry weight (Table 2). The highest germination percentage (95.2%) was achieved at 0.85 mM, while the minimum germination index (21.1) was recorded at 1.72 mM clopyralid. On the other hand, shoot and root length were significantly decreased when the clopyralid levels increased. A similar trend was observed in seedling fresh weight, which also decreased with higher clopyralid concentrations. This finding is surprising for canola, because clopyralid is registered for use with canola varieties. No significant effects of clopyralid levels on seedling dry weight were found. The response of seedling fresh weight of the IMI-R and the IMI-S hybrids to clopyralid was different, with a slight decrease as clopyralid levels increased. In contrast, dry matter increased with higher concentrations of clopyralid. The interaction between canola hybrids and clopyralid concentrations is displayed in Figure 4.

The germination index of canola hybrids varied with increasing concentrations of clopyralid. In the control, the IMI-S hybrid had a lower germination index than the IMI-R hybrid. However, in the presence of clopyralid, the IMI-S hybrid exhibited a higher germination index (Figure 4A). The mean germination time decreased in both canola hybrids as clopyralid levels increased (Figure 4B). Shoot length showed a clear response to clopyralid doses, with the IMI-R hybrid showing longer shoots length under all concentrations of clopyralid (Figure 4C). Increased clopyralid concentrations led to a decline in shoot length. Similarly, both canola hybrids had shorter root length with increasing clopyralid concentrations (Figure 4D and 5). The IMI-R hybrid, however, produced longer roots than the IMI-S hybrid. As shoot and root length decreased, seedling fresh weight decreased with increasing clopyralid levels (Figure 4E), with the IMI-R hybrid showing a heavier weight. The dry matter of canola hybrids was altered by clopyralid concentrations, with a slight increase observed as clopyralid concentrations increased (Figure 4F).

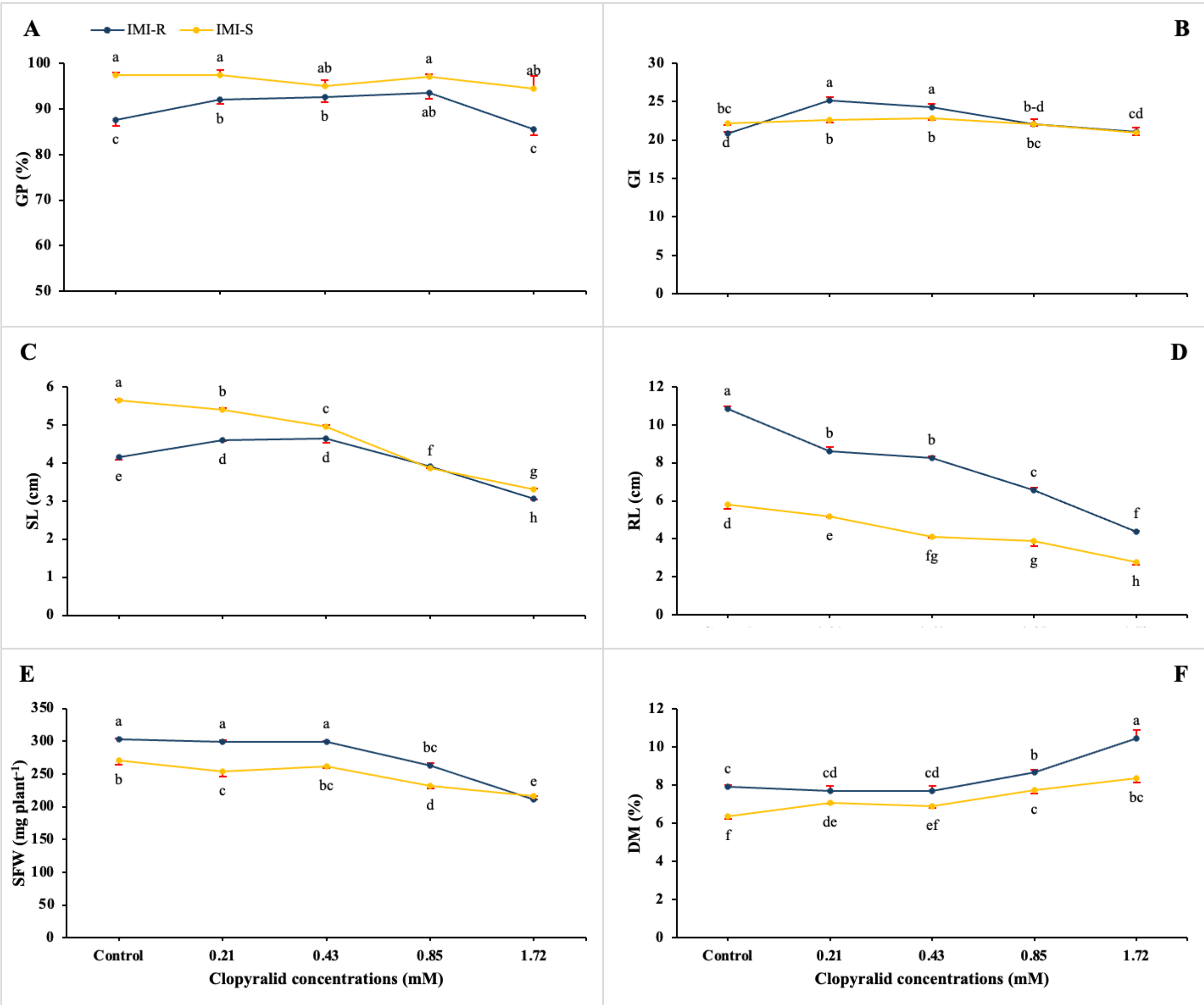

Figure 4. Changes in the investigated parameters of IMI-S and IMI-R canola hybrids under different clopyralid concentrations.

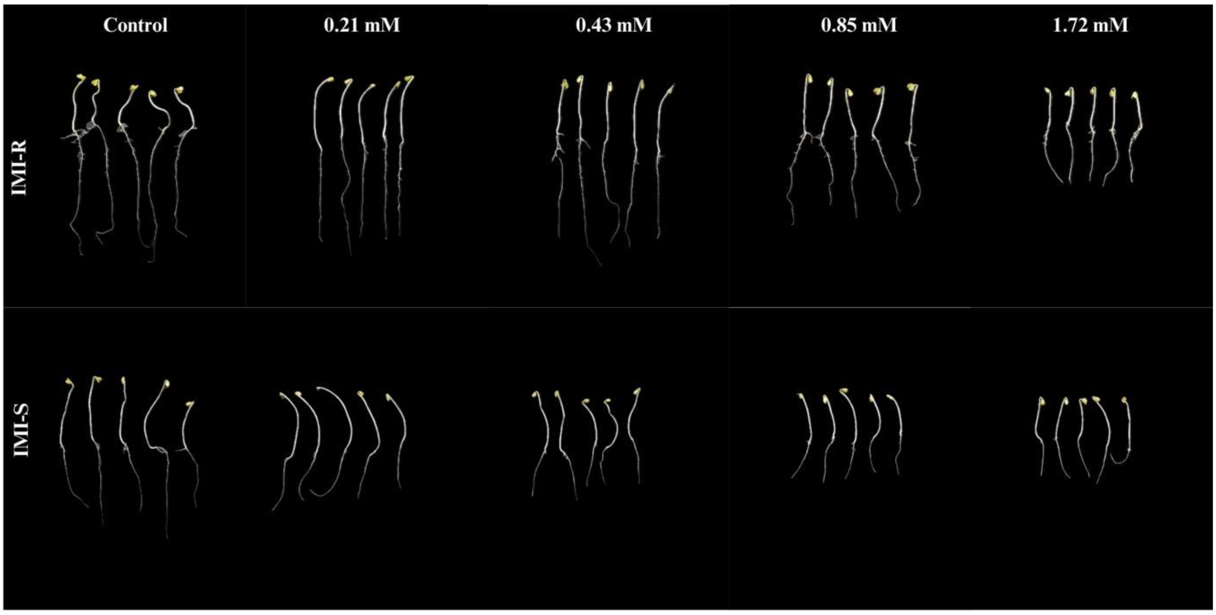

Figure 5. Pictures of seedling growth of IMI-R and IMI-S canola hybrids exposed to various concentrations of clopyralid.

4. Discussion

This study showed that the germination percentage of IMI-S and IMI-R winter canola hybrids was not affected by low, medium, and high doses of imazamox. However, germination was slightly inhibited by a high dose (1.72 mM) of clopyralid. Unlike imazamox, the mean germination time of canola hybrids was undistinguished, while the germination index was reduced as the clopyralid concentrations increased. No significant differences in these parameters were observed between the IMI-S and IMI-R hybrids. Our results are consistent with the findings of Harmancı et al. (2024) in sunflower, who found that the germination percentage of IMI-R and IMI-S hybrids was not influenced by imazamox doses. In the present study, this result argues that the toxicity of imazamox and clopyralid begins after the germinating seeds have absorbed water through the roots.

The seedling growth characteristics, including shoot length, root length, and seedling fresh weight, were severely inhibited by imazamox treatments in the IMI-S canola hybrid. In contrast, no signs of inhibition were observed in the IMI-R hybrid at concentrations up to 1.00 mM imazamox. The sensitivity of root growth in IMI-S canola was particularly noticeable, with inhibition observed at 2.00 mM imazamox. A clear distinction was evident in the root length between the IMI-S and IMI-R hybrids (Figures 1C and 2D, Figure 2E). Similarly, shoot length sensitively responded to imazamox and effectively distinguished the IMI-R hybrid from the IMI-S hybrid. The presence of imazamox led to a decrease in shoot length in the IMI-S hybrid, while it was reduced by the imazamox application of 0.50 mM in the IMI-R hybrid. The seedling fresh weight was also reduced by imazamox, but the response of canola hybrids varied depending mainly on shoot growth. Similar findings were reported in wheat by Breccia et al. (2018) and Haliloğlu et al. (2022), who observed inhibition of root and shoot growth with increasing doses of imazamox.

In the presence of clopyralid, no significant difference between the control and 1.72 mM clopyralid was observed for germination percentage and germination index (Figure 4A, B). Surprisingly, increased clopyralid concentrations restricted shoot length, root length, and seedling fresh weight in both canola hybrids. Furthermore, the sensitivity of shoot growth in the IMI-R hybrid was more pronounced, with depletion observed at all doses of clopyralid. A clear difference was determined between the shoot and root length of the IMI-S and IMI-R hybrids (Figure 4E, F). Compared to imazamox, shoot length did not respond to clopyralid and did not successfully separate the IMI-R from the IMI-S hybrid. The availability of clopyralid resulted in a decrease in shoot length in the IMI-S hybrid, while it first increased and then decreased in the IMI-R hybrid. No dead seedlings were observed in this study. Therefore, the experiment was terminated at 7 days because the canola seedlings in the control group started to deteriorate, which was not enough time for the seedlings to die. When the clopyralid concentrations increased, both IMI-R and IMI-S hybrids showed a dramatic reduction in root length (Figure 4F). This result indicates that clopyralid should not be used as a pre-sowing or pre-emergence herbicide during sowing time because of its inhibitory effects on early seedling growth of IMI-R and IMI-S canola varieties.

5. Conclusion

These results indicate that germination parameters cannot be used as selection criteria in canola plants for herbicide resistance. Apart from imazamox herbicide, clopyralid also caused a decrease in the growth of seedlings in both canola hybrids. The seedling growth was much more sensitive to imazamox, with the IMI-S hybrid being more affected by imazamox than the IMI-R hybrid. Root length, shoot length, and seedling fresh weight are reliable indicators for identifying imazamox-resistant parents in canola germplasm. The optimal concentration of imazamox during the early growth stage of canola was found to be 0.50-1.00 mM. Clopyralid also significantly inhibited seedling growth in both canola hybrids. This inhibition may be attributed to the sensitivity of canola to clopyralid during the early seedling growth stage, making its application not recommended at this stage. Root length and seedling fresh weight may serve as useful indicators for assessing clopyralid resistance in canola.

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Compliance with Ethical Standards

Ethics committee approval was not required for this study because there was no study on animals or humans.

Conflict of Interest

The authors declare no conflict of interest.

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RESEARCH ARTICLE

Criterion-Based Evaluation of Water Management Performance of Irrigation Cooperatives in Pasinler District, Erzurum

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Water management

ABSTRACT

The performance of irrigation cooperatives is pivotal in ensuring sustainable water management in agriculture-dependent regions. Pasinler district, located in the Eastern Anatolia Region of Türkiye, is one of the key agricultural production areas, with the local economy largely reliant on agriculture and livestock. In this context, the efficiency of irrigation systems plays a critical role not only in enhancing agricultural productivity but also in improving the quality of life and socioeconomic well-being of the local population. This study aims to assess the water management performance of irrigation cooperatives in the Pasinler district of Erzurum, Türkiye, based on five critical dimensions: physical and technical infrastructure, land and irrigation area management, irrigation methods and practices, operational maintenance and management, and economic-financial management. Data were collected from nine cooperatives operating in the region through structured evaluations and cooperative records. Findings reveal significant disparities in infrastructure capacity, with large cooperatives such as Pasu owning up to 120 wells and pumps, whereas others, like Alvar and Porsuk, operate with minimal or no infrastructure. Despite differences in scale, all cooperatives rely on traditional surface irrigation methods, indicating low water-use efficiency. Furthermore, none of the cooperatives have undergone land consolidation, leading to inefficient irrigation practices due to fragmented land structures. Most cooperatives depend on electricity for irrigation, yet lack renewable energy integration, creating financial vulnerabilities amid rising energy costs. Additionally, the absence of digital payment systems and structured fee collection mechanisms undermines financial transparency and sustainability, with some cooperatives consistently operating at a loss. This study underscores the necessity of targeted improvements in infrastructure modernization, renewable energy integration, institutional capacity building, and financial governance. Encouraging land consolidation, adopting smart irrigation technologies, and strengthening managerial frameworks are essential steps toward enhancing irrigation efficiency and agricultural sustainability. These findings suggest that future interventions should prioritize integrated policy frameworks that align technical upgrades with institutional and financial reforms to ensure the long-term viability of irrigation cooperatives.

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1. Introduction

In regions where agriculture is heavily reliant on irrigation, the performance of irrigation cooperatives holds critical importance for effective water management (Molle & Berkoff, 2007). Evaluating the performance of these cooperatives reveals the complex and multifaceted nature of agricultural water governance. Irrigation cooperatives play a crucial role in efficiently managing water resources, enhancing agricultural

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productivity, and promoting sustainable practices (de Deus Ribeiro et al., 2024). Key performance indicators often include irrigation coverage rates, cost recovery ratios, and the effectiveness of water fee collection (Bos et al., 2005). For instance, studies conducted in different regions have shown significant variations in irrigation rates and cost recovery levels, highlighting the role of financial management efficiency as a prominent performance criterion (Aydın & Akçay, 2023). The physical and technical infrastructure of irrigation cooperatives is fundamental to their overall performance. Core indicators include the condition of irrigation canals, water distribution systems, and drainage infrastructure. Research indicates that the physical performance of cooperatives varies considerably depending on regional characteristics and management practices (Gondwe & Mayo, 2018). These disparities underline the need for tailored strategies that align infrastructure capacity with localized environmental and operational demands. Therefore, a comprehensive understanding of both technical and managerial dimensions is essential for enhancing the effectiveness and sustainability of irrigation cooperatives.

The water management performance of irrigation cooperatives is of vital importance for the sustainability of agriculture, efficient utilization of water resources, and rural development in Türkiye (Kirmikil, 2025). This study examines the performance of irrigation cooperatives across five critical dimensions: physical and technical infrastructure, irrigation area and land management, irrigation methods and practices, operational maintenance and management, and economic and financial administration. Previous research has also been evaluated in the context of these dimensions. Findings from earlier studies indicate that physical and technical infrastructure plays a decisive role in determining the efficiency of irrigation systems. It has been observed that many irrigation cooperatives in Türkiye operate with outdated and inefficient infrastructure, which contributes to significant water losses. For instance, a study conducted in the province of Aydın revealed that irrigation coverage rates among cooperatives ranged from as low as 7% to as high as 94%, and in some cases, the return on investment was found to be far from sustainable (Aydın, 2019). These results highlight the critical need for infrastructure modernization and targeted investment to enhance system performance and long-term viability.

Land and irrigation area management remain ineffective, particularly due to the lack of land consolidation practices and the prevalence of fragmented land structures. These conditions hinder the uniform distribution of water and significantly reduce overall efficiency. In regions where land planning is not aligned with irrigation project implementation, water wastage increases, and the cost-effectiveness of irrigation systems declines (Rogy et al., 2022). The adoption of modern irrigation methods also has a substantial impact on the performance of cooperatives. Although surface irrigation systems are still widely used, more efficient techniques such as drip and sprinkler irrigation have not been broadly adopted due to high initial costs and a lack of technical expertise. A study conducted in Şanlıurfa revealed that farmers face significant financial and technical barriers in transitioning to drip irrigation systems (Aydoğdu et al., 2021). These constraints have negative implications for water conservation and crop productivity, underscoring the need for supportive policies and capacity-building initiatives to enhance the uptake of modern irrigation technologies.

Operational maintenance and management capacity plays a critical role in the overall success of irrigation cooperatives. This capacity directly influences the efficient operation of infrastructure, the regular execution of maintenance activities, the rational use of resources, and the sustainability of service quality. For example, a study conducted in Aydın province found that cooperatives demonstrating higher water use efficiency and financial sustainability also possessed stronger operational maintenance and management capabilities. Specifically, indicators such as the proportion of maintenance expenses relative to income and the irrigated area per staff member were found to significantly reflect cooperative performance (Aydın & Akçay, 2023). Similarly, research on cooperative systems in Tanzania emphasized that limited managerial capacity and institutional shortcomings hindered the potential of cooperatives to alleviate poverty and ensure sustainable agricultural production (Zhang et al., 2021). Moreover, the strategic capacity development framework developed by the FAO underscores the importance of training cooperative managers and technical personnel as a vital prerequisite for the efficient operation of modern irrigation systems (Facon et al., 2008). In this context, the long-term success of irrigation cooperatives depends not only on physical infrastructure investments but also on institutional capacity building to effectively operate and sustain that infrastructure.

Economic and financial management capacity is considered a fundamental element for the long-term sustainability of irrigation cooperatives (de Deus Ribeiro et al., 2024). It is not sufficient for cooperatives to merely generate income; they must also effectively plan and allocate these revenues, establish structures capable of covering operational and maintenance costs, and maintain financial resilience against unexpected expenditures. These factors are critical for ensuring the overall sustainability of the irrigation system. A field study conducted in Nepal revealed that effective financial management and accounting practices in agricultural cooperatives not only contribute to economic sustainability but also strengthen institutional capacity and trust among cooperative members. The use of computerized accounting systems, regular financial reporting, staff training, and managerial transparency were identified as key factors that positively influence cooperative performance (Pandey et al., 2024). These findings suggest that financial management should not be viewed merely as an administrative necessity, but rather as a cornerstone for rural development and the continuity of agricultural services.

In conclusion, achieving sustainable and effective water management through irrigation cooperatives in Türkiye requires a comprehensive, multidimensional assessment. Enhancing both the technical and managerial capacities of these cooperatives necessitates the modernization of physical infrastructure, optimization of land use, promotion of modern irrigation technologies, professionalization of operational maintenance processes, and the establishment of a robust financial management framework. This study evaluates the performance of irrigation cooperatives in the Pasinler district of Erzurum across five critical dimensions: physical and technical infrastructure, irrigation area and land management, irrigation methods and practices, operational maintenance and management, and economic and financial governance. By analyzing these aspects, the study aims to identify best practices, existing challenges, and areas in need of improvement, offering insights that can inform more effective and sustainable irrigation governance strategies. Accordingly, the study hypothesizes that the water management performance of irrigation cooperatives in the Pasinler district is significantly influenced by disparities in infrastructure capacity, irrigation practices, land fragmentation, operational management, and financial sustainability.

2. Materials and Methods

This study analyzed nine irrigation cooperatives in the Pasinler district of Erzurum across five critical dimensions: (1) physical and technical infrastructure, (2) irrigation area and land management, (3) irrigation methods and practices, (4) operational maintenance and management, and (5) economic and financial administration. Data were obtained directly from cooperative officials through structured inquiries and documentation.

Within the physical and technical infrastructure category (Bos et al., 2005), the following indicators were assessed: number of wells, average well discharge, electrical power capacity, number of pumps, quantity of tools and equipment, and the method used for measuring water consumption. For the irrigation area and land management dimension (Garces-Restrepo et al., 2007), key variables included the size of the irrigated area, the proportion of land being irrigated, and the status of land consolidation efforts. The irrigation management and practices dimension (Pereira et al., 2012) covered the type of water source, irrigation method (e.g., surface, drip, sprinkler), and energy source used (electric or gravity-based systems). Regarding operational maintenance and management (Ashine et al., 2025), data were collected on the construction institution, well maintenance and repair status, and the number of technical staff employed. Lastly, the economic and financial management dimension (Kirmikil, 2025) focused on how water fees are determined, the financial balance status (profit/loss), and the methods used for fee collection. These parameters were used to comprehensively evaluate the cooperatives' capacity to deliver sustainable irrigation services.

3. Results

The data collected were analyzed and presented across five critical dimensions: physical and technical infrastructure, irrigation area and land management, irrigation methods and practices, operational maintenance and management, and economic and financial administration.

2.1. Physical and Technical Infrastructure

This section presents findings related to the current physical capacity and technical adequacy of the irrigation cooperatives. Key indicators assessed include the number of wells, average discharge rates, electrical power of pumps, total number of pumps, and the availability of tools and equipment owned by the cooperatives. The status of these indicators across different cooperatives is detailed in Table 1. These metrics provide valuable insights into the operational capacity of the irrigation systems and the adequacy of their supporting infrastructure.

The findings presented in Table 1 highlight significant scale-based differences in infrastructure capacity among the irrigation cooperatives. In particular, large-scale cooperatives such as Pasu (Central) possess a high number of wells and pumps, whereas cooperatives like Alvar and Porsuk operate with notably fewer resources. This indicates that cooperatives serving larger areas have made substantial infrastructure investments, while smaller-scale cooperatives rely on lower-cost, localized solutions. Technical indicators such as well discharge rates and pump capacity directly affect irrigation efficiency. Therefore, infrastructure improvements are necessary in regions with low discharge levels. Although high electrical power increases irrigation speed, it also leads to elevated energy costs. Thus, integrating renewable energy sources is of critical importance for long-term sustainability. Additionally, the lack of equipment and inadequacies in water measurement systems represent key weaknesses in operational efficiency and resource management. In this context, infrastructure investments must be strategically planned by local conditions, while improvements in metering accuracy and the adoption of sustainable energy alternatives should be prioritized in both academic and policy-oriented frameworks.

Table 1. Physical and technical infrastructure information of the irrigation cooperatives.

Indicator	Status by Cooperative	Commentary and Recommendations
Number of Wells	Highest: Pasu (120 wells) Medium: Tepecik (30), Yiğittaşı-Pusudere (7), Karakoç (5) Lowest: Alvar (2), Porsuk (0)	Large cooperatives tend to have higher infrastructure investments; smaller ones operate with simpler and lower-cost systems.
Average Well Discharge (L/s)	High discharge: Alvar (65), Tepecik (55) Low discharge: Karavelet (22)	Cooperatives with higher discharge rates have advantages in irrigation efficiency. Improvements are needed in low-discharge regions.
Electrical Power (kW)	Highest: Alvar (47.5 kW) Lowest: Pusudere (23.5 kW)	Higher power consumption increases irrigation performance but also raises energy costs; energy-efficient alternatives should be considered.
Number of Pumps	Highest: Pasu (120), Tepecik (27) Medium: Yiğittaşı (7) Low: Alvar (2) None: Porsuk (0)	A large number of pumps implies high maintenance costs; effective maintenance and management systems are essential.
Number of Tools and Equipment	Generally unavailable or very limited	Lack of equipment poses risks to operational continuity; this gap should be addressed through targeted investments.
Water Measurement Practice	In most cooperatives, water usage is measured at the distribution point (e.g., Karavelet, Pasu, Yiğittaşı, Alvar, Tepecik)	More accurate monitoring of water use should be ensured through advanced metering systems such as flow meters.

2.2. Irrigation Area and Land Management

This section presents findings related to the service area of irrigation cooperatives, the extent to which these areas are irrigated, and the status of land consolidation. Key indicators such as total irrigated land (in decares), the proportion of irrigated to total service area, and whether land consolidation has been implemented are detailed in Table 2. These metrics are evaluated in terms of their implications for irrigation efficiency, production capacity, and resource utilization effectiveness.

Table 2. Irrigation area and land management by cooperative.

Indicator	Status by Cooperative	Commentary and Recommendations
Irrigation Area (decare)	Largest: Pasu (75,000 decares) Medium-sized: Alvar (20,000), Tepecik (15,000) Smallest: Karavelet (600), Karakoç (1,700)	Managing large-scale areas is challenging; although economies of scale are beneficial, specific policies are needed for effective management.
Proportion of Area Irrigated	Karavelet: 58%, Yiğittaşı: 67%, Pasu, Tepecik, Porsuk, Karakoç: 100%. In some areas, data is unavailable (e.g., Büyüktüy-Küçüktüy-Saksı)	In areas where full capacity is not utilized, planning and management processes should be improved.
Land Consolidation Status	No land consolidation has been implemented in any cooperative (e.g., Karavelet, Pasu, Yiğittaşı, Pusudere, Alvar, Tepecik, Porsuk, Karakoç, Büyüktüy-Küçüktüy-Saksı)	Land consolidation efforts should be initiated, as they are essential for improving irrigation efficiency.

The data on irrigation area and land management (Table 2) reveal significant scale disparities and structural challenges among the cooperatives. Cooperatives such as Pasu (Central), which serve large irrigation areas (75,000 decares), benefit from economies of scale but also face complex management processes and high operational costs. In contrast, smaller cooperatives like Karavelet and Karakoç, operating on more limited land, may offer more manageable systems but are constrained in terms of production capacity. In terms of the proportion of irrigated land, some cooperatives (e.g., Pasu, Tepecik, Porsuk, Karakoç) have achieved full capacity (100% irrigation), while others, such as Karavelet (58%) and Yiğittaşı (67%), remain below potential. This discrepancy points to management or technical issues that prevent full utilization of existing infrastructure. A key structural deficiency is the absence of land consolidation in all cooperatives. Without consolidation, the equal, rapid, and efficient distribution of water becomes significantly more difficult. Therefore, land consolidation should be viewed as a strategic intervention essential for improving irrigation efficiency.

2.3. Irrigation Methods and Practices

This section presents findings on the irrigation methods employed by the cooperatives, the types of water sources they utilize, and the forms of energy used in water delivery. Variables such as irrigation technique (surface, sprinkler, drip), source of water (groundwater or surface water), and energy type (electricity or gravity-fed systems) are detailed in Table 3. These findings are assessed in the context of water-use efficiency and environmental sustainability.

Table 3. Irrigation methods and practices by cooperative.

Indicator	Status by Cooperative	Commentary and Recommendations
Type of Water Source	Groundwater: Most cooperatives Surface water: Only Porsuk	Groundwater sources pose sustainability risks. Surface water is more vulnerable to drought but offers more sustainable management.
Irrigation Method	All cooperatives (Karavelet, Pasu, Yiğittaşı, Pusudere, Alvar, Tepecik, Porsuk, Karakoç, Büyüktüy-Küçüktüy-Saksı) use surface (flood) irrigation methods.	Surface irrigation has low water-use efficiency. Transition to drip or sprinkler systems is recommended for improved sustainability.
Type of Energy Used	Electricity is used in most cooperatives (e.g., Karavelet, Pasu, Yiğittaşı, Pusudere, Alvar, Tepecik, Karakoç). Only Porsuk uses gravity-fed systems.	Cooperatives relying on electricity should consider renewable energy alternatives. Gravity systems are environmentally advantageous.

The findings related to irrigation methods and practices (Table 3) reveal the current status of water and energy use among the cooperatives, as well as the sustainability risks they face. The majority of cooperatives rely on groundwater sources, with only the Porsuk cooperative operating through a surface (gravity-fed) water system. The widespread dependence on groundwater presents a serious environmental sustainability concern, as it may lead to the depletion of underground reserves in the long term. In contrast, although surface water sources are more susceptible to climatic fluctuations, they offer a more environmentally friendly alternative when managed responsibly.

Moreover, all cooperatives currently utilize traditional surface (flood) irrigation methods, indicating low water-use efficiency. This approach not only results in considerable water loss but also diminishes irrigation effectiveness. Transitioning to more efficient irrigation techniques—such as drip or sprinkler systems, which are widely used in modern agriculture—would significantly enhance water conservation and crop health.

In terms of energy use, electricity dominates across the cooperatives, with only Porsuk utilizing a gravity-based system. Reliance on electricity for irrigation poses a financial burden, especially during periods of rising energy prices. For this reason, the adoption of renewable energy sources—such as solar or wind power—at the cooperative level is essential. Such integration would not only reduce operational costs but also enhance environmental sustainability. Overall, modernization in both irrigation techniques and energy use is fundamental to achieving long-term sustainable agricultural development.

2.4. Operational, Maintenance, and Management Information

This section presents findings related to the administrative and technical management capacities of the cooperatives, including the institution responsible for construction, the entities in charge of well maintenance and repair, and the number of employed personnel. These indicators are evaluated to assess the organizational sustainability and operational management adequacy of the cooperatives. Detailed data for each cooperative are provided in Table 4.

Table 4. Operational, maintenance, and management information by cooperative.

Indicator	Status by Cooperative	Commentary and Recommendations
Constructing Institution	All cooperatives (Karavelet, Pasu, Yiğittaşı, Pusudere, Alvar, Tepecik, Porsuk, Karakoç, Büyüktüy-Küçüktüy-Saksı) were established by the State Hydraulic Works (DSİ).	Support from central institutions (e.g., DSİ) is beneficial; however, strengthening local management capacity is necessary.
Well Maintenance and Repair Responsibility	Maintenance is generally handled by private individuals (e.g., Karavelet, Yiğittaşı, Karakoç, Pusudere), while DSİ support is observed in Tepecik, Alvar, and Büyüktüy-Küçüktüy-Saksı.	Professionalizing and standardizing maintenance procedures can enhance service quality and operational reliability.
Number of Personnel	Pasu employs 12 staff; Tepecik employs 3 staff; most other cooperatives do not have permanent personnel.	Lack of personnel poses risks to operational continuity; staffing needs should be addressed to ensure effective management.

The data presented in Table 4 provide important insights into the institutional structures and human resource capacities of the irrigation cooperatives. All cooperatives were established by the State Hydraulic Works (DSİ), indicating the existence of a centrally coordinated and standardized infrastructure. While this foundation represents a significant initial advantage, insufficient development of local management capacity may undermine the long-term operational sustainability of these systems in the field. In terms of well maintenance and repair, responsibilities are often outsourced to private individuals, as observed in cooperatives such as Karavelet, Yiğittaşı, Karakoç, and Pusudere. In contrast, cooperatives like Tepecik, Alvar, and Büyüktüy-Küçüktüy-Saksı receive direct support from DSİ. Maintenance systems reliant on private individuals are prone to inconsistent practices and lack quality control, highlighting the need for institutionalization and the establishment of standardized technical protocols in maintenance procedures.

Regarding staffing, only the Pasu cooperative (12 personnel) and Tepecik (3 personnel) employ permanent staff, while other cooperatives exhibit a notable lack of dedicated personnel. This shortage poses a significant risk to operational continuity, particularly in situations requiring urgent intervention or scheduled maintenance. Consequently, human resource planning within cooperatives should be restructured, and support should be provided for the recruitment of both technical and administrative staff. Furthermore, enhancing the training levels of personnel and clearly defining their roles are essential steps to improving overall management quality.

2.5. Economic and Financial Management

This section presents findings on the financial management systems of the irrigation cooperatives, including their fee-setting mechanisms, collection methods, and profit/loss status. Whether fees are determined based on electricity bills or alternative approaches, along with how payments are collected and how financial balance is maintained, are analyzed in terms of long-term financial sustainability. Detailed cooperative-specific results are provided in Table 5.

Table 5. Economic and financial management by cooperative.

Indicator	Status by Cooperative	Commentary and Recommendations
Method of Determining Water Fees	The electricity bill-based method is commonly used (e.g., Karavelet, Pasu, Yiğittaşı, Pusudere, Tepecik, Karakoç). No clear pricing system exists in Porsuk and Alvar cooperatives.	A fair pricing system based on water meters and actual consumption should be adopted.
Profit–Loss Status	Most cooperatives operate at break-even. However, some (e.g., Alvar, Büyüktüy-Küçüktüy-Saksı) consistently operate at a loss.	Cooperatives with ongoing losses should reassess cost-control measures and revenue management strategies.
Water Fee Collection Method	Collections are made manually with receipts (e.g., Karavelet, Yiğittaşı, Pusudere, Tepecik, Karakoç). No digital payment systems are in use.	Transitioning to digital payment systems is recommended to enhance transparency and efficiency in tracking payments.

The findings related to economic and financial management (Table 5) indicate several challenges faced by irrigation cooperatives in maintaining a balanced income-expenditure structure, collecting payments from users, and ensuring sustainable financial practices. The widespread use of electricity bill-based pricing systems (e.g., Karavelet, Pasu, Yiğittaşı, Pusudere, Tepecik, Karakoç) suggests that fixed costs are distributed evenly among users. However, this approach may create inequities between farmers who use varying amounts of water, and it fails to encourage efficient resource use.

In contrast, the absence of any structured pricing system in cooperatives such as Porsuk and Alvar poses a serious risk to financial sustainability. Without a clear and fair fee structure, these cooperatives are unable to secure the revenues needed for continued operation. Regarding profit and loss, while most cooperatives can break even, others, such as Alvar and Büyüktüy-Küçüktüy-Saksı consistently operate at a loss. These deficits are often driven by high energy costs, low fee collection rates, and unplanned expenditures. To address this, these cooperatives implement improved cost control mechanisms, adopt revenue-enhancing strategies, and conduct detailed efficiency analyses.

As for collection methods, most cooperatives rely on manual, receipt-based systems (e.g., Karavelet, Yiğittaşı, Pusudere, Tepecik, Karakoç). While functional, this method presents drawbacks in terms of tracking, transparency, and time efficiency. Transitioning to digital payment systems would facilitate more reliable and accessible transactions while enhancing financial accountability. In conclusion, strengthening the economic and financial structure of cooperatives, establishing fair and consumption-based pricing systems, and integrating digital financial tools are critical steps for ensuring the long-term sustainability of irrigation services.

4. Discussion and Conclusion

The research findings reveal significant variations in the physical and technical infrastructure capacities of irrigation cooperatives, depending on their scale. While large-scale cooperatives operate with more wells and high-capacity pumping systems, smaller cooperatives function with more limited resources. Although high energy consumption enhances irrigation efficiency, it also increases operational costs, thereby jeopardizing long-term sustainability (Stashuk et al., 2024). The integration of renewable energy sources—particularly solar power—into irrigation systems is crucial both for reducing costs and ensuring environmental sustainability. Solar-powered irrigation systems significantly reduce energy consumption and greenhouse gas emissions while improving water use efficiency and crop yields (Daraz et al., 2025; Karnib et al., 2024; Thokal et al., 2024). In this context, solar energy offers a strategic pathway toward achieving sustainable development goals in agriculture. Moreover, deficiencies in water metering systems hinder proper planning and monitoring, emphasizing the need for infrastructure investments tailored to local conditions.

The size of the irrigated area directly affects the managerial effectiveness and operational efficiency of cooperatives. While large cooperatives benefit from economies of scale, they also face more complex management processes and higher operational costs (Ministry of Agriculture and Forestry, 2021). In contrast, smaller cooperatives are easier to manage but are limited in terms of production capacity. The fact that some cooperatives achieve 100% irrigation rates while others remain below capacity points to managerial or technical shortcomings. The absence of land consolidation in all cooperatives is a fundamental structural weakness. Without consolidation, it is difficult to distribute water equitably and efficiently. Therefore, land consolidation must be considered a strategic requirement for improving irrigation performance (DSİ, 2017; Patlar, 2018).

Current water and energy use practices within irrigation cooperatives present notable sustainability risks. The widespread reliance on groundwater could lead to resource depletion and ecological imbalance in the long run. This underscores the need for alternative approaches to ensure sustainable water management (Ministry of Agriculture and Forestry, 2021). The continued use of traditional surface irrigation methods results in water inefficiency and waste. Replacing these with drip irrigation systems would not only improve water efficiency but also support plant health (Kaur et al., 2024; Swadia, 2017). Heavy dependence on electricity also places financial pressure on cooperative budgets, particularly during periods of rising energy prices. Thus, incorporating renewable energy sources such as solar energy would support both cost reduction and environmental sustainability (Abu-Nowar, 2020; Bhatt & Kalamkar, 2017; Guno & Agaton, 2022).

Data on operational, maintenance, and management processes reveal key institutional and human resource deficiencies. Although all cooperatives were established by the State Hydraulic Works (DSİ), which ensured a standardized infrastructure, the lack of investment in local management capacity undermines operational sustainability (Ministry of Agriculture and Forestry, 2021). In many cooperatives, maintenance and repair services are handled by private individuals, raising concerns over non-standard practices and quality control. Institutionalizing these services and implementing technical standards are critical steps (Büyükbaş, 2015). A shortage of personnel, particularly for urgent or scheduled maintenance, also threatens operational continuity. Therefore, cooperatives must restructure their human resource planning, support the hiring of technical and administrative staff, and ensure their training and role clarity to enhance management quality (Everest et al., 2019).

The financial management practices of irrigation cooperatives also highlight critical challenges for long-term sustainability. The widespread use of electricity bill-based pricing creates inequality, as it does not account for actual water usage, potentially penalizing low-usage farmers (Büyükbaş, 2015). While some cooperatives operate at break-even, others, such as Alvar and Büyüktüy-Küçüktüy-Saksı suffer from persistent deficits driven by high energy costs and poor fee collection rates. To address these issues, improvements in cost control, revenue enhancement, and energy efficiency are necessary (Ministry of Agriculture and Forestry, 2021). The prevalent use of manual, receipt-based payment systems also leads to issues in record-keeping and transparency. Implementing digital payment systems would enhance both convenience and accountability (Everest et al., 2019).

Compliance with Ethical Standards

Ethical committee approval is not required for this type of study.

Conflict of Interest

The authors declare no conflict of interest.

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Kasumyan, A. O., & Døving, K. B. (2003). Taste preferences in fishes. *Fish and Fisheries*, *4*(4), 289-347. https://doi.org/10.1046/j.1467-2979.2003.00121.x

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Book:

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Sönmez, A. Y. (2011). *Karasu ırmağında ağır metal kirliliğinin belirlenmesi ve bulanık mantıkla değerlendirilmesi* (Doctoral dissertation, Atatürk University).

Taştan, Y. (2018). *Tatlısu kerevitindeki (Astacus leptodactylus) siyah solungaç hastalığı etkeni mantar Fusarium oxysporum'un PCR yöntemi ile teşhisi* (Master's thesis, Akdeniz University).

Conference Proceedings:

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Institution Publication:

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Lastname, N. (Year). *Title of the work*. Retrieved May 15, 2020, from URL

Perreault, L. (2019). *The future of agriculture: Polyculture*. Retrieved January 12, 2020, from https://www.agriculture.com

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