ACADEMIC STUDIES IN AGRICULTURE

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Institution of Economic Development and Social Researches Publications®
(The Licence Number of Publicator: 2014/31220)
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USA: +1 631 685 0 853
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ISBN: 978-625-378-210-8
Cover Design: İbrahim KAYA
January / 2025
Ankara / Türkiye
Size: 16x24cm

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PREFACE

The world's population is expected to reach 9.7 billion by the year 2050. This increase in population will result in a substantial rise in food demand, necessitating an increase in agricultural output to meet these needs. However, the current methods of agricultural production cannot be expanded sustainably due to constraints such as limited farmland, decreasing water supplies, and the effects of climate change. At this critical juncture, it has become essential to develop and implement new technologies aimed at enhancing agricultural efficiency.

Technological advancements such as cutting-edge sensor systems, AI-powered analytics, autonomous agricultural machinery, and IoT (Internet of Things)-based monitoring solutions are driving the evolution of modern agriculture. Precision farming techniques enable farmers to track soil and crop health in real time, optimize irrigation and fertilization processes, and thereby enhance resource efficiency while reducing environmental impacts.

However, the integration of agricultural technologies is not limited to just increasing productivity. Within the framework of sustainable agriculture, factors such as the preservation of biodiversity, long-term sustainability of soil health, and reduction of carbon footprint must also be considered. The recycling of water used in agricultural production, integration of renewable energy sources, and widespread adoption of data-based decision support systems will contribute to making the agricultural sector more resilient in the future.

This book explores, based on scientific foundations, how new technologies can be effectively employed in agriculture, the effects of digital transformation on agricultural production, and the necessity of sustainable agricultural practices. Aiming to serve as a reference source for farmers, researchers, engineers, and policymakers, this study seeks to provide a comprehensive perspective on the future of the agricultural sector.

I would like to thank all the academics, field experts, and researchers who contributed to the preparation of this work, and I hope that the book will be a useful resource for everyone seeking innovative solutions in agricultural production.

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CHAPTER 1

EVALUATION OF COOPERATIVE MEMBER DAIRY CATTLE FARMS IN TERMS OF MARKETING EFFECTIVENESS

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DOI: https://dx.doi.org/10.5281/zenodo.15092352

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1. INTRODUCTION

Milk is a product rich in animal proteins for healthy and balanced nutrition of the society. For this reason, milk and dairy products play an important role in meeting the daily protein needs of humans. Demand for milk is increasing globally due to rapid population growth, urbanization and changes in nutritional levels (Gaillard and Derville, 2022). Given that more than 70% of the future world population will live in cities by 2050, milk demand will be largely concentrated in urban areas (Valin et al., 2014).

Dairy cattle breeding in Türkiye has the resources to contribute greatly to the economic and social development of Türkiye. These resources need to be used efficiently and at high capacity (Yeteroglu, 2010). Dairy farming is a source of income for many people living in rural areas. Since milk is produced every day and converted into money in a very short period of time, it contributes to the family economy and helps to meet the daily subsistence needs. However, milk is a difficult product to store and market and must be sold immediately or evaluated in different ways during the day. This situation reduces the milk producer's power to direct the market (Hekimoglu and Altındeger, 2008).

Integrated food supply chains serving urban areas are one of the fastest growing and most remarkable market trends. However, in developing countries, small-scale milk market intermediaries still play an important role in supply chains providing fresh milk and traditional dairy products (Kumar and Staal, 2010). Although the national milk master plan favors formal market chains, the majority of milk produced (80%) is sold through informal market chains (Migose et al., 2018).

In running the farms, farmers often join cooperative organizations. Milk Producer Cooperatives (MPC) are the primary cooperatives at the sub-regional level (there is only one cooperative per sub-region) that organize dairy farmers who are members (Asmara et al., 2017). Dairy cooperative is a source of pooling milk supplies and sales, reducing price risks, increasing the bargaining power of dairy farmers, and providing quality milk at fair prices to consumers (Holloway et al., 2000). In their study conducted by Koc and Uzmay (2018) on producers engaged in dairy cattle breeding in the Thrace Region, they found that the share of those who want to continue dairy cattle breeding is higher among those who market their milk to the cooperative. This situation shows that cooperatives are important for the sustainability of dairy farming.

The dispersed nature of small dairy farms leaves a big question mark on farm economies and the adoption of modern dairy technology. For rapid milk development, it is necessary to organize small-scale milk producers, integrate the marketing system with production, upgrade the milk collection mechanism, improve market knowledge and improve farm profitability. In order to access a wide range of benefits from milk value chains and improved milk practices, close cooperation of farmers in cooperative form can serve as a tool for sustainable development (Milford, 2014).

Agricultural Development Cooperatives, which have the largest share among agricultural cooperatives, make a significant contribution to small family dairy farms in terms of input supply in milk production and marketing of their products (Can et al., 2023). However, in our country, most of these cooperatives do not operate effectively. However, effectively operating agricultural cooperatives can be effective in price formation in the markets and ensure that a large portion of the profits going to intermediaries are transferred to the producers (Engindeniz et al., 2017). For this reason, it is necessary to investigate the situation of dairy cattle farms that are members of cooperatives, which have an important role in agricultural development, in terms of marketing efficiency in different regions.

When the studies examining the marketing structure of dairy cattle farms in the world and in Türkiye are examined; cooperative member farmers' milk marketing channels (Koc and Uzmay, 2018; Gaillard and Derville, 2022; Habiyaremye et al., 2023) and quality-based payment programs (Botaro et al., 2012), the impact of cooperatives on milk producers' income (Onyango et al., 2023; Kaur and Singla, 2024) and market competitiveness (Graubner et al., 2011; Toiba et al., 2023), the feasibility of traditional milk marketing (Kumar and Staal, 2010), the impact of rural development programs on the welfare of farmers (Amolegbe and Adewumi, 2022), farmers' raw milk marketing channels and interventions to improve the market (Hellac, 2019; Mengistu and Merassa, 2023; Temesgen et al., 2024), milk sales and marketing channels (Artukoglu and Olgun, 2008; Ariningsih et al., 2019), milk marketing cost and efficiency (Khalil and Ahmad, 2013; Satashia and Pundir, 2021; Bhargav et al., 2023) and milk marketing problems of farmers (Akkılıc et al., 2001). However, it was determined that studies in Türkiye are limited. Therefore, there is a need for studies to improve the milk marketing structure in order for farmers to prosper and continue their activities and for consumers to consume milk at affordable prices.

In this study, the marketing efficiency of milk farmers was determined in the light of the information obtained from dairy cattle farms that are members of S.S. Cavuslu Village Agricultural Development Cooperative in Derince district of Kocaeli. Changes in marketing margins and marketing efficiency of farmers according to marketing conditions were analyzed. Marketing margins, absolute margins and relative margins of milk farmers according to direct and indirect marketing methods were calculated. According to the findings obtained as a result of the study, suggestions were made regarding the effective sustainability of dairy cattle farming in the region in terms of marketing.

2. GENERAL INFORMATION ABOUT THE RESEARCH REGION

2.1 Geographical Location

Kocaeli province is located in the east of the Marmara Sea and the Marmara Region, at the crossroads of the roads connecting Asia and Europe**.** The province is bordered by the Black Sea in the north, Sakarya in the east and southeast, Bursa in the south, and Yalova and Istanbul in the west. Its surface area is 3505 km^2, which constitutes 0.45% of Türkiye's surface area (Kocaeli Agriculture Master Plan, 2002). Kocaeli, the third largest city in the Marmara Region, is one of the important industrial and commercial cities of Türkiye.

Derince district is a district of Kocaeli with a surface area of approximately 196 km^2. To the north of the district is the Sile district of Istanbul province, to the northeast is the Kandıra district of Kocaeli province, to the east is the İzmit district and to the west is the Gebze district. It is 26 km away from Kocaeli city center.

2.2 Climate

Kocaeli shows the characteristics of Mediterranean climate and Marmara climate. There are climatic differences between the coasts of the Gulf of Izmit and the coasts facing the Black Sea. Summers are hot and rainy throughout Kocaeli province, while winters are rainy, sometimes in the form of snow.

The highest and lowest temperature values realized in Kocaeli province during the period 1929-2023 are given in Table 1. Looking at the long-term temperature data in Kocaeli province, it is seen that the lowest temperature data was recorded as -18°C in February in 1929. The highest air temperature was 44.1°C in July 2000.

Table 1: Highest and Lowest Temperature Values Realized in the Research Region in the Period 1929-2023

Months	Kocaeli Province	
	Highest temperature (°C)	**Lowest temperature (°C)**
January	24.9	-13.1
February	26.7	18.0
March	30.8	-6.5
April	35.0	-1.0
May	37.2	1.8
June	40.7	4.0
July	44.1	10.1
August	42.9	10.9
September	40.2	4.9
October	36.2	2.4
November	30.0	-3.4
December	27.4	-8.8

Source: General Directorate of State Meteorology (https://www.mgm.gov.tr)

2.3 Population

Kocaeli province has 12 districts. According to 2023 population statistics, the population of the province is 2,102,907. The area of the province is 3,505.27 km^2 and the average population density is 599 people/km^2.

General census statistics for Türkiye and Kocaeli between 2014-2023 are shown in Table 2. The population growth rate of Kocaeli province is not regular between 2014 and 2022. In 2018 and 2021, it was observed that it increased less than the previous years. When the population growth rate of Kocaeli province is compared with the population growth rate of Türkiye in general, it is seen that the rate of increase is high in the province. This is due to the fact that Kocaeli province is an industrial city and receives a lot of immigration, which is why the population density is quite high.

Table 2 Population Statistics for Türkiye and Kocaeli Province between 2013-2023

Years	Türkiye	Türkiye annual population rate of increase (%)	Kocaeli Province	Kocaeli annual population rate of increase (%)
2014	77,695,904	1.34	1,722,795	2.78
2015	78,741,053	1.35	1,780,055	3.32
2016	79,814,871	1.36	1,830,772	2.85
2017	80,810,525	1.25	1,883,270	2.87
2018	82,003,882	1.48	1,906,391	1.23
2019	83,154,997	1.40	1,953,035	2.45
2020	83,614,362	0.55	1,997,258	2.26
2021	84,680,273	1.27	2,033,441	1.81
2022	85,279,553	0.71	2,079,072	2.24
2023	85,372,377	0.11	2,102,907	1.15

Source: TURKSTAT (https://data.tuik.gov.tr/)

Table 3 shows the population distribution of Kocaeli province by districts. In 2023, Kandıra district has the lowest population with 53,845 people. Gebze district has the highest population with 407,436 people. The population per km^2 in Derince district is 735 people. In terms of population per km^2 in Kocaeli province, Kandıra district has the lowest number with 63 people/km^2. The reason for this is that the young population migrates to urban areas rather than staying in rural areas due to the high job potential.

Table 3: Kocaeli Province Population Distribution by Districts (2023)

Districts	Population	Areas of districts (km^2)	Population (per km^2)
Başiskele	121,278	218	556
Çayırova	153,301	29	5,286
Darıca	227,892	27	8,440
Derince	146,409	199	735
Dilovası	54,391	129	422
Gebze	407,436	424	961
Gölcük	177,441	225	789
İzmit	378,656	488	776
Kandıra	53,845	856	63
Karamürsel	59,952	258	232
Kartepe	142,175	267	532
Körfez	180,131	302	596
Kocaeli Total	2,102,907	3,422	615

Source: TURKSTAT, Address Based Population Registration System (https://data.tuik.gov.tr/)

2.4 Agricultural Situation

2.4.1 Availability and use of agricultural land

According to 2023 TURKSTAT data, Kocaeli province's total agricultural land is 81,901 hectares, which constitutes 0.34% of Türkiye's total. Of the total land, 65.27% was cultivated land, 17.69% was fruit, beverage and spice crops land and 17.04% was other land (Table 4).

Table 4: Land Use Status of Kocaeli Province (2023)

Land use pattern	Kocaeli province (ha) (1)	Land distribution in Kocaeli province (%)	Türkiye (ha) (2)	% (1/2)
Planted	53,456	65.27	16,744,635	0.31
Fallow	11,827	14.44	2,814,307	0.42
Vegetable	2,061	2.52	712,264	0.29
Land for fruit, beverage and spice crops	14,489	17.69	3,694,256	0.39
Ornamental plant land	69	0.08	5,769	1.19
Total	81,901	100.00	23,971,231	0.34

Source: TURKSTAT (https://data.tuik.gov.tr/)

2.4.2 Crop Production

The most important crops grown in Kocaeli province are corn, hazelnut, wheat, oats, vetch, alfalfa and tomato. Apart from these, many important agricultural products are also grown. According to TURKSTAT data for 2022, 1.95% of Türkiye's oat production, 1.85% of hazelnut production, 1.83% of quince production and 1.29% of plum production were produced in Kocaeli province (Table 5). Kocaeli province has the largest share in oat production in the Eastern Marmara Region with a share of 21.60%. This was followed by cucumber production with a share of 11.53% and vetch production with a share of 10.18%.

Table 5: Production Amounts of Some Crops in the Research Area (tons) (2022)

Crops	Kocaeli province (1)	Eastern Marmara Region (2)	% (1/2)	Türkiye (3)	% (1/3)
Maize (silage)	242,943	3,097,002	7.84	28,558,983	0.85
Hazelhut	14,165	198,049	7.15	765,000	1.85
Wheat	26,539	907,018	2.93	16,000,000	0.17
Oats (green grass)	90,719	420,032	21.60	4,649,051	1.95
Vetch	18,351	180,185	10.18	4,020,433	0.46
Alfalfa (green herb)	54,772	1,113,967	4.92	19,064,213	0.29
Tomato	27,819	1,719,633	1.62	13,000,000	0.21
Barley	22,814	420,843	5.42	8,100,000	0.28
Watermelon	12,817	308,427	4.16	3,394,783	0.38
Cucumber	9,557	82,902	11.53	1,938,545	0.49
Cherry	4,696	98,476	4.77	656,041	0.72
Pepper	6,723	214,417	3.14	3,018,775	0.22
Plum	4,482	51,178	8.76	348,750	1.29
Apple	5,243	130,817	4.01	4,817,500	0.11
Pear	4,299	251,597	1.71	551,086	0.78
Quince	3,614	128,579	2.81	197,503	1.83
Peach	2,338	162,743	1.44	803,514	0.29
Sunflower	3,908	144,054	2.71	2,550,000	0.15

Source: TURKSTAT (https://data.tuik.gov.tr/)

Although many products are grown in Derince district, it has an important place especially in the production of field crops. Wheat production has gained the most importance in the district. As seen in Table 6, 19.48% of wheat production of Kocaeli province was realized in this district. After wheat production, maize production ranks second with 19.26%.

Table 6: Production Amounts of Some Products Produced in Derince District (2022)

Crops	Production (tons)		% (1/2)
	Derince district (1)	Kocaeli (2)	
Maize (silage)	46,800	242,943	19.26
Hazelhut	71	14,165	0.50
Wheat	5,171	26,539	19.48
Oats (green grass)	13,000	90,719	14.33
Alfalfa (green herb	3,900	54,772	7.12
Tomato	28	27,819	0.10
Watermelon	-	12,817	-
Cucumber	3	9,557	0.03
Cherry	71	4,696	1.51
Pepper	81	6,723	1.20
Plum	45	4,482	1.00
Apple	47	5,243	0.90
Quince	-	3,614	-
Pear	15	4,299	0.35

Source: TURKSTAT (https://data.tuik.gov.tr/)

2.4.3 Number of animals and animal production

According to TURKSTAT data for 2023, Kocaeli province has 93,716 heads of cattle, 1,727 heads of buffalo, 105,619 heads of sheep, 20,031 heads of goats and 7,844,027 poultry. When the number of animals in Türkiye and Kocaeli province were compared, poultry constituted the largest share with 2.13% (Table 7). A total of 75,296 tons of milk produced in Kocaeli province in 2009 accounted for 0.60% of total milk production in Türkiye. It accounted for 4.29% of white meat production, 1.00% of egg production and 0.68% of honey production (Table 8). Kocaeli's milk production increased by 44.48% from 75,296 tons in 2009 to 108,784 tons in 2022.

Table 7: Number of Animals in the Research Area (head) (2023)

Animals	**Kocaeli Province (1)**	**Türkiye (2)**	**% (1/2)**
Cattle	93,716	12,535,516	0.75
Buffalo	1,727	57,499	3.00
Sheep	105,619	42,060,470	0.25
Goat	20,031	10,302,940	0.19
Poultry	7,844,027	368,624,420	2.13

Source: TURKSTAT (https://data.tuik.gov.tr/)

Table 8: Production Quantities of Some Animal Products in the Research Area (tons) (2009)

Animal products	**Kocaeli Province (1)**	**Eastern Marmara Region (2)**	**% (1/2)**	**Türkiye (3)**	**% (1/3)**
Milk	75,296	759,471	9.91	12,542,185	0.60
Red meat	-	-	-	412,621	-
White meat	59,428	722,374	8.23	1,323,624	4.49
Wool/clay/wool fiber			-	42,446	-
Egg (1000 pcs)	138,246	1,228,178	11.26	13,832,726	1.00
Honey	561	3,084	18.19	82,003	0.68

Source: TURKSTAT (https://data.tuik.gov.tr/)

2.5 Agricultural Organization Status

Economic organizations established by producers and protecting the interests of producers through mutual assistance are grouped as cooperatives, producer associations and breeder associations (Can et al., 2017). Data on the state of agricultural organization in Kocaeli province for the year 2024 are given in Table 9. Accordingly, there are 87 farmer organizations in Kocaeli province, including 52 Agricultural Cooperatives, 7 Producer Associations, 2 Agricultural Cooperative Associations, 4 Breeder Associations for Breeding Purposes, 15 Agricultural Credit Cooperatives and 7 Chambers of Agriculture.

Table 9: Agricultural Organization Structure in Kocaeli Province

Organization Type		**Number of Organizations**	**Number of Partners/ Members**
Cooperatives	Agricultural Development Cooperative	40	3,092
	Irrigation Cooperative	1	147
	Fisheries Cooperative	11	686
	Total	52	3,925
Cooperative Regional Union		2	23
Unions	Producer Associations (Law No. 5200)	7	2,039
	Breeder Associations (Law No. 5996)	4	2,201
Chambers of Agriculture		7	21,903
Agricultural Credit Cooperatives		15	8,387
Total		87	38,478

Source: Records of Kocaeli Agriculture Provincial Directorate (2024)

Table 10 shows the distribution of agricultural cooperatives by districts in Kocaeli province. When the table is analyzed, Kandıra district ranks first with a total of 15 agricultural cooperatives. Kartepe, Gölcük, Izmit and Başiskele are the districts with the highest number of agricultural cooperatives. In the agricultural organization structure of Derince district, where the research area is located, there are 2 Agricultural Purpose Cooperatives, 1 Agricultural Credit Cooperative and 1 Chamber of Agriculture.

Table 10: Agricultural Cooperative Organization Structure by Districts in Kocaeli Province

Districts	Agricultural Organizations	Agricultural Credit Cooperative	Chamber of Agriculture	Total
Izmit	6	2	1	9
Gebze	2	1	1	4
Derince	2	1	1	4
Karamürsel	5	1	1	7
Körfez	3	1	0	4
Kandıra	10	5	1	16
Gölcük	8	1	1	10
Kartepe	9	2	1	12
Darıca	1	0	0	1
Çayırova	0	0	0	0
Başiskele	5	1	0	6
Dilovası	1	0	0	1
Total	52	15	7	70

Source: Records of Kocaeli Agriculture Provincial Directorate (2024)

3. MATERIALS AND METHODS

The main material of this study consists of the data obtained by questionnaire from 61 dairy cattle breeding farms in Çavuşlu Village of Derince District of Kocaeli Province. The survey was conducted in September and October 2021. The 2020 production period was taken as the basis for obtaining the data in the research. Secondary data sources of the study were obtained from previous domestic and foreign scientific studies, publications, statistical records and reports of official organizations.

Complete census sampling method was used to determine the number of milk farmers interviewed in Derince district. Accordingly, farmers who are members of Çavuşlu Agricultural Development Cooperative in Çavuşlu village of Derince District of Kocaeli province were interviewed. In this context, there are 70 farmers actively operating as members of the Cooperative. As part of the study, face-to-face interviews were held with a total of 61 farmers residing in the village, who were members of the cooperative, engaged in cattle breeding, and agreed to have an interview.

In the analysis of dairy cattle farms, the number of milking animals is very important in economic terms. While the average number of cattle in livestock farms in Türkiye is 4 heads, this number is 44 heads in EU countries (Yılmaz and Köknaroğlu, 2007). In the analysis of the data, the farms are divided into three groups primarily according to the number of their dairy cows, with farms with 5 or fewer dairy animals designated as Group I (19 farms), farms with 6-10 dairy animals as Group II (21 farms), and farms with 11 and more dairy animals as group III (21 farms) (Table 11).

Table 11: Distribution of the Investigated Farms According to Groups

Farm Groups	**Farm size number of dairy animals (head)**	**Number of Farms in Group**	**Distribution (%)**
Group I	≤5	19	31.14
Group II	6 -10	21	34.43
Group III	≥11	21	34.43
Total		61	100.00

The data obtained from the questionnaires in the study were coded appropriately and the necessary statistical analyzes were performed and interpreted in SPSS 22.0 (Statistical Package for Social Sciences) program. In the analysis of the data, firstly, the socio-economic characteristics of the farms examined were revealed.

In this research, some analyzes were carried out to reveal the marketing effectiveness of dairy cattle farms as well as their marketing margins. Marketing margin is used to examine the differences between farmer and consumer prices, calculated in absolute and relative terms. The absolute marketing margin is defined as the difference between the price that consumers pay for the final product and the price that farmers receive for the raw materials they produce (Inan, 2006). This differential represents the price charged by intermediaries for services such as purchasing, packaging, transportation, storage and processing (Zeb et al., 2007; Adanacıoglu, 2014). In addition, the relative marketing margin was calculated in the study to show how much of the price paid by consumers remains with the intermediaries. The following formula is used to calculate the relative margin (Smith, 1992).

Relative Marjin = [(retail price– the price received by the farmer) / (retail price) x 100]

In this research, marketing efficiency for dairy farms was also calculated. Marketing efficiency is defined as the ratio of market output (benefit) to marketing input (cost of resources). An increase in this ratio indicates an improvement in effectiveness (Hussein et al., 2013; Adanacıoğlu, 2014). While calculating marketing efficiency, Acharya's Modified Marketing Efficiency formula, which is one of the widely used measures in the literature, was used (Dastagiri et al., 2010; Adanacıoglu, 2014).

MME = FP/(MC+MM)

In the above formula; MME: adjusted marketing efficiency measure; FP: price received by farmers; MC: marketing cost; MM: marketing margin.

4. RESULTS

4.1. General Characteristics of Farmers and Dairy Cattle Farms

In the general characteristics of the interviewed farmers, it was determined that the age of the farmer was 52.41 years, the duration of education was 6.60 years and the duration of agricultural experience was 38.46 years. The ratio of male and female in the total population is 48.72% and 51.28%, respectively. In terms of age groups, the 15-49 age group has the highest share with 50.64%. The average population per farm is 4.70 people. The third group has the highest average population of 4.95 people per farm. The average number of land parcels is 15.59 and the average land size is 15.14 hectares. In terms of average land size, the third group of farms constitutes the group with the largest land width with an average land size of 20.27 hectares. Of the interviewed dairy cattle farmers, 61.34% of them produce only on the land they own, 36.37% produce on the land they own as well as on the land they obtain through partnership and 2.29% produce only on the land they operate through partnership. It has been determined that tenancy practices are common especially in the 3rd group enterprises and share cropping practices are common in the 1st group enterprises.

Looking at the production pattern of the farms examined, it is noteworthy that product diversity is limited. According to the farms groups, the first crop grown in the first place is the same in all groups as corn. Among the crops grown among the farm groups, the third group of farms has the highest rate with 62.86% corn cultivation. Barley, oats and wheat are the other most grown crops.

It is seen that the average livestock per farm is 17.02 Cattle Unit (CU) for bovine animals and 0.45 CU for ovine animals. The third group has the highest number of livestock per farm with 32.19 CU in cattle animals, while the first group has the highest number with 0.79 in ovine animals.

4.2 Marketing Margin and Marketing Effectiveness of Farmers in Dairy Cattle Farms

In this section, marketing margins and marketing efficiency of dairy cattle farms under traditional marketing conditions are presented. Marketing margins and efficiency of dairy cattle farms were analyzed based on raw milk. When the relative margin of farmers in traditional marketing conditions for raw milk is analyzed, it is seen that an average of 48.63% of the absolute margin remains with the intermediaries. This ratio is lower for large farms in group 3, averaging 44.48%. For small and medium sized farms in the 1st and 2nd groups, the relative margin is slightly higher, 50.95% and 50.72% respectively (Table 12). In general, the relative margin in dairy marketing is high, in other words, a significant part of the price difference between the farmer and the consumer remains with the intermediaries. Farmers are negatively affected by this.

It can be said that the fact that large-scale farms have higher farmer margins is due to the fact that they sell the milk they produce to factories that offer higher prices.

Table 12: Marketing Margin of Dairy Cattle Farms

Marketing Margin	Farm Groups			General
	Group I (19 farms)	Group II (21 farms)	Group III (21 farms)	
Average selling price of the farmer (TRY/kg)(1)	2.58	2.72	3.17	2.83
Retail sale price (TRY/kg) (2)	5.26	5.52	5.71	5.51
Absolute margin (TRY/kg) (2-1) (3)	2.68	2.80	2.54	2.68
Relative margin (%) ((3/2)*100)	50.95	50.72	44.48	48.63

The mean marketing efficiency index for raw milk of farmers under traditional marketing conditions was 0.91 (Table 13). The marketing efficiency index was calculated as 0.83 for small farms in group 1 and 0.85 for medium-sized farms in group 2. The highest marketing effectiveness index was found in large farms in group 3, with an average of 1.05. In general, a marketing effectiveness index of less than 1 indicates that the farms do not work effectively in marketing and do not use marketing channels correctly.

Table 13: Indirect Marketing Effectiveness Index of Dairy Cattle Farms

Marketing Effectiveness	Farm Groups			General
	Group I (19 farms)	Group II (21 farms)	Group III (21 farms)	
Average selling price of the producer (TRY/kg)(1)	2.58	2.72	3.17	2.83
Retail sale price (TRY/kg) (2)	5.26	5.52	5.71	5.51
Total marketing margin of intermediaries (MM) (TRY/kg) (2-1) (3)	2.68	2.80	2.54	2.68
Total marketing costs of the farmer (MC) (cooling, transportation etc.) (TRY/kg) (4)	0.43	0.41	0.47	0.44
Marketing effectiveness analysis (1/(3+4))	0.83	0.85	1.05	0.91

The gross and net prices obtained by the farmers in case of direct sales are given in Table 14. As can be seen from the table, the net price received by the farmer in direct marketing is calculated as 3.35 TRY/kg on average.

Farmers' net price of milk was calculated by deducting the sum of marketing costs and possible product losses from the gross selling price.

Table 14: Gross and Net Prices Received by Farmers in Direct Marketing in the Investigated Farms

Gross and Net Prices	**Farm Groups**			**General**
	Group I (19 farms)	**Group II (21 farms)**	**Group III (21 farms)**	
Possible gross selling price of the farmer (TRY/kg)(1)	3.55	3.87	4.05	3.82
Marketing costs (TRY/kg) (2)	0.43	0.41	0.47	0.44
Crop losses (TRY/kg) (3)**	0.03	0.03	0.04	0.03
Net price (TRY/kg (1-(2+3))	3.09	3.43	3.54	3.35

*Transportation, transportation labor, packaging, storage, broker and other marketing expenses

The direct marketing effectiveness index for milk production in the farms within the scope of the research is given in Table 15. In the marketing efficiency for the farms, the net price was found to be 3.35 TRY/kg, total marketing costs 0.44 TRY/kg, post-harvest loss 0.03 TRY/kg. The net marketing margin was assumed to be zero since direct sales to consumers were in question. Direct marketing efficiency index was calculated as 7.13. The comparison of direct and indirect marketing efficiency index in the analyzed holdings shows that when the producers market the milk produced directly to the consumers, they will make a higher profit and play a more effective role in the milk market.

Table 15: Direct Marketing Effectiveness Index in the Investigated Farms

Marketing Effectiveness Index	Farm Groups			General
	Group I (19 farms)	**Group II (21 farms)**	**Group III (21 farms)**	
Possible gross selling price of the producer (TRY/kg)(1)	3.09	3.43	3.54	3.35
Marketing costs (TRY/kg) (2)	0.43	0.41	0.47	0.44
Crop losses (TRY/kg) (3)**	0.03	0.03	0.04	0.03
Net Marketing Margin (4)	-	-		-
Marketing Effectiveness Index (1/(2+3+4))	6.72	7.79	6.94	7.13

*Transportation, transportation labor, packaging, storage, broker and other marketing expenses, ** In the calculation of post-harvest loss rate, 1.25% was taken.

5. CONCLUSION

For a healthy and balanced diet, the population across the country needs to consume milk and dairy products at sufficient levels. However, it is seen that milk consumption is not at a sufficient level in our country. Due to the fact that most of the dairy cattle farms in our country are family-owned and insufficient in terms of feed, our milk farmers cannot play an effective role in the market. Therefore, most consumers consume milk at high prices, resulting in inadequate milk consumption. For this reason, it is of great importance for milk farmers to gather under the roof of cooperatives in order to play a more effective role in the market.

In this study, the socio-economic structure and milk marketing efficiency of cooperative member milk farmers were revealed, problems were identified and solutions were proposed. According to the results of the research; it was determined that 48.63% of the absolute margin of farmers in traditional marketing conditions for raw milk remained with intermediaries. It has been determined that a significant portion of the price difference between the farmer and the consumer remains with the intermediaries in the farms. Large-scale businesses have higher farmer margins because they sell the milk they produce to factories that offer higher prices. It was found that the marketing efficiency index for raw milk was generally below 1 under traditional marketing conditions. The average net price received by the farmer in direct marketing was found to be 3.35 TL/kg in the analyzed farms. When the direct and indirect marketing efficiency index was compared in the analyzed holdings, it was found that when the farmers marketed the milk directly to the consumers, they would make a higher profit and play a more effective role in the milk market. It is thought that the cooperative can play an important role in the milk market by directing the milk farmers in the research region, especially the large farms, to market the milk they produce through the cooperative and by increasing the farmer support.

Farmers who are members of the cooperative gain a more competitive position in the market by benefiting from opportunities such as collective bargaining power, ensuring product quality standards, information and training support provided by the cooperative in the marketing processes. Farmers who sell milk through cooperatives are able to reduce their costs and earn more stable incomes. In addition, the logistical support, storage and distribution facilities provided by cooperatives reduce marketing costs for farmers and allow their products to reach a wider audience. This contributes to increased marketing efficiency and income stabilization. Cooperatives' active role in market research, providing market information and setting prices helps cooperative member farmers better adapt to market conditions

As a result, cooperative membership increases the marketing efficiency of farmers and provides a more sustainable and stable production process. Increasing the support of cooperatives in this area is critical for the development of the dairy sector and the sustainability of employment in rural areas. This research has shown that the marketing advantages provided by cooperatives have a positive impact on milk farmers and it is concluded that supporting such structures will increase efficiency and productivity throughout the sector.

Acknowledgements

The authors thank Kocaeli University Scientific Research Projects Coordination Unit for its financial support. Project Number: FBA-2021-2479.

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CHAPTER 2

A RESEARCH ABOUT PROVEN MAXIMUM LENGTH OF ATLANTIC BONITO (*Sarda sarda* Bloch, 1793) FROM NORTHERN AEGEAN SEA (TÜRKİYE)

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DOI: https://dx.doi.org/10.5281/zenodo.15092354

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1. INTRODUCTION

15 genus and 55 species make up the family Scombridae (Eschmeyer's Catalog of Fishes, 2024). Ten of these species [Orcynopsis unicolor (Geoffroy Saint-Hilaire, 1817), Scomber colias (Gmelin, 1789), Thunnus thynnus (Linnaeus, 1758), Scomberomorus commerson (Lacepède, 1800), Euthynnus alletteratus (Rafinesque, 1810), Scomber scombrus (Linnaeus, 1758), Katsuwonus pelamis (Linnaeus, 1758), Auxis rochei (Risso, 1810), Sarda sarda (Bloch, 1793) and Thunnus alalunga (Bonnaterre, 1788)] are known to exist in Turkish seas (Fricke et al., 2007).

The Atlantic, Black Sea, and Mediterranean shores are home to the tropical and temperate Atlantic bonito, Sarda sarda (Bloch, 1793) (Yoshida, 1980). This neritic schooling scombrid is epipelagic, and able to adjust to small environmental changes (Collette and Nauen, 1983). Atlantic bonito migrate from May to July in the eastern Mediterranean Sea in the direction of the Black Sea for spawning, and then they migrate back the other way (Nümann, 1954). The main food sources for S. sarda during its migrations to the Black Sea are anchovies, with smaller amounts of horse mackerel, sprat, and other fish species (Genç et al., 2019)

Prior studies as regards this species in Turkish waters focused on growth parameters (Nümann, 1955;Türgan, 1958;Ateş et al., 2008), and fisheries (Oray and Karakulak, 1997;Ateş and Kahraman, 2002;Zengin et al., 2005), in epitome. Encircling nets, handlines, and purse-seiners are used so as to catch this species, which is one of the more significant species from commercial fisheries in all Turkish seas (Cengiz, 2013)

The fisheries management officials need to look at some biometric data in order to keep an eye on and protect fish stocks. Key statistics, such fish weight and length, are usually gathered via fish sampling programs. The data gathered is necessary for assessing length and age ranges, growth rates, and other aspects of fish population dynamics (Kolher et al., 1995). The two foremost theoretical components of studies on fish are peak performance weight and length (Dulčić and Soldo, 2005). The bulk of models used in stock evaluations encapsulate these measurements, both through direct and indirect ways (Borges, 2001).

Notably, methods for enhancing our understanding of community makeup and function, like evaluating fish based on size, are spreading more and more (Jennings and Dulvy, 2005) and it might be a helpful tool for rapidly assessing growth rates in situations when primary data is limited (Filiz and Sevingel, 2015). Because of all these factors, it is essential for keeping current information about the greatest size of a species that may one day be employed for commercial or recreational use (Navarro et al., 2012).

Given that biological rates and ecological functions shift with measurement, biologists and ecologists require faultlessly to figure out the most massive fish size that exists within a population (Peters, 1983; Pope et al., 2005). As an example, body length has a negative correlation with metabolic rate and an upward correlation with total intake of food. The maximum size of a fish is vehemently influenced by its size at hatch, lifelong, growth in sexuality, and maturation (Freedman and Noakes, 2002; Vander Veer et al., 2003). This investigation was undertaken in an effort to contribute to the species' documented maximum length.

2. MATERIALS AND METHODS

The northern Aegean shores of Türkiye are made up of the Edremit Bay, Saros Bay, the Gökceada and Bozcaada Islands, and the Gallipoli Peninsula (Cengiz and Paruğ, 2020) (Figure 1).

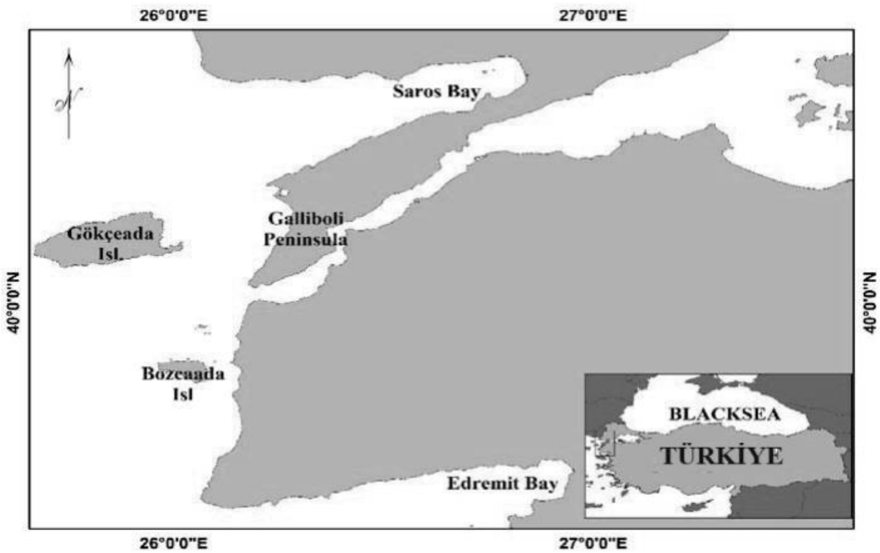

Figure 1. Gallipoli Peninsula and Türkiye's northern Aegean shores

On December 10, 2023, at a depth of around 20 meters, a commercial fisherman in Gallipoli Peninsula (Northern Aegean Sea, Türkiye) obtained a single *Sarda sarda* example. The distance between the anteriormost portion of a fish and the end of its caudal fin rays is used to calculate the animal's overall length when compressed dorso-ventrally (Anderson and Gutreuter, 1983). To accurately measure the entire length, a photo of the fish was taken using a ruler, and a scale of one centimeter was used as a reference. After transferring the acquired images to the Imaje J 1.46 program, the measurements were verified (https://imagej.nih.gov/ij/download.html). To the nearest gram, the specimen was weighed. Additionally, Froese and Pauly (2024) was consulted to verify the species' scientific name.

3. RESULTS AND DISCUSSION

On December 10, 2023, a commercial fisherman caught just one *Sarda sarda* specimen at a depth of roughly 20 meters. The specimen weighed 7200.00 g and had overall length of 81.0 cm (Figure 2).

Figure 2. Atlantic bonito (*Sarda sarda* Bloch, 1793)

As Turkish waters, Kara (1979) sampled 1608 individuals. According to his description, the species' fork length ranged from 14.0 to 90.0 cm. Oray et al. (2004) underlined that the largest size value was 66.0 cm (FL), in brief.

Froese and Pauly (2024) emphasized its maximum size value was 91.4 cm (FL). It is the largest individual in the world by this measure of size.

It is well established that populations under high levels of fishing pressure will respond by producing fewer individuals at average ages and sizes, which might end up in a decrease in the maximum lengths that can be attained. However, only a single individual who hadn't been vulnerable to overfishing pressure could reach that length (Filiz, 2011). However, factors that may impact growth encompass the availability of nutrients, oxygen, nourishment, conditions of lighting, temperature, contamination, current speed, nutritive concentration, salinity, predator density, intraspecific relations with others, and heredity (Helfman et al., 2009). These viewpoints point out that geographical variations in maximal length and weight vary via environmental factors and overfishing pressure.

4. CONCLUSION

These habitat-specific observations may offer vital information that gets incorporated into these calculations and stock assessments, considering the importance of the maximum length and/or weight for certain fishery types, which includes the Gompertz and von Bertlanffy theories of growth (Quinn and Deriso, 1999). Considering what came up from this study could help fishery management and contribute to international scientific literature.

Acknowledgments

The author acknowledges and is grateful to the fishermen for their priceless help in sampling specimen.

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CHAPTER 3

ESTIMATION OF SOIL SALINITY: REMOTE SENSING AND MACHINE LEARNING APPROACHES

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DOI: https://dx.doi.org/10.5281/zenodo.15092358

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INTRODUCTION

Degradation of farmlands are caused in part by increasing salinity brought on by climate change and human activity. This could lead to a decrease in arable and grazing land. Climate factors accelerate salinization while expanding agricultural areas, and increased use of land and water resources exacerbates the problem (Savin et al., 2023). Imperfect irrigation and drainage systems lead to increased salinity in the upper soil layers. Soil salinity has a negative impact on crop yields, which in turn has a negative impact on agricultural output. Addressing secondary land salinization and regulating water use are critical issues for agricultural production efficiency and food security.

Soil salinity is one of the primary factors contributing to land degradation, desertification, and a decline in agricultural productivity. Around half of all agricultural land worldwide is expected to be saline by 2050 (Abdelaziz et al., 2019) and it is particularly prevalent in arid and semi-arid regions (Wen et al., 2020). Therefore, soil salinity plays an important role in agricultural management, development, and worldwide ecological conservation (Jia et al., 2023). Therefore, accurate large-scale soil salinity monitoring and a systematic understanding of its temporal-spatial variations are essential for food production (Mukhopadhyay et al., 2021) ecological security (Sun et al., 2022) and sustainable agricultural development (Zhang et al., 2020)

Remote sensing methods are widely used for estimating soil salinity in arid and semi-arid regions due to their efficacy and broad coverage (He et al., 2023). Satellite image texture features have found application in land cover and tree species classification (Zhu et al., 2019), wetland detection (Chatziantoniou et al., 2017), soil organic carbon estimation (Nguyen et al., 2022), plant biomass (Dube and Mutanga, 2015) and other agricultural monitoring and classification. The spatial distribution of the soil surface is also captured by texture features, which makes it easier to identify the spatial pattern of salt distribution. Texture information can reveal soil surface roughness and texture, which are traits associated with salt accumulation and soil salinity.

Machine learning techniques have increasingly been utilized for mapping soil salinity using remote sensing data. Various soil salinity indices derived from satellite imagery spectral bands are commonly employed to monitor the spatial distribution of saline soils. However, factors such as soil color, texture, and moisture significantly influence the surface reflectance of salt-affected soils, making it challenging to rely on a single salinity index for accurate predictions across all scenarios (Daliakopoulos et al., 2016). As a result, researchers often test multiple salinity indices, vegetation indices, and environmental parameters to identify the most suitable variables that correlate strongly with ground measurements for model development (Gorji et al., 2020).

Machine learning methods have demonstrated their effectiveness in accurately mapping soil salinity by leveraging multivariate calibration, clustering, and classification of remote sensing data (Vagen et al., 2013). These techniques, combined with multispectral satellite imagery, have significantly improved the classification of saline soils. For instance, Wang et al. (2020) employed the Cubist model, a non-linear, rule-based machine learning approach, to predict soil salinity in an arid desert region of Northwest China. The model incorporated spectral bands, Tasseled Cap wetness (TCW), soil salinity indices, and laboratory-measured electrical conductivity (EC) data. Similarly, in the Xinjiang Uyghur Autonomous Region (XJUAR) of China, algorithms such as Random Forest (RF), Multiple Adaptive Regression Splines (MARS), Classification and Regression Trees (CART), Stochastic Gradient Treeboost (SGT), and LASSO were applied to predict soil salinity across three distinct geographical areas (Wang et al., 2019). Additionally, the effectiveness of Support Vector Regression (SVR) and Random Forest Regression (RFR) algorithms for soil salinity prediction was evaluated in Central Mesopotamia, Iraq (Wu et al., 2018).

Previous studies have shown that the performance of machine learning algorithms will vary by field, remote sensing, and research areas (Zarei et al., 2021). Therefore, adaptive machine learning methods and appropriate remote sensing imagery must be combined to produce salinity maps with high accuracy.

1. SOIL SALINITY DETERMINATION METHODS

Soil salinity has been measured using five different techniques thus far; i) plants can be observed visually, ii) electrical conductivity of soil saturation leachate or iii) leachate made with more water than usual can be measured in situ, iv) electrical resistivity (ER) can be measured by electromagnetic emission (EM), and v) the Time Domain Reflectance Method (TDR), which has gained popularity recently, can be measured electrically. ER, EM, and TDR techniques can be used to measure the volumetric electrical conductivity (ECa) of soil (Corwin and Lesch 2005). Despite being a quick and low-cost technique, visual plant observations can be carried out when salinity damages plants. Clearly, this approach should be used sparingly to gather data on soil salinity. Because it requires soil sample collection and extract production, the conventional saturation soil leach method for measuring soil salinity is not suitable for field use or intensive mapping and imaging applications. This approach also costs more money and time. Electrical conductivity in filtrates from soils made with a lot of water is simpler to measure than with the soil saturation method, has less correlation with significant soil characteristics, and has drawbacks like being more prone to errors brought on by peptization, hydrolysis, cation exchange, and mineral matter solution (Corwin and Lesch 2005). The formation mechanism of soil salinity arises from a combination of natural and human-induced processes. Figure 1 illustrates the formation mechanism of soil salinity. This process is triggered by factors such as rising groundwater levels, increased evaporation rates, and irrigation practices. As groundwater moves toward the soil surface, it carries salts with it. When evaporation occurs at the surface, the water evaporates, leaving salts to accumulate on the soil surface, leading to salinity issues. Additionally, improper irrigation techniques and inadequate drainage are significant factors that exacerbate salt accumulation in the soil. This mechanism becomes a critical problem, particularly in arid and semi-arid regions, negatively impacting agricultural productivity. Figure 1 demonstrates how these processes combine to create soil salinity.

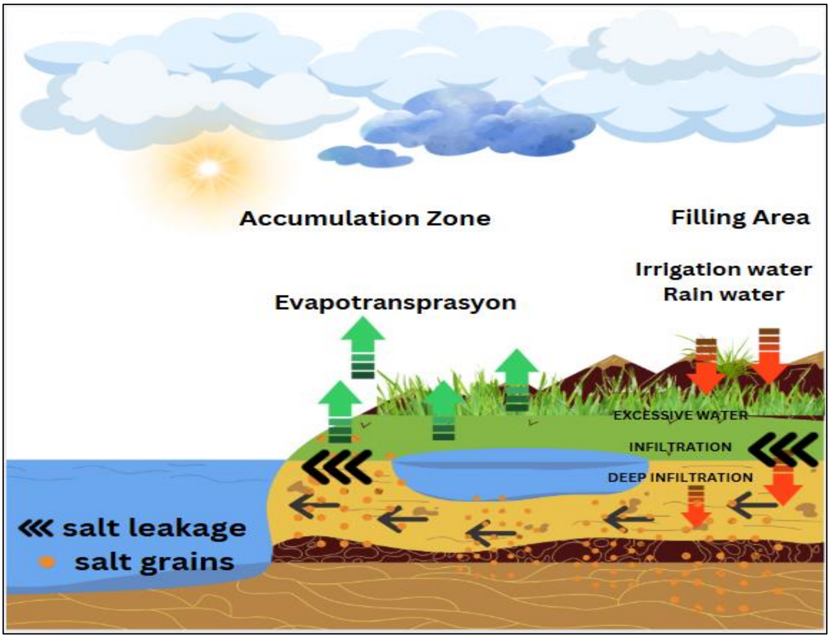

Figure 1. Formation mechanism of soil salinity

2. REMOTE SENSING TECHNIQUES AND MACHINE LEARNING MODELS USED TO DETERMINE SALINITY

2.1. Methods of Remote Sensing and Soil Salinity

Remote sensing utilizes the interaction of light at various wavelengths of the electromagnetic spectrum with the soil surface or vegetation to characterize soil salinity. Saline soils exhibit higher reflectance, particularly in the visible (VIS) and shortwave infrared (SWIR) bands, due to the high reflectivity of salt crystals, which form a white crust on the soil surface. These reflectance data are analyzed using spectral indices such as the Normalized Difference Salinity Index (NDSI) to quantitatively determine salinity levels. If the soil surface is covered with vegetation, salinity is assessed through the stress effects on plants. Saline soils hinder water and nutrient uptake by plants, altering their spectral reflectance properties. Changes in reflectance, especially in the infrared bands, are analyzed using indices like the Normalized Difference Vegetation Index (NDVI). In conclusion, remote sensing creates salinity maps by leveraging the high reflectance properties of saline soils or the spectral signatures of plants under salt stress (Metternicht and Zinck, 2003).

Remote sensing is the process of gathering information about objects on the earth's surface using data from instruments like satellites, airplanes, or drones. Remote sensing data is frequently used to examine vegetation status, moisture content, and soil surface characteristics in order to determine soil salinity (Allbed and Kumar, 2013). These data enable mapping and monitoring of salinity issues by providing both direct and indirect indicators of soil salinity. Remote sensing methods for determining soil salinity are crucial for land use planning, agriculture, and environmental management. Increased concentrations of dissolved salts in the soil can cause a problem known as soil salinity, which can hinder plant growth and lower agricultural productivity. Rapid, cost-effective, and extensive soil salinity assessment is made possible by remote sensing techniques (Metternicht and Zinck, 2003). These methods are more time-efficient and offer more thorough studies in broader areas than traditional methods.

2.2. Machine learning soil salinity modeling

Machine learning techniques use various inputs such as remote sensing data, soil properties, climate data, and land use information to predict soil salinity. These data are trained using models like Random Forest, Support Vector Machines, or Artificial Neural Networks; the model learns the patterns and relationships with salinity in the data. The trained model analyzes new input data to predict salinity levels. This process provides faster and higher accuracy compared to traditional methods, enabling effective mapping of soil salinity (Were et al., 2015).

Machine learning-based soil salinity determination has grown in popularity in the agricultural and environmental sciences in recent years. Ground measurements and remote sensing data (spectral, thermal, and microwave) are combined to create machine learning algorithms that estimate the salinity of the soil. The most popular algorithms in this process are Random Forest (RF), Support Vector Machines (SVM), and Artificial Neural Networks (ANN). Were et al. (2015), for instance, estimated the soil salinity in Kenya using the RF algorithm and obtained an accuracy rate of 85%.

Figure 2 outlines the systematic steps involved in determining soil salinity using remote sensing and machine learning methods. The process begins with the integration of multiple data sources, including remote sensing data (spectral, thermal, and microwave), soil properties (moisture, texture, pH), climate data (temperature, precipitation), and land use information. These data are then analyzed using advanced machine learning algorithms such as RF, SVM, and ANN. These models identify complex patterns and salinity-related parameters within the data to predict soil salinity levels. This method offers superior accuracy, speed, and scalability compared to traditional approaches, enabling effective mapping and management of soil salinity (Were et al., 2015).

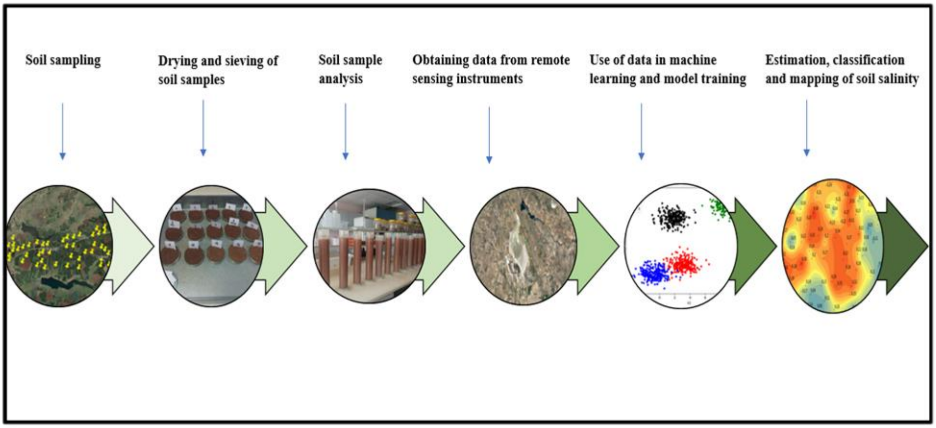

Figure 2. Steps followed to determine soil salinity using remote sensing and machine learning methods

3. REVIEW OF PREVIOUS STUDIES ON DETERMINATION OF SOIL SALINITY BY MACHINE LEARNING AND REMOTE SENSING

He et al. (2024) conducted a series of experiments to fully explore the value of texture features and the combination of texture features with spectral data for estimating soil salinity. The research was carried out in the Shahaoqu Irrigation Area, Inner Mongolia, China, from April to August 2019. The study utilized measured soil salinity data along with texture and spectral data from Sentinel-1/2 satellites. To evaluate the effectiveness of Sentinel-1/2 texture features in soil salinity estimation, the out-of-bag score was employed. Soil salinity inversion models were developed using spectral data and four machine learning algorithms: random forest, Cubist, support vector machines (SVMs), and backpropagation (BP). The results revealed that Sentinel-1 texture features were particularly sensitive to bare soil salinity, with the top four most significant features being HOM, ENT, COR, and CON. In contrast, Sentinel-2 texture features were more responsive to vegetated soil salinity, with VAR, CON, HOM, and ENT ranking as the most important features. Additionally, combining texture features with spectral data enhanced model performance, with random forest yielding the best results. The random forest model achieved R^2 values of 0.494 and RMSE of 0.308 for vegetated soil, and R^2 values of 0.688 and RMSE of 0.207 for bare soil (He et al., 2024).

Amirgaliyev et al. (2024) highlighted the significant challenges posed by land degradation and salinization in southern Kazakhstan, driven by human activity, climate change, and the unequal distribution of water resources. A critical issue in the region is the management of water resources, particularly the transboundary flow of the area's major rivers. In response to concerns over food and water security, new approaches for managing soil salinity have emerged, utilizing geographic information systems (GIS) and remote sensing technologies. The primary aim of the study was to assess the potential of high-resolution radar images, which are particularly useful for continuous monitoring and effective in cloudy conditions. In southern Kazakhstan, machine learning techniques can be employed to automatically map the salinity of agricultural land, providing an essential tool for mitigating the effects of salinity on agriculture. By accurately mapping salinity-affected areas, preventive measures can be taken more effectively. The study demonstrated, through experiments on a small dataset, that complex models like Light GBM do not significantly outperform simpler models such as Ridge regression in terms of accuracy. Based on these findings, the authors recommend a mapping approach for agricultural lands that could be further improved with the integration of advanced deep-learning techniques and ground-based measurement data (Amirgaliyev et al., 2024)

Han et al. (2023) identified soil salinization as a major threat to land degradation in arid and semiarid regions, with particular emphasis on its impact in Da'an City. The study utilized machine learning techniques in combination with Landsat 8 Operational Land Imager (OLI) imagery to estimate soil salinity. A total of 19 spectral indexes were computed using the blue, green, red, and near-infrared bands of the Landsat 8 OLI images, which included three vegetation indexes, fifteen salinity indexes, and a brightness index. Four machine learning regression algorithms-Cubist, support vector regression, random forest regression, and extreme gradient boosting regression-were applied to estimate soil salinity based on these spectral indexes. The results revealed that the Cubist model outperformed the other algorithms, achieving the highest prediction accuracy with an RMSE of 0.31 mS/cm. This model also provided the most accurate spatial distribution of soil salinity, aligning well with the authors' expectations. Furthermore, the canopy salinity index (CRSI) was found to have the strongest correlation with electrical conductivity measurements, with a correlation coefficient of -0.44. Following variable screening using the random forest method, the Cubist model, based on nine spectral indexes, still delivered satisfactory prediction accuracy with an RMSE of 0.34 mS/cm. The authors recommend the Cubist method for monitoring soil salinity in arid and semiarid regions (Han et al., 2023).

Kaplan et al. (2023) emphasized the growing concern of increased soil salinity due to climate change and environmental contamination stemming from excessive industrial and agricultural activities. They argue that precise and up-to-date measurements of soil salinity are essential for addressing this issue. Remote sensing data, they suggest, can greatly enhance the speed and accuracy of soil salinity mapping. Their study explores the use of various machine learning models and approaches to forecast soil salinity in hyper-arid environments, specifically utilizing Sentinel-2 satellite imagery. In their research, 393 soil samples were collected in the United Arab Emirates to test and model the soil salinity levels. Additionally, the study leveraged open-source platforms such as Google Earth Engine and Weka for data analysis. The results showed a strong correlation (0.84) between the test data and the model predictions. Kaplan et al. (2023) also highlight the intriguing findings of their study and propose further exploration of these results in future studies across different regions. They conclude that for more precise soil salinity modeling and mapping, future research should integrate evolving machine learning techniques to keep pace with advancements in the field.

Das et al. (2023) examined soil salinization, a major cause of land degradation affecting millions of hectares of land worldwide. They highlighted the potential of hyperspectral remote sensing (HRS), when combined with modern data mining techniques, for real-time and cost-effective monitoring of salt-affected soils. The study utilized data from the Airborne Visible-Infrared

Imaging Spectrometer-Next Generation (AVIRIS-NG) to predict soil salinity in low to moderately salinized cropland soils across five locations in India. Using a hybrid feature selection algorithm, the researchers identified four distinct spectral absorption features responsive to soil salinity. To estimate the electrical conductivity (EC) of the soil, several machine learning models were employed, including deep learning (DL), gradient boosting machines (GBM), and random forest (RF). The results showed that an ensemble of RF and DL models achieved the best performance, with normalized root-mean-squared errors of 0.15 and 0.16 for the training and test datasets, respectively, and coefficients of determination (R^2) of 0.89 and 0.55. Furthermore, the authors proposed a new hyperspectral soil salinity index based on Shannon entropy and the aggregation of specific absorption features. This newly developed index outperformed other widely used remote sensing-based salinity indices and exhibited strong correlations with both measured EC ($r = 0.68$) and ML-predicted soil EC ($r = 0.78$) at the 1% significance level. The index was successfully used to classify HRS images into six distinct salinity classes. The study also determined the optimal spectral and spatial resolution for salinity prediction and assessed the feasibility of applying the proposed index to future hyperspectral missions by simulating various spectral-spatial resampling scenarios. The hyperspectral salinity index can be directly calculated from HRS data in field settings, offering a viable alternative to costly and time-consuming field sampling for assessing soil salinity (Das et al., 2023).

Golestani et al. (2023) explored the impact of soil salinization, a major phenomenon of land degradation that disrupts ecological balance and contributes to desertification. The study focused on the use of satellite imaging and remote sensing techniques to evaluate, map, and monitor saline lands across different global locations. To assess the significance of salinity indices for prediction during two distinct seasons (summer and winter) and to examine the suitability of Landsat-8 and Sentinel-2A imagery for tracking the spatiotemporal variations of electrical conductivity (EC), 90 soil samples were collected from the marginal lands of Sirjan Playa in southeast Iran, using a systematic sampling method. Satellite images were obtained close to the sampling dates for both seasons, and the soil salinity indices were determined. The spatiotemporal changes in soil salinity were modeled using four machine learning algorithms: artificial neural networks (ANN), decision trees (DT), random forests (RF), and support vector machines (SVM). The results showed that the ANN model, using Sentinel-2A imagery, was the most effective at predicting ECe in winter, with $R^2 = 0.77$, RMSE = 16.1, and NRMSE = 27.1. In the summer, RF also yielded the lowest error in predicting ECe, regardless of the satellite data used. Moreover, Sentinel-2A data consistently outperformed Landsat-8 data, producing lower RMSE and NRMSE values across both seasons. The study also found that the Vegetation Soil Salinity Index (VSSI) was the most accurate indicator of soil salinity among all the indices tested. Overall, the study highlights the potential of satellite imagery combined with machine learning algorithms to track and predict soil salinity, offering valuable insights for the sustainable management of marginal lands in arid and semi-arid regions. Additionally, the findings underscore the importance of selecting suitable satellite data and salinity indices to ensure accurate and reliable predictions (Golestani et al., 2023).

Cui et al. (2023) investigated the impact of soil salinization on sustainable agricultural production, emphasizing the importance of accurately, efficiently, and promptly estimating soil salt content (SSC). The study examined the feasibility of using machine learning models to retrieve SSC information, leveraging a multi-spectral remote sensing platform driven by an unmanned aerial vehicle (UAV). To enhance model accuracy, two variable screening techniques-Pearson correlation analysis and Grey relational analysis (GRA)-were employed to assess the importance of 20 commonly used spectral indices. The sensitive spectral variables were then grouped into three categories: combination variables, vegetation indices, and salt indices. The study developed three machine learning regression models-Support Vector Machine (SVM), Random Forest (RF), and Backpropagation Neural Network (BPNN)-to estimate SSC for two soil depths: 0-20 cm and 20-40 cm. Using the best-performing estimation model, a salt distribution map for the 0-20 cm soil depth was generated. The results demonstrated that GRA outperformed Principal Component Analysis (PCA) in improving the model’s accuracy, with the combination variable group, which included soil moisture information, yielding the best performance. Overall, the prediction outcomes from all three machine learning models were positive. The best model achieved a Mean Absolute Error (MAE) of 0.038, a Root Mean Square Error (RMSE) of 0.055, and a coefficient of determination (R^2) of 0.775 on the validation set. Notably, the prediction accuracy for the 0-20 cm soil depth was higher than for the 20-40 cm depth, considering both accuracy and stability. The spatial distribution of salinization in the study area was successfully visualized in the soil salt spatial map created using the best estimation model. This study demonstrates the effectiveness of combining machine learning models with UAV-based multispectral remote sensing platforms to improve the monitoring of soil salt content in agricultural lands (Cui et al., 2023).

Merembayev et al. (2022) examined the impact of soil salinity on agriculture in the southern region of Kazakhstan, highlighting the importance of estimating and forecasting soil salinity prior to the planting season to plan for salt leaching. The study utilized machine learning algorithms in conjunction with satellite data, including radar data, to classify soil salinity in the Turkestan region, which encompasses over 102 sampling points. Several machine learning algorithms were compared, including Gaussian Process, Random Forest, and Decision Tree, with the models being evaluated based on metrics such as accuracy, recall, and F1 score. In addition, the study explored the influence of various dataset features on the classification performance of the algorithms. The results were further validated using the Shapley Additive exPlanations (SHAP) model, providing insights into the significance of different features in the classification process. The findings demonstrate the effectiveness of machine learning models in soil salinity classification and underscore their potential for improving agricultural planning and decision-making in the region (Merembayev et al., 2022).

Klibi et al. (2020) highlighted the environmental threat posed by soil salinity, which is driven by both natural and human-induced processes. Effective soil salinity monitoring is crucial for ensuring sustainable land management and usage. Hyperspectral satellite imagery is a valuable tool for assessing soil salinity, especially in semi-arid and arid regions like Zaghouan in northeastern Tunisia, where agricultural productivity is closely linked to soil conditions. To predict soil salinity in this area, the study utilized the spectral signature and feature vector from the Hyperion hyperspectral image. For feature representation, the AutoEncoder (AE) neural network architecture was employed. The study also applied several classification methods, including Decision Trees (DT), K-Nearest Neighbors (KNN), and Support Vector Machines (SVM). The results demonstrated that the AE-SVM combination outperformed the other three methods in terms of predicting soil salinity, highlighting its potential for improving soil management practices in the region (Klibi et al., 2020). Remote sensing tools used to determine soil salinity are summarized in Table 1. Machine learning tools used to determine soil salinity are given in table 2.

Table 1. Remote sensing tools used to determine soil salinity

No	Remote sensing	Resources
1	Sentinel-1 data	(He et al., 2024).
2	Sentinel-2 data	(He et al., 2024).
3	Landsat 8 (Spectral Band)	(Han, et al. 2023).
4	Google Earth Engine	(Kaplan et al., 2023).
5	EM-38 (Elektromanyetik İndüksiyon Tekniği)	(Bilgili et al., 2015)
6	VNIRS (Yakın Kızılötesi Yansıma Spektroradyometre)	(Kaplan and Bilgili, 2024)
7	MODIS (Moderate Resolution Imaging Spectroradiometer)	(Xiong et al., 2015).

Table 2. Machine learning tools used to determine soil salinity

No	Machine Learning Model	Resources
1	Random forest (RF)	(He et al., 2024).
2	Linear Regression	(Kaplan et al., 2023).
3	Support Vector Machine (SVM)	(He et al., 2024).
4	Extreme Gradient Boosting Regression (XGR)	(Han et al., 2023).
5	Support vector regression (SVR)	(Han et al., 2023).
6	Random forest regression (RFR)	(Han et al., 2023).
7	Exponential Regression	(Hihi et al., 2023).
8	Cubist	(He et al., 2024).
9	Backpropagation	(He et al., 2024).
10	Polynomialand Linear Regression	(Hihi et al., 2023).
11	Instance-bases learning with parameter k(IBk)	(Kaplan et al., 2023).
12	Generalized Linear Model	(Das et al., 2023).
13	Multivariate adaptive regression splines Model	(Erkin et al., 2019).
14	Deep Learning (multilayer feed-forward ANN) Model	(Das et al., 2023).
15	Backpropagation Neural Network (BPNN)	(Cui et al., 2023).

3.1. Accuracy assessment and validation

The performance of machine learning models is evaluated using specific metrics that measure how close the model's predictions are to the actual data. These metrics include accuracy and error, which provide insights into the model's effectiveness. Accuracy measures how closely the model's predictions align with the true values, while error metrics quantify the differences between predicted and actual values. In Table 3, the performance of various machine learning models is displayed using these metrics.

Table 3. Metrics used to determine the accuracy of machine learning models

No	Accuracy assessment	Resources
1	Mean Absolute Error (MAE)	(Cui, et al. 2023).
2	Root Mean Square Error (RMSE)	(Cui, et al. 2023).
3	Relative Absolute Error (RAE)	(Kaplan, et al. 2023).
4	Root Relative Squared Error (RRSR)	(Kaplan, et al. 2023).
5	Coefficient of determination (R^2)	(He., et al. 2024).
6	Residual prediction deviation (RPD)	(Xiao, et al. 2023).

4. CONCLUSION

Determining soil salinity can be achieved in a creative and scientifically effective manner through the integrated use of machine learning and remote sensing methods. Remote sensing technologies enable the collection of high-resolution and temporal data from vast geographical areas, providing detailed analysis of the physical and chemical properties of the soil surface. The collected data, processed through machine learning algorithms, allows for the generation of high-accuracy maps that depict the spatial distribution of soil salinity. These maps play a critical role in identifying yield losses due to salinity, pinpointing at-risk areas, and developing sustainable land management strategies. Particularly in arid and semi-arid regions, where soil salinity has become a serious issue due to climate change and improper agricultural practices, the use of these technologies is of great importance. However, continuous updating research and multidisciplinary studies are required to enhance model performance and adapt them to different soil types, climatic conditions, and farming systems. In the future, it is expected that these technologies will advance and become indispensable tools for increasing agricultural productivity and preserving ecological balance, especially in regions with limited water resources and widespread land degradation. This will significantly contribute to ensuring food security and achieving sustainable development goals.

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CHAPTER 4

BIOTECHNOLOGY AND ITS IMPORTANCE IN ORNAMENTAL PLANTS

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DOI: https://dx.doi.org/10.5281/zenodo.15092366

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INTRODUCTION

Biotechnology is a technology born from the integration of biological sciences and agricultural, medical and technical engineering knowledge and is based on the use of living organisms or their products to produce materials, products, and services and meet the needs of humans or the environment. Which is known as one of the seven key fields in the world. Use of this technology in the past decades was exclusive to developed countries, and developing countries also felt the need to use it and sought to achieve it by investing in this sector. It may be safe to say that the most important application of biotechnology is in the agricultural sector so the progress of agriculture in the world today is due to scientific achievements in production and investment in this area. Agricultural biotechnology can be used in various fields of agriculture, including plant, animal, microbial, food products, and the production of new products and the environment. Societies that have more capabilities in science and technology benefit from the achievements and benefits of biotechnology. Using this opportunity and benefiting requires creating the necessary background and conditions. A capable human force equipped with science and efforts to create science-based technology paves the way for the commercialization of technology and the collective use of its benefits at the national level.

Modern Flower And Ornamental Plant Hybridization Methods

Modern breeding methods have been invented to solve the need to create diversity in ornamental flowers and plants, which is a global industry. On the one hand, these methods significantly reduce the length of the correction period, and on the other hand, they can play an effective role in improving the quality of plants that cannot be corrected by traditional methods. Creating genetic changes to improve quality is necessary for any breeding program. The use of natural and induced mutations has been very effective in improving genetic resources and has successfully helped in the development of improved and new cultivars of ornamental plants. On the one hand, the creation of haploid plants significantly shortens the time required for the production of inbred lines for the breeding of first-generation hybrids; on the other hand, they facilitate the selection of recessive traits. Polyploid plants, both individually and in populations, in comparison with their diploid parents, usually have a high level of heterozygosity and are polyphyletic. Haploid, double haploid, and polyploid plants are new sources of germplasm that can be introduced as new cultivars or used in breeding programs. With access to new techniques such as genetic engineering, it is possible to significantly save the time and cost of breeders by making small changes in the genetic structure of the plant and preserving its other desirable traits while making the necessary changes to achieve the traits desired by the consumer. The genetic engineering of new traits in a variety depends on the ability to reproduce from the transgenic plant, which, fortunately, this technique is expanding significantly, especially in ornamental plants.

The financial turnover of the cut flower industry in the world is estimated to be around 27 billion dollars annually, and the growth of this industry has been achieved exclusively with the arrival of new cultivars. The most important global producers of ornamental plants are the Netherlands (33%), Japan (24%), Italy (11%), America (12%), and Thailand (10%), while other countries produce about 14% of the world's ornamental plants. they produce. The main global exporters of ornamental plants are the Netherlands (59%), Italy (16%), Colombia (10%), Palestine (4%), and Spain (2%), respectively, and the share of exports from other countries is (18%). So far, 156 types of ornamental plants have been produced and propagated through tissue culture in different laboratories around the world. In general, the cultivation of plant cells, tissue, and organs is done for three main purposes: a) sanitization and mass multiplication, b) germplasm storage and c) preparation of test materials needed for breeding programs. The attention-seeking improvement traits in ornamental plants are divided into two categories: the attention-seeking attributes of the consumer and the attention-seeking traits of the grower. Both of these types of traits have been and are the goals of traditional improvement programs, but in modern improvement programs, due to the cost of the methods, more attention has been paid to the traits of consumers. Variation in traits such as color, shape, and flower fragrance is one of the most important goals of ornamental plant breeding.

Somaclonal Variations And Induced Mutations

Genetic changes, including changes in the DNA sequence (such as point mutations and activation of transposons), changes in the structure of chromosomes (such as translocations), and changes in the number of chromosomes (such as polyploidy and aneuploidy) can cause somaclonal variations. Although many research groups following the theory of Larkin and Scowcroft (1981) based on the fact that somaclonal variations can be one of the sources of diversity in plant breeding have started breeding programs and created new ornamental plants using this method, Somaclonal variations have not yet been considered as a reliable breeding method that can be widely used. Among the ornamental plants that have been introduced as new ornamental plants after the creation of somaclonal varieties, we can refer to two chrysanthemums produced by Khalid et al. (1989). In general, most of the genetic variations observed in plants today are the result of spontaneous changes that have been created over time in different germplasms.

Crossbreeding between and within species in plants has helped to develop desirable traits, but the existing germplasms still cannot meet the needs of consumers seeking diversity. Therefore, breeders and researchers always try to use other sources to create diversity. Since spontaneous mutations rarely occur, the production of induced mutations is considered a suitable way to create diversity in plants. Cultivation in glass has made it possible to use the mutation technique well for plants that are propagated sexually and asexually. According to the report of the International Atomic Energy Agency, among the 2300 mutated numbers that have been officially released around the world, 625 numbers belong to ornamental plants. Some of the most important ornamental plants that have been used in the form of cut flowers or potted plants for improvement through mutation are rose, chrysanthemum, carnation, orchid, candlestick, and akhtar (Jain, 2006). In roses, a mutation was created using the chemical ethyl methane sulfonate by Yamaguchi in 2018 and by X-rays by Walther and Sauer in 1986. In Davoudi, the creation of diversity has been done with both chemical and physical mutants (Huttema et al., 1986). The creation of somatic mutation to change the color of chrysanthemum using gamma rays was reported by Mandal et al. (2000). Sun et al. (2007) developed a new breeding method for *chrysanthemum* by creating mutations by combining in vitro cultivation with electron beam irradiation. Lu et al. (2007) also showed that the use of gamma radiation (with a dose of 10 Gy) was successful in creating mutations and survival in the Jinzhanyantai variety of *Chinese daffodils*.

Haploid and Polyploidy

In the breeding of different pollinating populations to have the ability to combine, the use of self-pollination can increase the selection efficiency in each generation, but performing self-pollination increases the duration of the breeding period. With the production of homozygous double-diploid lines, the length of the correction period is significantly reduced. On the other hand, anther cultivation can simultaneously stabilize the recombinations obtained from meiotic divisions (Bhojwani et al., 2001). To produce virus-free plants, in addition to meristem cultivation, anther cultivation can also be used. Han et al. (1997) produced virus-free haploid liliums through anther cultivation. Considering that in most monocotyledons and several dicotyledons, plant regeneration from transgenic cells or protoplasts is difficult, in such cases, the technique of rescuing premature embryos obtained from microspores can be used. Bhojwani et al. (2001) reported that due to the haploid nature of embryos obtained from microspores, the resulting plants show the success of gene transfer easily. Identifying and isolating recessive spontaneous mutations in the haploid stage and quickly obtaining the mutated gene in homozygous form are other special advantages of creating haploid lines in plants. The use of mutagens in the microspore stage, which has a single-cell structure, can prevent the production of plants with heterogeneous tissue (Sopory and Munshi, 1996). Another feature of using the haploid technique is the manifestation of recessive mutant genes in gametoclonal variations, which has been reported in many cereals, but has not been reported in ornamental plants. Since double haploid plants are a stable population, without risk of heterozygosity, can be repeated at any time, and can be used in different laboratories, they can also be used in drawing linkage maps. Meynet et al. (1994) succeeded in producing a dihaploid rose that was able to produce flowers and fertile pollen by using parthenogenesis through pollination and insemination with sterile irradiated pollen and then using the embryo rescue technique. Therefore, the production of haploid and dihaploid plants alone can be used as one of the sources of diversity in flower and ornamental plant breeding programs.

Polyploidy is generally divided into two groups: autopolyploidy and allopolyploidy. An autotetraploid plant has four identical copies of a set of chromosomes. On the other hand, an allotetraploid (amphidiploid) plant has two sets of diploid chromosomes obtained from separate species. This distinction between autopolyploidy and allopolyploidy brings valuable genetic results. In general, autopleploid does not have any new alleles and does not have much genetic superiority over its diploid ancestors. For example, the fertility of autotetraploids is often reduced due to multiple chromosomes dependent on meiosis I. In the allotetraploid plant with the combination of two genetically different species, the chromosomes are regularly paired in pairs in meiosis I. As a result of hybrid strength and high fertility of allotetraploids compared to their diploid ancestors, it allows them to compete with their ancestors (Byrne and Carne, 2003). The success of polyploidy induction depends on the genotype and ploidy level of the primary plant. Khosravi et al. (2008) used three substances oryzalin, trifluralin, and amiprofosemethyl to increase the ploidy level of roses and create autopleploidy in them and showed that the success rate in doubling the chromosome number of diploid, triploid and tetraploid roses under the same conditions respectively 60%, 6.3%, and 0%, and there was no significant difference in the efficiency of the ploidy level increasing substances.

Polyploidy usually results in larger plants with thicker and darker leaves. Kermani et al. (2003) showed that roses with doubled chromosomes had more petals, more viable pollen, longer stem length, and greater width-to-length ratio in leaflets.

Also Kermani (2001) showed that the leaves of the plants whose chromosomes were doubled were significantly different from the mother plants in terms of resistance to the fungal disease of rose black spot. In some plants, the amount of resistance increased and in others, it decreased. He attributed these differences to morphological traits such as leaf thickness and stated that although the plants with doubled chromosomes do not have new genes, with the increase in the ploidy level, the strength of the heterozygous plants can be increased in the form of resistance to Diseases should be stated. Nimura et al. (2006) also showed that amphidiploids resulting from the doubling of carnation chromosomes had larger flowers and more fertile pollen grains and seeds. Fukui and Yokota (2007) showed that Rosa multiflora with doubled ploidy level had larger stomatal guard cells and larger flowers.

Increasing The Ploidy Level In Ornamental Plants

Between 50 and 80% of flowering plants (Angiosperms) are among many polygamous garden plants (Sun et al, 2015), and polygamy in them has made different species of these plants to be able to adapt to different weather conditions. Jowkar et al. (2009) after a cytogenetic study on 10 species of wild roses, showed that the ploidy level in these roses varied from diploid to hexaploid. Multiples usually show new phenotypic characteristics that are not present in their diploid parents, and in some cases, these characteristics have not been observed even in similar species. Some of these traits include dense growth, resistance to drought, resistance to stresses, apomixis, resistance to pests, change in flowering time, change in size, and change in the volume of biomass, which makes them suitable for selection in multi-breeding programs (Lu et al., 2006; Pieres et al., 2004; Ranney, 2006). In a study on evening primrose, Talebi et al. (2016) showed that in tetraploid plants resulting from doubling the chromosomes of diploid plants, the amount of nuclear genome was more than double that of diploid plants. In addition, the content of essential oils in tetraploid and diploid plants was 2.78% and 1.32%, respectively, which indicates a significant increase in tetraploid plants.

The induction of multiples in ornamental plants to create new and different commercial cultivars from the parents has been of interest to breeders for a long time. Multiple inductions in *Cyclamen* flower using colchicine were performed by Takamura and Miyajima (1996). They reported that tetraploid plants had larger petals and higher chalcone content than their diploid parents, resulting in more yellow flowers. In Pelargonium × (*Hortorum Pelargonium*), multiplicity was also induced using colchicine, which was accompanied by changes in leaf color and flower shape (Jadrna et al., 2010). With the induction of tetraploidy in gerbera (*Gerbera jamesonii*), an increase in the thickness of the leaves, an increase in the flower size, an increase in the length of the peduncle, and an increase in the longevity of the flowers after harvesting, which increased their marketability (Gantait et al., 2011). Multiple inductions in 1 diploid and 2 triploid cultivars of commercial rose (*Rosa hybrida*) was performed by Kermani et al. (2003) using oryzalin. They reported that leaf thickness was greater in tetraploid and hexaploid plants than in their diploid and triploid parents. Also, the leaves of the neopolyploids had a richer green color, a higher ratio of leaf width to length, and pollen grains with higher viability than their parents. In this research, it was reported that the internode distance in tetraploid plants was longer than diploids, but the internode distance in hexaploids was shorter than triploids, and the number of petals in one of the tetraploid roses was twice that of its diploid parent. They concluded that the method of increasing the ploidy level can be used as a transgenic strategy to transfer stress resistance genes from wild rose species to commercial cultivars. Because many rose species are diploid, while commercial cultivars are tetraploid, and in breeding programs between the two, usually sterile or low-fertility triploid progeny are created, which increases the ploidy level of diploid wild species to tetraploid. Or increasing the ploidy level of the triploid progeny to hexaploid will solve this problem. In subsequent research by Khosravi et al. (2008), tetraploid roses were created from diploid rose species (*Persica rosa*) and hexaploid roses from commercial triploid Iceberg rose (*Rosa hybrida* cv Iceberg).

Ahmadi et al. (2014) compared the morphological characteristics of iceberg roses with hexaploids resulting from the increase in ploidy level and reported that while the phenotypic characteristics of the two were very different, the survival of pollen grains and pollen germination in hexaploid plants It was almost 3 times that of their triploid parents. Also, the production rate of some secondary metabolites in hexaploid plants was different from their production rate in triploid plants. This difference can be attributed to the difference in the expression of the genes encoding the studied compounds.

The increase in the production of some secondary metabolites that are related to the production of flower fragrance is of particular importance in the breeding of ornamental plants. The results of a study conducted by Talebi et al. (2017) In tetraploid plants, it was more than their diploid parents, other morphological characteristics such as leaf length and width, the distance between nodes, leaf surface, plant height, fresh and dry weight, and flower cluster length were increased in the resulting tetraploid plant.

Measurement of Ploidy Level

Measurement of the ploidy level is usually done by a microscope and by using the chromosome counting method of meristem tissue cells (in most plants, the root meristem). The mitotic cells are stopped in the metaphase stage by the pretreatment substance, then staining and slide preparation are done, which is difficult and time-consuming.

Of course, determining the ploidy level by measuring pollen grains and chloroplasts in the protective cells of the epidermis is also possible, but these methods are not accurate enough, especially where the difference in the ploidy level is very small (for example, comparing triploids and tetraploids). Since fluorescence staining methods were introduced (De Laat et al., 1987). The flow cytometry method has been a very successful method for measuring the amount of DNA in many plant species. This method is often preferred over chromosome counting methods because several individual plants can be prepared during one preparation step, and this method has sufficient speed and accuracy (De Laat et al., 1987). The flow cytometry method can quickly detect the amount of DNA from any type of plant tissue in a large number of plants in a short period, and from there confirm the ploidy level after induction of multiples, which usually multiples must be selected from a large number of treated explants. It is a good method.

Genetic Engineering

The engineering of new traits in plants depends on the possibility of regeneration from the transgenic plant, and fortunately, this technique is expanding significantly, especially in ornamental plants. The expression of genes in different plant species is not always predictable and requires trial and error to bring the breeder to a stable commercial trait in the desired plant. Manipulation in metabolic pathways usually requires the transfer of multiple genes, which itself can be problematic and indicates the complexity of interactions within and between cells at the gene and gene product level (Tanaka et al., 2005). In genetic engineering programs, the first step is to have information about the use of specific genes. Among the successes of using this technique in the improvement of ornamental plants, we can mention the creation of special colors in ornamental flowers. Other traits that have attracted special attention include the structure and shape of flowers and plants, flower fragrance, shelf life after harvest, and resistance to diseases and pests.

Flower Color

Flower color is influenced by three types of pigments, flavonoids, carotenoids, and betalains, among which flavonoids are the most common and create a wide range of colors from yellow to red to blue. Among the important flavonoids in creating flower color are anthocyanins, which are found in the epidermal cells of petals. Carotenoids are placed in the cell plastid and produce yellow colors. These pigments together with anthocyanins cause bronze, brown, orange, or red colors in the petals. Betalains are rarely found and create milky, yellow, orange, and purple colors. The variation in flower color is concentrated by using genetic engineering to create changes in the metabolic pathways of flavonoid production.

The genes responsible for the production of enzymes of the mentioned pathway have been cloned in many plants, including ornamental plants, and are available in public DNA information centers such as the National Center for Biotechnology Information. Changes in primary anthocyanins (anthocyanidin 3 O-glucosides) in the metabolic pathway of flavonoid production can be done by changing the production of sugars, acids, and corresponding methyls, but the final color visible in the flower is usually affected by several factors, including primary anthocyanin molecules, pigments and vacuole pH (Tanaka et al., 2005). Different hybrids of Anagallis monelli were studied by Quintana et al. (2007), and they showed that the vacuole pH of the leaf surface cells was different based on the color of the hybrids. The creation of color diversity in all kinds of ornamental plants has been done through hybridization and mutation methods, and some of these methods have turned into experimental models. However, the use of genetic engineering to change the color of the flower is important because the other desirable characteristics of the plant, which may have taken years to create, have not changed, and only the color of the flower changes. This method is considered the best complement to traditional breeding methods, especially when the parent plant is sterile or a flower with new color schemes has been created.

The natural color of *Charleston* rose petals changes from yellow to red over 10-12 days. This color change is due to the accumulation of two anthocyanins, cyanidin-3-glucoside (*chrysanthemin*) and cyanidin-3 and 5-diglucoside (cyanin). Anthocyanin production is controlled by the expression of at least four genes: dihydroflavonol-4-reductase (DFR), anthocyanidin synthase (ANS), flavonoid-3-oxy-glucosyltransferase (UF3GT) and flavonoid-5-oxy-glucosyltransferase (UF5GT). The expression of DFR gene was detected during the initial stages of flower opening and the highest expression of UF3GT, ANS, and UF5GT genes during the last half of flower opening were reported by Hennayake et al. (2007). By turning off or reducing the expression of structural genes or controlling the metabolic pathway of anthocyanin production, it is possible to create white flowers. The reduction of anthocyanin biosynthesis in different plants has been successfully reported. Including in Petunia plant by van der Krol et al. (1998), in Gerbera by Elomaa et al. (1993), in Daffodil by Courtney-Gutterson et al. (1994) and in Rose and Carnation by Gutterson (1995). The blue color of Gentiana triflora plant was transgenic with Gentiana chalcone synthase (CHS) antisense gene and flowers with white to pale blue colors were created (Nishihara et al., 2003, Valizadeh et al., 2024, Mohammadi et al., 2025). CHS gene is one of the genes whose antisense is used for negative control and reduction of anthocyanin biosynthesis. But according to the theory of Winkel-Shirley (2002), since transgenic plants with the antisense of this gene are without flavonoids and flavonoids play an important role in protecting plants against ultraviolet rays and other environmental stresses, these plants generally have little resistance. Negative control of other genes of the metabolic pathway of anthocyanin production, including DFR or F3H, is another way to create white flowers without lowering the resistance level.

Zuker et al. (2002) showed that with the negative control of the F3H gene in cloves, the amount of anthocyanin changed, but simultaneously with the increase in the amount of methyl benzoate, the amount of plant aroma also increased. Many blue flowers have delphinidin derivatives that are aromatically acylated (acylated delphinidin). The three plants rose, clove and chrysanthemum accumulate only derivatives of pelargonidin and cyanidin that are not changed using aromatic acyl groups. Therefore, one of the goals of genetic engineering programs has been trying to induce the synthesis of delphinidin derivatives to create blue flowers in these plants. The key enzyme in delphinidin biosynthesis is F3'5'H. It has been shown that the F3'5'H gene obtained from Petunia and Lisianthus causes the direct production of blue color in Petunia and Tobacco flowers (Holton et al., 1993; Shimada et al., 1999). Color change to blue in Lobelia plant (*Lobelia erinus*) with F3'5'H lisianthus gene was done by Kanno et al. (2003). Florigene Ltd and Suntory Ltd created purple carnations by transferring the F3'5'H and FDR Petunia genes and showed that the petals of transgenic plants have delphinidin, which is not present in native carnations (Mol et al., 1999). Eucalyptus flowers rarely have pelargonidin-type anthocyanins, so they cannot produce orange or brick red colors.

Mizutani et al. (2003) succeeded in the genetic engineering and production of the *Petunia multiflora* (Red flower) line by reducing the expression of the F3'H gene and the expression of the DFR gene. Recently, Schlangen et al. (2007) stated the necessary strategies to produce yellow color in ornamental plants by cloning and determining the characteristics of chalcone hydroxylase genes.

The creation of floral designs in the flowers and leaves of ornamental plants has been of great value and has been studied for many years in *Ipomoea tricolor* flowers. Iida et al. (1999) showed that it is possible to create alabaster in the flowers of this plant by transposons. Adding a transposon to the flavonoid biosynthesis gene or biosynthesis pathway regulator gene leads to the formation of white parts in a colored background. Separating such a transposon from a particular gene often leads to the formation of colored sections on a white background.

Durability of Flowers

Another goal of improving ornamental plants is to create varieties with longer flower durability in the post-harvest stage. The life after harvesting of flowers is mainly affected by nutrition, bacterial contamination, and the amount of ethylene produced in the plant. The most important cut branch flowers are rose, carnation, and chrysanthemum, among these three flowers, only the endogenous production of ethylene in carnation leads to the aging of its flowers (Tanaka, 2005). All cut branch flowers are sensitive to bacterial contamination in flower water to different degrees. This pollution leads to the closing of the vessels and the stopping of the movement of water in the stem, and as a result, wilting and shortening the lifespan of the flowers after harvesting. Observance of health standards in the post-harvest stages can help in solving this problem. The lack of nutrients, mainly sugars, is another factor that accelerates aging, which can be increased by adding food additives to the water of the flowers.

Treating cloves with silver thiosulfate is one of the ways to increase the life span of cut flowers, but since silver is a toxic substance, breeders are determined to stop aging in cloves by using other methods. Reducing the expression of ethylene production by turning off the specific gene for the production of ACC Oxidase and ACC Synthase enzymes, which are considered endogenous ethylene production catalysts, was done by Savin et al. (1995). Although the presence of exogenous ethylene in the chain of clove transfers has not been raised as an important issue, there has always been a feeling that the transgenic product produced is less attractive than flowers treated with chemicals. With the clarification of the metabolic pathway of ethylene production in the Arabidopsis model plant (Bleecker and Schaller, 1996; Fluhr, 1998), the gene coding for the ethylene acceptor (Etr1) was isolated from Arabidopsis and then the mutated ethylene acceptor gene (Etr1-1) was introduced. By transferring this gene to carnation, flowers with long flowering life and insensitive to internal and external ethylene and free from chemicals were produced. Shaw et al. (2002) showed that when the Petunia with an ethylene-accepting mutated gene obtained from cabbage (*Brassica oleracea*) was transplanted, the flowers of the resulting plants were insensitive to external ethylene and their freshness and color were similar to those of non-transgenic plants. They kept longer.

Also, these plants produced larger flowers, but their mortality increased, which could be due to the greater sensitivity of transgenic Petunia plants to diseases. Zheng et al. (2007) made the pBinETR1D3 plasmid containing the antisense ETR1 cDNA from Texas rose and transferred it to the flower with the help of *Agrobacterium tumefaciens* and produced transgenic Petunia plants with less sensitivity to ethylene to increase the durability of flowers against ethylene. They did not wither after using ethylene.

Morphological Traits

So far, many potentially useful genes have been cloned in the shape of flowers and plants. Transcription factors regulating plant growth and biosynthetic or regulatory genes involved in plant hormones are conventional candidates. But only a very small number of these genes have been used in breeding programs for ornamental plants. In some cases, the expression of these useful genes has been associated with the creation of plants that did not have high potential in terms of marketability. For example, Winefield et al. (1999) showed that the expression of the rolC gene from *Agrobacterium rhizogenes* causes the production of β-glucosidase-cytokinin enzyme. Petunia plants transgenic with the mentioned gene showed morphological changes, including a decrease in plant height, leaf and flower size, and the production of numerous lateral branches. But according to the studies of van der Salm et al. (1997), the transfer of C and rol A, B genes in the rose cultivar *R. hybrida* cv. Money way led to the production of better roots in these plants. Chemicals substance such as Uniconazole are widely used to shorten plants, but today many genes involved in gibberellin biosynthesis and signaling have been isolated, and Some breeding centers, such as Suntory company, successfully use the gai-1 gene to produce short Petunia flowers (Tanaka et al., 2005).

Flower Fragrance

Flower fragrance is of special importance in attracting pollinators and for the consumers of the flower and plant market. The aromatic substance of flowers consists of various compounds, more than 700 compounds have been identified in 60 plant families, which are mainly derivatives of fatty acids such as benzoids, phenylpropanoids, and terpenoids.

Although the number of cloned genes for the biosynthesis of aromatic substances is increasing day by day, there is very little biochemical and molecular biology information about the biosynthesis mechanism of these substances. These compounds are produced in the petals under the influence of the enzymes of the petals' epidermis cells and are affected by their developmental stage. The first isolated structural gene for the biosynthesis of perfume enzyme, S-linalool synthase (LIS), was obtained from a native plant of California, Clarkia breweri, whose main composition of the perfume was S-linalool. Lucker et al. (2001) transferred this gene to Petunia hybrida W115. By negatively regulating the F3H gene in cloves to reduce anthocyanin and make the flower lighter in color, Zuker et al. (2002) obtained plants with a higher amount of methyl benzoate production and, as a result, more fragrance. They concluded that blocking the anthocyanin biosynthesis pathway may have changed the metabolic flow through the phenylpropanoid pathway.

Resistance to Diseases

The commercial flower and plant market is always exposed to diseases and suffers a lot of losses every year. Many methods have always been used to fight their invasion and spread. Chemicals are usually used to deal with pathogenic agents and their carriers, both at a low level and a commercial level. These materials are expensive and dangerous to the environment. Sometimes making changes in crop management can be effective in fighting pests and diseases. For example, the use of hydroponic cultivation systems in cut flowers, including carnations, has helped to control pests and diseases, but these changes are mostly costly. One of the ways to reduce production costs is to breed plants that need less chemicals and are resistant to all kinds of fungi, bacteria, viruses, nematodes, and insects (Heydarzadeh et al., 2023). The traditional improvement of ornamental plants due to the lack of resistance genes in some of the important commercial varieties, the limitation of interspecies crossings, the time required for breeding programs, as well as the lack of stability of resistance in the improved plants due to the complex relationship between the host and pests and diseases are limited. It is special.

There are more than 100,000 species of fungi in the world, about 8,000 of which are capable of causing disease in plants. All plants are susceptible to infection by fungal diseases, and usually, one fungus can infect more than one plant species (Agrios, 1988). The cell wall of fungi is usually made of chitin and glucan (β-1, 3-glucan) polymers. Formed and therefore they are vulnerable to the degradation of chitinase or glucanase enzymes (β-1, 3-glucanases) or chitinases). These enzymes exist in plants and have been well described in tobacco. The strategies used to increase resistance in ornamental plants are generally limited to the expression of hydrolytic enzymes and antimicrobial compounds (Punja, 2001). By transferring the ChiA chitinase gene from *Serratia marsecens* bacteria to several carnation cultivars, new lines were created that caused a delay in the onset of disease symptoms and, as a result, a delay in the death of the plant (Tanaka et al., 2005).

The sensitivity of roses to all kinds of fungal diseases, including false powdery mildew, surface powdery mildew, and black spot, has caused a lot of damage to the commercial market of this plant. Marchant (1998) by transferring chitinase gene to *R. hybrida* cv. Glad Tidings reduced the sensitivity of this plant to black spot disease. Li et al. (2003) also reported that by transferring the gene of antibacterial resistance protein (Ace-AMP1) to rose *R. hybrida* cv. Carefree Beauty was affected by superficial whitefly disease in this plant. Antibacterial peptides and proteins are extracted from plants or synthesized in laboratories. By digesting fungi or disrupting the construction of the cell wall, these substances help to create resistance in plants (Punja, 2001). Bi et al. (1999) by transferring the antibacterial protein to the candlestick increased the resistance to Botrytis (*Botrytis cinerea*) in this plant. *Chrysanthemum* has always been exposed to viral and pseudo-viral infections due to its vegetative propagation. One of the most important of these viruses is *chrysanthemum* virus B (CVB). Skachkova et al. (2006) used carriers containing they made the antisense of the protein coat of the virus and transgenic *chrysanthemum* through *Agrobacterium* White Snowdon and obtained resistant lines from it. Also, the gene obtained from cry1Ab from *Bacillus thuringiensis* var kurstaki HD-1, which produces an endogenous toxin, To reduce the damage caused by scale insects, 5 varieties of *chrysanthemum* were transferred and resistant transgenic plants were produced (Shinoyama and Mochizuki, 2006).

The use of new bisexual methods of flowers and ornamental plants is expanding in the world. Because in traditional methods, despite spending time and high cost, the produced products often lack the desired indicators of breeders, and also these methods alone are not able to meet the needs of the diversified consumer market, therefore, the use of new methods As a complement and even an alternative to the traditional methods of correction, it seems necessary and unavoidable. By acquiring new breeding techniques such as mutation induction, polyploidy, or genetic engineering, it is possible to make partial changes in the genetic structure of the plant and preserve its other desired traits, while making the necessary changes to achieve the traits desired by the consumer in the time and cost of the breeders. It saved a lot. Due to the progress of modern technologies, the costs and time needed to optimize these methods are decreasing day by day, and the improvement of ornamental plants through new methods is economically justifiable in many cases. On the other hand, the laws for the release of transgenic plants, especially in the case of ornamental plants, have been approved in some countries and are being approved in others, so in the future, we will see a more effective role of using new techniques in improving flowers and ornamental plants.

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CHAPTER 5

MECHANIZATION AND FEASIBILITY ANALYSIS OF WATER CONSUMPTION IN LIVESTOCK PRODUCTION

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DOI: https://dx.doi.org/10.5281/zenodo.15092369

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INTRODUCTION

Water is an essential nutrient for animals, as it is for all living organisms, and is of paramount importance at every stage of production. Water constitutes a significant amount of all molecules in the animal body and accounts for approximately 50–81% of an animal's total body weight during adulthood. It is vital for regulating body temperature and for supporting growth, reproduction, lactation, digestion, joint lubrication, and vision. Providing adequate water to livestock is crucial for maintaining animal health and optimizing livestock production. Loss of 10% of body water is fatal in most domestic animal species (Meehan et al., 2015). Different sectors are increasingly concerned with finding solutions for the rational and sustainable use of water owing to the escalating scarcity of this vital natural resource. Small ruminants, mainly sheep and goats, have significant social and economic value because of their remarkable ability to adapt to adverse environmental conditions and efficiently utilize water. Consequently, these animals represent a viable alternative for mitigating the impacts of climate change, expanding market share, and improving living conditions in many regions worldwide (Araújo et al., 2015). Water requirements for livestock production vary significantly among species and are influenced by several factors, including age, growth rate, pregnancy, lactation, activity level, ration type, feed intake, and ambient temperature. Various sources, such as wells, fountains, surface water, and moisture content in feedstuffs, are utilized to fulfill the water needs of livestock production. The concept of water efficiency in animal production is relatively new, and there is limited global research, particularly in Turkey. Further research and innovative technologies related to watering mechanization are essential to improve water efficiency in livestock production. Conducting a study focused on designing livestock watering mechanization and assessing its feasibility would significantly enhance internal mechanization processes. Within this context, this study evaluated relevant research and recent findings from various countries, including Turkey. The present work is intended to benefit researchers, decision-makers, and policymakers involved in this field.

Water Requirements

Livestock water requirements, as listed in Table 1, represent the daily minimum values essential for designing a water delivery system. According to previous studies, hot weather conditions can increase water requirements by more than twofold, and when feeding less moisture-containing feedstuffs, consumption can increase by up to fourfold. Therefore, a watering system must accommodate at least double the normal consumption; however, designing for a fourfold increase may be impractical or cost-prohibitive. Therefore, contingency plans should be implemented for periods of extreme heat.

Accurately determining water requirements based on specific conditions is essential for designing efficient watering systems and verifying the adequacy of water sources. When large numbers of animals are housed together, not only can the demand exceed the capacity of distribution systems, but it may also surprise available water resources, such as wells, springs, ponds, or reservoir storage. Therefore, watering systems should be designed considering the herd size, environmental factors, and operating conditions.

Table 1. Daily water requirements of livestock species (Parker and Brown, 2003)

Animal	**Minimum (L/day)**	**Average (L/day)**
Lactating cow	76	57-95
Beef cattle	57	46-76
Yearling cattle	38	23-53
Sheep	8	7-11
Poultry	0,1	1,3-8,3

Pipes and materials in livestock watering systems

When meeting livestock water requirements, the available water source may not flow naturally owing to gravity. Hence, the quality, quantity, and dimensions of the materials and fittings used in the watering system are significant factors that influence performance. Moving water upward or downward requires energy. As water moves through the pipes, frictional forces develop along the internal surfaces. Although the friction coefficients vary according to the pipe material (e.g., PVC and steel), friction occurs in all pipe types. However, smaller diameter pipes exhibit greater friction and higher water flow resistance than larger pipes. Moreover, new pipes with smooth internal surfaces produce less friction than older pipes. Over time, depending on the mineral deposits from the water source, the system may experience reduced pressure or decreased flow capacity. An increased flow velocity further amplifies friction; thus, boosting the water flow velocity necessitates an increase in pressure to overcome higher resistance levels. However, doubling the pressure (atm) does not double the water flow; instead, a fourfold increase in pressure is required to double the water flow. Consequently, attempting to increase the flow rate solely by increasing the pressure can quickly exceed the maximum operating pressure limit of the pipe system.

Pumping water to elevated locations, mainly those higher than 30 m, requires special attention and careful planning. To maintain efficient water flow and reduce the necessary pressure, it is advisable to utilize full-flow, low-resistance valves to control the water levels in storage tanks, minimize the number of elbows and valves, and use pipes with larger diameters. Larger-diameter pipes are recommended because less water contacts the pipe walls, significantly reducing frictional losses.

Watering system layout

Because the cost of a watering system strongly depends on the distance from the water source, it may be economically advantageous to use pipes with larger diameters over the first half of the distance to enhance the water flow. Generally, the carrying capacity of a single large-diameter pipe increases more rapidly than its cost, making one larger pipe typically cheaper than two smaller pipes of equivalent capacity.

Using white-colored pipes for aboveground installations is recommended, as designers believe they reduce solar heat absorption, thereby minimizing water heating. It is crucial to ensure the proper insulation of the distribution pipes.

It is important to determine whether water lines should be installed underground or above ground. Against freezing and to ensure year-round reliability, water lines are typically buried at depths between 30 cm and 45 cm. However, installing aboveground pipelines is less expensive, easier to repair, and more portable. Conversely, underground installations provide superior protection against freezing and physical damage. In particular, lines crossing vehicles or animal pathways should be adequately protected or buried underground.

Although most black plastic pipes appear similar, significant differences exist. Plumbing pipes intended for sanitary purposes are generally designed for underground use and lack adequate UV resistance for aboveground installations. However, agricultural pipes specifically designed for drip irrigation typically exhibit enhanced resistance to freezing and ultraviolet (UV) exposure, albeit at a slightly higher cost.

Watering system flow rate and storage considerations

A simple calculation to determine the daily water supply based on the required flow rate can be performed as follows:

$$(24\ hours\ x\ 60\ minutes\ x\ \ldots L/min) = \cdots L/day$$

However, relying solely on this calculation does not adequately support an effective watering system as it leaves no margin for error and overlooks other critical factors. For example, if a system operates continuously at the maximum flow capacity, ignoring potential breakdowns or downtime, it may fail to meet livestock needs under practical conditions. For instance, systems should generally be designed to deliver the required daily water within a maximum of 4 hours of continuous pump operation, thus allowing sufficient operational flexibility. Continuously running pumps, up to a maximum of 12 hours per day, maybe permissible in exceptional cases, but limiting operation to approximately four hours daily is strongly advised to account for maintenance and unforeseen disruptions.

It is crucial to consider livestock drinking behavior, as animals typically move in groups to drink water. Consequently, watering tanks should either be rapidly refilled to handle sudden demand, have large storage capacities, or combine both. Ideally, tanks should accommodate approximately 2-4% of the livestock group drinking simultaneously, with the watering system designed to supply the total daily requirement within four hours at maximum flow.

When animals are led to watering points in scheduled groups, the tank capacity should provide at least one complete cycle of water consumption per group, typically accounting for at least one hour of consumption. Tanks that cannot be completed within one hour should be increased in size to ensure adequate supply. Particularly for sheep, which may exhibit aggressive behavior when thirsty, larger drinking areas and personnel supervision are necessary to prevent injuries. The livestock movement distance, tank refill rates, and water flow rates should be strategically planned to maintain a continuous and efficient water supply.

Water system options

Water sources

Livestock watering systems commonly utilize wells, groundwater springs, ponds, lakes, streams, and other surface waters. In Turkey, livestock operations in continental climate regions generally rely on groundwater systems for winter feeding, whereas in milder winter climates, increasing livestock numbers have led to greater reliance on surface water. Wells equipped with electric pumps are often the most flexible and cost-effective water source. However, if grazing areas are located far from wells or wells are unavailable or insufficient in quality and quantity, surface water sources must be explored.

When water sources are located at considerable distances, the system must be portable or establish multiple mobile systems. In such cases, using plastic pipes from farm wells is typically the most economical and efficient option.

Because watering large animal groups during summer significantly increases water demand, it is recommended that drilling companies be worked closely with to test the capacity and yield of wells. Additionally, producers should consult relevant authorities and institutions to explore potential cost-sharing opportunities for improvements in the livestock watering system.

Although electric-powered pumps and pipelines are the most common approaches, having multiple water source options enhances flexibility and provides emergency backup capacity. Water is an invaluable resource, and contamination events, whether involving groundwater or surface water, cannot be easily or quickly remedied.

Water distribution system

Three primary methods for delivering water to livestock are direct Access to ponds, gravity-fed systems, and pumped-water systems.

Direct Access to surface water

Direct Access to surface water can be simple and inexpensive, but it limits water availability to a single point, requires maintenance and investment, and increases the potential for water contamination. Access ramps to watering points for livestock on slopes should have a gentle incline of approximately 1:6 and provide firm and stable walking surfaces constructed of concrete or gravel for slip resistance. Ramps built from crushed rock should include fine granular material to bind gravel and ensure a comfortable, nonabrasive walking surface. Although potentially costly, a geotextile sublayer can significantly enhance the longevity and stability of the ramps.

For livestock accessibility, ramps should be at least 3 m wide for 30 animals, with an additional 50 cm width required for each additional group of 10 animals (e.g., an 80-cow herd requires a 5.5 m wide ramp). The ramp edges should be protected or fenced to prevent damage, and a rough walking surface is essential, particularly under icy conditions.

Support regarding construction techniques and cost-sharing opportunities can be obtained by contacting relevant institutions and agencies.

Gravity-assisted watering systems

An essential consideration in livestock facility design is leveraging gravity to minimize the energy consumption for transporting water from the source to the watering points. Gravity-assisted systems provide free energy for water movement; however, ideal watering locations may not always be downhill from water sources. Gravity systems typically operate at lower pressures, necessitating larger pipe diameters to maintain adequate flow rates. If a reserve tank is employed, the water level must be regularly monitored, and the associated costs must be considered. When an elevated point near the water source is available, and grid electricity is inaccessible, water can be pumped into a storage reservoir using a high-capacity fuel-powered pump. Gravity then distributes the water from this reservoir for three to seven days. In continental climates, slow-moving gravity systems may freeze quickly unless an ample water supply and regular overflow maintain constant water movement. Although gravity is cost-free, designers should ensure that the limitations of gravity systems do not inadvertently result in higher overall costs compared with positive-pressure systems.

Pumps for livestock watering

Pumps move water primarily in two ways:

1. Suction pumps (centrifugal or diaphragm pumps) draw water upward from the source.

2. Submersible pumps, placed directly into wells or water sources, push the water upward. A similar type includes pumps that use pistons or impellers, which typically move water vertically to approximately 7 m above the surface. This limitation arises because atmospheric pressure pushes water into the vacuum of the pump rather than the pump itself, lifting water directly. These pumps are generally cost-effective and are suitable for transporting substantial amounts of water at medium pressure.

Another pump type, the piston pump, is commonly used as a booster pump in rural areas or windmill-based installations to increase pressure and elevation.

Pump power options

Water movement requires energy proportional to the volume being pumped. As livestock require water daily, it is advisable to utilize a steady, reliable, and low-cost energy source compatible with different pump types. Grid electricity is typically the preferred energy source; however, alternative energy sources must be considered due to their limited availability in remote regions. Each farm has unique resources and objectives, so each situation must be individually evaluated to determine the most suitable pumping solution.

Solar-powered pumping systems

If livestock facilities are located away from the grid electricity, solar-powered pumping systems can be an alternative. Solar-powered pumps are attractive because of their renewable nature, environmental friendliness, and the fact that energy is essentially “free” once the system is installed. Solar-powered pumps are relatively maintenance-free, portable, and compatible with various pump options.

Water consumption increases notably during hot and dry weather, which coincides with the conditions under which solar pumping systems achieve peak performance. However, the main drawback of solar-powered systems is that they function efficiently only during periods of clear weather and direct sunlight. In Turkey, solar pumps do not operate at night or during cloudy conditions. Therefore, energy storage systems (batteries) or water reservoirs are required to maintain a continuous water supply during non-sunny periods, thereby increasing the system's total cost.

Additional disadvantages include the potential vulnerability of solar power systems to vandalism in remote areas, technical complexity, and relatively high initial investment costs. Various DC-powered pumps exist, ranging from inexpensive bilge pumps to deep-well submersible pumps. Facilities can be designed with photovoltaic systems capable of fulfilling daily water requirements within approximately seven hours of sunlight exposure. Using water storage tanks instead of batteries is recommended to reduce the costs associated with batteries and avoid significant energy losses (approximately 40%) from converting photovoltaic power to stored electricity (URL, 2025a). Farmer experience with photovoltaic technology remains limited, with hesitancy mainly due to technical complexity and substantial initial investment requirements.

Animal-operated pumps

Nose pumps or animal-operated diaphragm pumps function by pushing a lever to draw water into the sloped drinking trough. After the animal drinks, the lever returns automatically, pumping approximately one liter of water back into the trough and preparing it for the next drink. Nose pumps are portable, simple, and practical; however, calves typically cannot operate them independently. Thus, an auxiliary collection trough below the central trough could supply water to smaller animals.

Proper installation is crucial to ensure that pumps are securely anchored to prevent cattle from moving the equipment during drinking or aggressive interactions. Additionally, pumps must be conveniently placed to prevent livestock interference during the operation. Animals usually require several training days to become accustomed to these systems before they depend solely on nose pumps, especially when transitioning away from other water sources. Dairy cows have demonstrated particular proficiency with nose-operated pumps.

In colder climates, nose pumps are vulnerable to freezing, particularly if residual water remains after animal use. Therefore, draining water troughs after watering is necessary at freezing temperatures to ensure continued operation.

System costs generally include those of pumps, necessary hoses, and fittings. Installation should involve firmly securing pumps without obstructing the animals' movement or accessibility to prevent damage or injuries.

Wind-powered pumping systems (Windmills)

Although not commonly utilized in Turkey, windmills offer a low-cost option for water pumping once installed. Capable of drawing water from surface or deep wells, wind-powered pumps present an economically favorable long-term solution. However, their disadvantages are similar to those of solar energy systems because they require consistent wind conditions. Without adequate wind, the system could not operate effectively. A suitable location for windmills should be wind-exposed and distant from obstructions, such as trees or windbreaks (ideally at a distance of approximately 20 times the height of nearby trees). Unfortunately, such optimal locations may not always be conveniently close to the water sources.

Smaller windmill systems generating pressurized air for water pumping can be significantly more affordable, typically costing approximately one-third of traditional deep-well windmill systems. Regardless of their cost advantages, these smaller systems share the inherent disadvantage of reliance on consistent wind speeds. In addition, the lack of portability and restrictions posed by densely forested or sheltered areas can limit the practicality and application of wind-powered pumping systems in specific agricultural settings.

Water-powered pumps

Two distinctly different pumps, the hydraulic ram pump, and the sling pump, utilize falling or flowing water as their power source.

If the water source is more than 250 m away, the tank volume should be sized to accommodate one-third (1/3) of the herd's daily water requirements. If the water source is nearby, the tank volume can be reduced to about one-fifth (1/50) of the daily herd requirement (URL, 2025b). The temperature and animal age should also be considered.

Gasoline/diesel pumps or generator and water transport

This is an alternative power source. Gas-powered centrifugal pumps, capable of rapidly moving large volumes of water, can be utilized to fill storage systems. Generators can supply electricity to operate standard electric pumps at remote locations. Except for fuel costs, generators and pumps are typically cheaper and more readily available than solar-powered systems. Most pickup trucks, tractors, and typical farm vehicles can transport approximately 4,000 liters of water. Four tons (4,000 liters) of water is sufficient to supply approximately 66 cows (60 liters/day each) or 100 yearling cattle (30 liters/day each). However, challenges arise during hot weather when consumption triples, necessitating increased animal movement (Northeast et al., 2025).

Livestock watering systems and facilities must be planned according to the herd size anticipated for each grazing unit, the expected carrying capacity (based on grazing plans and forage inventory), and the required storage, delivery rates, and interval requirements. Peak demand typically occurs when livestock are watered twice daily, consuming approximately half of their daily water requirements per watering session. Each animal typically drinks for approximately five minutes, and it is recommended that herd watering be completed within two hours. For systems relying on windmills or solar power, the total storage capacity should meet the demand for approximately five days. Electric-powered systems, rural water districts, and other public water systems should provide sufficient storage capacity for at least two days (NRCS, 2015; NRCS, 2017).

CONCLUSION

To optimize animal health, designing an appropriate watering system is crucial, as well as thoroughly understanding the daily water consumption needs and providing high-quality water. Ensuring sufficient water quality is essential for effective livestock production. Water constitutes approximately 50 - 80% of the animal's body weight, regulates body temperature, and plays a vital role in organ functions such as digestion, waste removal, and nutrient absorption. When designing a watering system, accurately determining the daily water requirements is of utmost importance, as they vary considerably between animal species. It is known that animal size and growth stage strongly influence daily water intake. Environmental and management factors such as air temperature, relative humidity, physical activity, and production levels can also significantly affect consumption rates.

Additionally, water quality, encompassing factors such as temperature, salinity, taste, and the presence of contaminants affecting odor, has a significant effect. The moisture content in the feed also influences water intake; feed with a relatively high moisture content reduces the volume of drinking water required. Given that drinking water needs vary by species, farm practices, and management, many producers have chosen to install water measurement equipment to obtain accurate water consumption data. If medication administration or animal cooling is integrated into the watering system, employing measurement devices can facilitate sustainable livestock production by ensuring appropriate dosing rates. This study was designed to contribute to mechanization and feasibility studies focusing on water requirements and equipment engineering for beef cattle and selected poultry species.

Rapid population growth, combined with limited freshwater resources, is a steadily increasing global water demand. The worldwide average annual per capita water consumption is approximately 800 m³. Today, roughly 1.4 billion people-nearly 20% of the global population-lack adequate drinking water, and 2.3 billion people do not have Access to safe water supplies. Furthermore, by 2050, the number of countries experiencing water scarcity is expected to increase to 54, with approximately 3.76 billion individuals affected. This indicates that approximately 40% of the projected global population of 9.4 billion in 2050 may face water shortages. Each year, approximately two million people die due to intestinal infections arising from improper water use and inadequate hygienic conditions. Chronic fluoride deficiency and other water-related health issues are becoming increasingly significant problems.

Improving available water quality and hygiene standards can mitigate these problems. For a country to be considered water-rich, the annual per capita water availability must be between 8,000 and 10,000 m³. With only 1,430 m³ per capita per year, Turkey does not fall into this category (URL, 2025c).

Approximately 87% of dairy cattle milk contains water (Ward and McKague, 2007). Therefore, providing sufficient high-quality water to dairy cows is critical. Farmers must always have free Access to fresh water. Lactating cows' water requirements depend significantly on milk production levels, feed moisture content, and environmental conditions such as temperature and humidity. Cows typically achieve maximum water intake during periods of highest feed consumption.

Feasibility assessments should emphasize the principles governing the design of animal watering systems and the influence of animal behavior on system design in the planning and design of livestock watering systems.

This study establishes the fundamental principles for planning and designing livestock watering systems, covering water resources, power, pump types, and the essential components of livestock watering infrastructure.

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CHAPTER 6

WHERE SHOULD WE GO?
(AIMING FOR FUTURE AGRICULTURAL MOVEMENT)
WHY SHOULD WORRY ABOUT SECURITY AND FOOD SAFETY?

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DOI: https://dx.doi.org/10.5281/zenodo.15092371

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Where should we go?

Studies indicate that the pace of life has increased by 10% since the 1990s (Wiseman, 2020), with this rate being even higher in developed countries (Levine and Norenzayan, 1999; Wiseman, 2020). Although the number of available choices in various aspects of life has expanded, individuals often lack the time or capacity to thoroughly evaluate these options and consider their long-term consequences.

The agricultural sector is not exempt from these challenges. The domestication of various plant and animal species during the first agricultural revolution marked the beginning of humanity's complex relationship with the land (Anonymous, 2019a). However, this relationship has not always unfolded harmoniously. The fundamental question remains: what steps must be taken to ensure a sustainable and prosperous future for agriculture? To determine the right path forward, it is crucial to understand how we arrived at our current situation.

Agricultural Challenges and Their Solutions

Throughout history, numerous examples illustrate the consequences of soil exhaustion and inefficiency on human societies. One such case is Ayn Ghazal, a settlement that emerged approximately 10,000 years ago. At its peak around 7000 BC, it was a thriving village with a population of 3,000. However, within a few generations, by 6500 BC, the population had declined to one-sixth of its former size. The depletion of trees for fuel and construction, coupled with soil degradation caused by intensive agriculture and animal husbandry, led to migration and ultimately the abandonment of the settlement (Rollefson et al., 1992). This marked the first instance in which human activity, rather than climatic conditions, forced a population to relocate.

During the Migration Period (300-800 AD), the increasing population in Europe intensified land use (Crabben, 2010). By the 14th century, events such as the Black Death and the Hundred Years' War drastically reduced the agricultural workforce. To combat poverty and famine, England introduced mass commercial farming and established agricultural markets in urban centers (Overton, 1996). By the 1600s, soil depletion became evident due to intensive farming, prompting solutions that emerged in England from the mid-17th to the late 19th century. Innovations such as Liebig's mineral nutrition theory, crop rotation with turnips and clover, selective breeding, and advancements in transportation contributed to what is now recognized as the Second Agricultural Revolution (Roudart, 2006).

Many modern challenges, including the overuse of synthetic fertilizers, mechanization, and rural depopulation, trace back to the post-Industrial Revolution era of the 19th century (Lucas, 2002). In England and other European countries, mechanization reduced the demand for rural labor, driving mass migration to cities. Consequently, urban populations surged while rural areas declined. At this juncture, humanity faced a new challenge: how to sustain the growing urban population. Solutions included improved drainage systems, the development of synthetic fertilizers, and the expansion of railway networks for efficient food transportation. This period marked the emergence of global supply chains for food production, storage, packaging, and marketing (Anonymous, 2019b). The transformation of raw materials into high-value products also gained prominence, ensuring that migrants from rural areas could access essential goods in exchange for wages.

The first Green Revolution, occurring between the 1960s and 1970s in the United States and other industrialized nations, aimed to address food shortages through technological advancements. This movement introduced high-yielding varieties (HYVs), mechanization, agrochemicals, and irrigation techniques to enhance agricultural productivity (Melillo, 2012). The second Green Revolution, led by the Rockefeller Foundation in collaboration with the Mexican government, enabled Mexico to achieve self-sufficiency in wheat production and transition into an exporter. In India, the Green Revolution began in 1967, supported by the Ford Foundation and the Indian government, introducing high-yield rice varieties (IR8), chemical fertilizers, and tractors (Anonymous, 2006). Between the 1960s and mid-1990s, India’s rice yields increased from 2 to 6 tonnes per hectare (Wei, 2012), while cereal production in developing countries rose 2.7 times compared to 2.3 times in developed nations (Koohafkan, 2012).

Although the Green Revolution initially addressed food shortages and improved farmers' livelihoods, it also fostered widespread agrochemical use, leading to the growth of a new industrial sector and increased local employment. While these developments seemed promising at the time, the long-term environmental and health consequences are now evident. Presently, 822 million people suffer from obesity, while 820 million experience hunger, and 2 billion individuals face food insecurity (FAO, 2019). These statistics underscore the inefficiencies and inequalities of modern food systems.

In response to mounting health and environmental concerns, the concepts of food security and food safety have gained prominence. The United Nations' Committee on World Food Security defines food security as the condition in which “all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life” (IFPRI, 2020). In contrast, the FAO defines food safety as the absence of hazards in food that may pose risks to consumers, including microbiological, chemical, or physical contaminants such as bacteria, viruses, or pesticide residues (FAO, 2020).

The subsequent sections of this study will explore how post-industrial and Green Revolution-era solutions have compromised natural resources, food security, and food safety, and will propose measures necessary for restoring environmental balance and public health.

Unemployment, Bankruptcy, and Migration

Unemployment and bankruptcy, which started with the industrial revolution in rural areas and increased rapidly after the green revolution, were the main factors triggering regional and urban migration (Nardinelli, 2019). Some of the farmers in the developing countries willingly and the others forced to keep up with the green revolution. HYVs were costly because of their excessive need for agrochemicals; moreover, they caused an increase in labor and cost of weed control resulted from herbicide resistance. These were among the factors that distressed the farmers (Norsworthy et al., 2012). In addition, the development of Genetic Use Restriction Technology (GURT) increased sales of seeds since they produce only once; therefore, the farmers' dependency on companies and increasing high production costs started to cause serious problems (Jefferson et al., 1999).

Some of the farmers got into debt, got poor or went bankrupt to get the necessary inputs for cultivation. The gap between rich and poor people has increased day by day (Dhanagare, 2019). The use of machinery in agriculture caused the unemployment rate, especially in the countrysides, to boost (Feldmann, 2013; Nardinelli, 2019). While the agricultural outputs doubled between 1960 and 1994 in America, the employment rate declined by 57% (Ahearn et al., 1998). As a result, suicide cases appeared in some parts of the world. Not surprisingly, in the African continent, the Green Revolution failed due to a lack of infrastructure (Vasavi, 2009).

Rapidly rising unemployment followed by the industrial revolution and the increasing gap between rural and urban incomes provoked regional migration. Rural residents started to move towards industrialized cities or regions where intensive agriculture is carried out. In India, where the second green revolution took place, approximately 1 million agricultural workers regionally migrated from the eastern provinces to Punjab and Haryana each year, and this number increased more in the following years (Oberai and Singh, 1980).

Today, several issues determined in development policies for rural areas which should be considered against migration listed as follows:

- Increasing the competitiveness of rural areas in the global system by mobilizing alternative sources of income such as tourism and industry other than agricultural income.
- Increasing government incentives in rural development policies. Providing the physical and social infrastructure attracting the investors to the rural areas.
- Implementing a model of vertical and horizontal governance among international, national, regional and local management and local stakeholders (public, private and non-governmental organizations).

Monopolization

The challenges brought about by the Green Revolution, including unemployment and migration, have raised critical questions over time: Was the Green Revolution truly initiated to solve global hunger, or did it primarily serve commercial monopolization? Alternatively, did it begin with benevolent intentions but later shift in purpose and direction? Ultimately, the fundamental question remains-who truly benefited from the Green Revolution?

Globally, approximately 10 to 15 major corporations control the production and distribution of fertilizers, agrochemicals, and seeds. The consolidation of these industry giants, such as the merger of Bayer and Monsanto, has intensified concerns over monopolization (Neslen, 2018; Bayer, 2020). A potentially even more pressing issue is the emergence of corporations that not only dominate seed production but also control critical agricultural inputs, including soil, climate data, and genetic modifications. Such companies effectively dictate access to seeds, pesticides, fertilizers, and agricultural machinery, thereby exerting unparalleled influence over global food production systems.

To mitigate the risks associated with agricultural monopolization, national and regional competition policies should ensure that local farmers retain the ability to exchange seeds, practice traditional breeding methods, and access markets and financial resources. Additionally, governments must rigorously oversee cross-sectoral mergers, demanding full transparency from corporations to uphold market fairness and public interest. In assessing the suitability of a merger, all stakeholders including competing companies, employees, and related industries should have access to relevant corporate data. Decision-making should take into account not only economic implications but also human rights considerations, as well as potential health and environmental risks.

Particular attention must be given to the control and ownership of agricultural data, ensuring that community rights take precedence over corporate shareholder interests. In this regard, democratization of data protection is essential. If an assessment indicates potential negative consequences arising from corporate consolidation, the proposed merger should be rejected. Furthermore, legal frameworks should be developed to prevent the formation of excessively large conglomerates, and the digitalization of agriculture should be closely monitored to prevent the emergence of new mega-corporations that could further entrench monopolistic practices.

Uncontrolled population growth

One of the most glaring consequences of the green revolution is population growth. It is estimated that the world population, which increased by 5 billion after the revolution, will increase by 2 billion more in the next 30 years, and will peak with 11 billion in 2050 (Worldometer, 2019; UN, 2019) . The United Nations Population Fund (UNFPA) listed what needs to be done with the increasing population in the 7 billion actions campaign launched in 2011 as follows (UNFPA, 2011):

1. Reducing poverty and inequality also slows population growth.
2. "Investing in the power of women and girls will accelerate progress on all fronts."
3. "Energetic and open to new technologies, history's largest and most interconnected population of young people is transforming global politics and culture."
4. "Ensuring that every child is wanted and every childbirth safe leads to smaller and stronger families."
5. "Demands for water, trees, food and fossil fuels will only increase as the world population grows to 7 billion and beyond."
6. "Lower fertility and longer life expectancy add up to a new challenge worldwide: aging populations."
7. "The next two billion people will live in cities, so we need to plan for them now."

Although the trend of relocating to rural areas has gained attention since the 1970s driven by fatigue from the fast-paced, stressful, and health-compromising nature of modern urban life projections indicate that by 2050, approximately 66% of the global population will reside in cities. Consequently, governments must develop the necessary infrastructure to accommodate this forecasted urban growth using sustainable methods and resources. Simultaneously, raising public awareness about self-sufficiency and the importance of meeting basic needs through sustainable sources is essential.

Historically, individuals possessed the knowledge and skills to independently secure fundamental necessities such as water, food, shelter, and clothing. However, with the Industrial Revolution, the perception of freedom evolved. In modern society, there is a prevailing misconception that freedom is equated with the ability to purchase goods rather than the capacity to produce them independently. Despite significant advancements in human rights and freedom of thought through legal and institutional reforms, individuals today are more reliant than ever on governments and external resources to meet their basic needs, resulting in a paradoxical reduction in personal autonomy. Recently, practices such as urban and balcony gardening have gained popularity in metropolitan areas, primarily as hobby activities. Expanding and institutionalizing these practices, particularly in urban settings, could encourage individuals to take an active role in meeting their own needs, fostering a culture of both production and consumption rather than mere consumerism.

Urban agriculture plays a crucial role in employment and income generation, particularly for marginalized groups such as women and low-income populations. Approximately 65% of urban producers are women, and a significant proportion of urban farmers belong to the lowest income brackets. Given that 85% of expenditures among the poorest populations are allocated to food, urban agriculture presents a viable strategy for improving food security (Orsini et al., 2013). Additionally, urban gardens are 15 times more efficient than rural farms, with just one square meter capable of yielding up to 20 kg of food per year. Urban food production also reduces costs associated with transportation, packaging, and storage. Furthermore, urban farmers can directly market their products through street stalls and farmers' markets, bypassing intermediaries. From an environmental perspective, urban agriculture significantly mitigates waste production, fossil fuel consumption, and packaging requirements while enhancing biodiversity and air quality (FAO, 2020).

Despite its benefits for food security, urban agriculture still faces challenges regarding food safety. Globally, between 100 and 200 million urban farmers supply fresh food to city markets, often operating without adequate regulatory oversight (Orsini et al., 2013). Uncontrolled agricultural practices in urban environments pose risks such as contamination of natural resources, odor and noise pollution, and the unregulated use of fertilizers and pesticides, all of which threaten public health and environmental sustainability (Orsini et al., 2013; Aubry and Manouchehri, 2019).

Green buildings present another promising solution for addressing the needs of future urban populations, providing both sustainable food production and environmentally friendly living spaces. These structures are designed to minimize ecological damage during construction, incorporate waste recycling systems, and utilize clean energy technologies. Additional features include green roofs that purify rainwater, reducing pressure on urban sewage systems; oxygen-producing vegetation layers that mitigate the greenhouse effect; and insulation technologies that decrease heating and cooling costs while reducing carbon dioxide emissions (Cedeno-Laurent et al., 2018).

Although green buildings are approximately 2% more expensive to construct than conventional structures, they offer a 20% greater efficiency in meeting long-term needs (Kats, 2003). Their positive impact extends beyond individual health and economic benefits, contributing to broader environmental improvements. For example, research indicates that if 20% of all industrial and commercial buildings in Detroit were equipped with sedum green roofs, approximately 889 tons of NO_2 equivalent to 0.5% of the area's total emissions-could be eliminated annually (Clark et al., 2005). Similarly, in Singapore, green roof systems have been shown to directly reduce SO_2 levels by 37% and HNO_2 levels by 21% (Tan and Sia, 2005).

Despite their potential, green buildings face challenges related to high initial costs and extended construction timelines. Moreover, for these structures to be effectively integrated into future urban planning, various technical issues must be addressed, including the development of an adequately trained workforce for design and construction, the advancement of environmentally sustainable building materials, and the engineering of structural systems capable of supporting vegetation while mitigating potential damage from root growth (Cedeno-Laurent et al., 2018).

Environmental Issues

Agricultural fields, which increased approximately 6 times in less than 300 years between 1700-1980, are now one of the largest ecosystems (Lindwall, 2019). Today, nearly half of the habitable areas in the world are used for agricultural purposes to feed the world population, while 77% and 23% of this area are used as animal husbandry and cultivation, respectively. It is known that 70% of habitable areas should be devoted to agriculture to meet the needs of the increasing world population up to 2050. Moreover, the problem is not only the destruction of nature and also the reduction of biodiversity due to opening up space for agricultural activities. To create the necessary conditions for agriculture, a large number of footprints are left to nature by cleaning the lands and releasing the carbon stored in the forests to the environment (Anonymous, 2020).

After the industrial revolution, the problem of intensive use of fossil fuels, as well as soil compaction and deterioration of the soil structure, came to the agenda with the widespread use of machinery in agriculture (Van Oost et al., 2006; Ritchie and Roser, 2020; Çokkızgın et al., 2022; Kara and Aydemir, 2023; Kara, 2024). In addition to this, in these areas where intensive monocultural farming is carried out to feed the masses, the development of pest resistance plant, pollution of water and air and also salinity problems in the soil have inevitably appeared in time as a result of excessive irrigation, fertilization and use of pesticides (Finckh and Wolfe, 1997). In particular, HYVs varieties require more agricultural input than normal species, and when these inputs are sufficient, they yield more products than traditional species and vice versa. Not only the use of synthetic nitrogen fertilizers but also their production causes a lethal greenhouse gas effect, which is another issue to be considered (Lindwall, 2019).

According to the National Water-Quality Assessment, agricultural nonpoint source (NPS) pollution is the third source of damage for lakes, the second for wetlands and a major source for estuaries and groundwater (EPA, 2018). Nitrogen and phosphorus-filled, nutrient-rich materials, such as fertilizers that accumulate in soil and water, lead to excessive growth of algae in freshwater and marine ecosystems, hence living organisms in these ecosystems cannot benefit from sunlight. The death of these organisms and their decomposition by aerobic bacteria caused rapid depletion of oxygen in the marine ecosystems (Lindwall, 2019). Studies show that pesticide accumulation rate is 90% in currents and rivers (Ginty, 2016). Also, their particles emitted into the air after application are deadly for pollinators such as monarch butterflies and rusty patched bumblebees. The situation is getting worse when the pesticide massacres are added to the decrease in biodiversity by using only a few GMO seeds which pollinate similar cultures and wild species (Key et al., 2008; Carpenter, 2011).

Alternative systems that do not require soil use, such as hydroponics and aquaponics; are among the most valid solutions for preventing environmental damage to open up agricultural land; eliminating the problem of biodiversity; discharging pollution; reducing pesticide, fertilizer and water use. As the cultivation is carried out indoors, it is a great advantage that the system allows advanced control of the plant's growing conditions (light level, wavelength, temperature, mineral substance concentration, etc.); therefore, there is no risk of NPS (Maucieri et al., 2018). Moreover, it reduces pesticide usage and prevents seasonal limitations. Vertical cultivation is one of the best solutions to prevent the destruction of habitats to open the agricultural area. Today, the largest vertical farm in the world is being built in Dubai with 130 000 m^2, and the farm plans to produce approximately 2700 kg of product daily using 99% less water (Page, 2018).

However, the high installation and maintenance cost and energy problems are the primary problems that should be resolved in the future for landless and vertical farms. Besides, qualified staff with knowledge is required for both installation and maintenance. A regular and uninterrupted electrical system is essential, otherwise serious problems and significant yield loss may occur. Lacking hygiene and sterile conditions cause several root diseases and the disease can spread rapidly through the solution (Maucieri et al., 2018). Especially, R&D studies on aquaponics systems should be increased and system errors should be eliminated.

Traditional polyculture farming practices had been declining with the dominance of monocultural farming, which has started to become widespread since the 1950s with the increasing use of pesticides, herbicides, and fertilizers (Iverson et al., 2014). Today, polycultural practices, which have been brought to the agenda with the emergence of the mentioned problems, are seen in Himalaya, East Asia, Africa, and South America at a rate of 15-20% (Geno and Geno, 2001; Liebman et al., 2001). Many different methods of polycultural applications including permaculture, cover-cropping, intercropping and integrated aquaculture are economically advantageous and ecologically sustainable in terms of reducing pesticide and fertilizer inputs, obtaining products with high economic value from the unit area, and protecting the soil structure (Mollison, 1997; Geno and Geno, 2001).

These polycultural systems can also meet all the food needs of a family in terms of self-sufficiency. Having economically salable products at different times of the year will protect a family from financial collapse and serious losses in a product due to product pests or bad weather. Permaculture systems, which prefer polycultural agriculture, are designed by taking into account the relationships between the elements, animals, and plants within the boundaries of the farm, and using passive solar systems to control the energy entering and leaving the system (Mollison, 1997; Geno and Geno, 2001).

Another leading problem caused by the industrial revolution and especially the green revolution is the excessive carbon pollution in meats.

Producing 1000 calories of beef meat requires more food, water, and soil than producing 1000 calories of grains. The footprint created by the same amount of beef is 34 times the footprint created by legumes. Meanwhile, the production of the necessary nutrients for livestock is carried out with fertilizer, pesticide and irrigation inputs. In short, CAFO (Concentrated Animal Feeding Operation), which refers to the feeding, slaughtering, and transportation of billions of animals, is environmentally costly (Lindwall, 2019; USDA, 2020).

Meat consumption has doubled from 1961 to 2004. As a result of The Natural Resources Defense Council (NRDC) analysis, it was determined that 34% of the food-borne greenhouse gas emission in the US was due to beef meat. In addition, the animal feces in production areas are among the serious environmental problems. Fertilizer lagoons, where fertilizers are stacked and kept until use, are a mixture of phosphorus and nitrogen consisting of toxic antibiotic residues, chemicals, and bacteria that decompose waste. Often, their limits are uncertain and tend to overflow, leak and spill. These nutrient-rich materials mix with natural water resources and cause eutrophication followed by the growth of plankton and algae which share the nutrients of the marine flora and fauna; consequently, prevent organisms from benefiting from the sun by blocking the sun's rays (Henry, 2015). The poultry feces contain higher levels of phosphorus than other animal fertilizers, so they tend to damage the waterways with the flow of phosphorus (Almeida et al., 2019). Moreover, the gases produced by the enteric fermentation of feces from sheep, goats, and cows are also the most important sources of greenhouse gas emissions in agricultural production and contribute approximately 2558 million tonnes of carbon dioxide equivalent emission (EPA, 2017).

It is an urgent need for governments and institutions to develop and implement appropriate policies at national and international levels that focus more on and explain animal husbandry-environment interaction. One of the key points in the policy should be towards eliminating subsidies that directly or indirectly promote overgrazing, land degradation, deforestation, excessive water use or greenhouse gas emissions. Nevertheless, sanctions such as taxes and fees should be reviewed for natural resource use. Tools, methodologies, and protocols should be developed to measure animal emissions more healthily.

Research predicts that current advanced livestock practices can reduce emissions by 18 to 30% in all production systems and improve food safety. To improve feed quality, improvement of grassland management, pasture species, forage mix, feed processing and strategic use of supplements are the key factors. Extending the animal's reproductive life and improving reproductive efficiency will improve lifetime performance per animal and reduce greenhouse gas emission intensity. Greenhouse gas (GHG) propagation, poor productivity, and inefficiency can be prevented by regularly controlling and improving animal diseases, parasites, and insects. Well-planned raising and breeding programs with careful attention to animal genetic diversity can enable farmers to obtain animals with high adaptability. Better integration into the circular economy can be achieved by the safe recycling of the non-edible parts of the animals and their feces (such as biogas production) (Chen et al., 2015). It is also important to balance the spatial and temporal existence of animals with new technologies such as solar electric fences to improve pasture quality, increase soil carbon and also prevent overgrazing (Bishop-Hurley et al., 2007).

The development of transportation systems after the industrial revolution made that products can now be easily transported to any desired regions. This transferring system, which is carried out using steam vehicles, would not be a problem until the invention of vehicles powered by fossil fuels. But today, non-renewable energy sources such as coal, oil and natural gas meet 80% of the world's energy needs (Nunez, 2019) and according to the United Nations, transportation is responsible for 3% of the carbon emissions in the world (Purdy, 2018). Ensuring that the public is conscious of using products known to be local and natural and supporting the local economy is very important for both the consumer and the environment, as it will reduce intermediary institution, transportation, storage, packaging, and marketing expenses, as well as fossil fuel consumption. Pretty et al. stated that, based on a classic supply model with a long supply chain, consumers pay 3% more for transportation, and environmental costs will be 90 percent lower if these products arrive within 20 km of the place of delivery (Pretty et al., 2005).

Health Issues

There are several reasons for the increase in food prices which are the most important factor in ensuring food security and safety. These are including rising prices of agricultural inputs, decreasing agricultural lands, increasing market competition, restriction the entry of small farmers into the market, and aggressive investments in the agricultural sectors with speculative funds and uneven distribution of investments. Increasing food prices reduces the purchasing ability of consumers and affects the quantity and quality of food; therefore, it increases the risks leading to serious health problems in food safety (Kraychev, 2010).

Gene transfer is performed for different purposes such as resistance against fungi, insects, parasites, viruses, and bacteria, increasing the amount of yield, late-ripening, and durability of plants, obtaining therapeutic proteins, making vaccines and increasing production (Key and Drake 2008; Ormandy et al., 2011). However, it is difficult to determine whether GMOs, are harmful to health, due to difficulties in nutritional epidemiology, problems in the risk assessment process, limitations in animal experiments, and doubts about the impartiality of knowledge (Ergin and Karababa, 2011).

Some of GMO products have a remarkable loss of flavor. The problem stems from the fact that the producers emphasize on other characters such as storage life and durability rather than taste (Folta, 2015). When it comes to health, the loss of flavor in GMO products is perhaps the last thing to worry about. Although the effects of GMOs on human metabolism and its allergic consequences are still not fully known, it is known that the foods and DNA transferred to these foods are mostly protein in nature and cause a little more immune response than natural foods due to the development of an allergic reaction after it becomes transgenic (Lee, 2017).

The direct and indirect carcinogenic effects of GMOs is a matter that leads the scientific world to chaos. Seralini et. al. conducted a study to clarify the link between GMOs and cancer for 2 years. Results showed that at least 2 and 3 times more deaths due to cancer occurred in mice fed GMO corn (Seralini et al., 2012) Immediately after the publication of the results of the analysis, EFSA (2012) stated that the rat race prone to tumor development was selected, the sufficient number of animals were not used and accurate statistical analyses were not made. Also, internationally accepted Economic Development and Cooperation Organization (OECD: Organization for Economic Cooperation and Development) protocols are not followed in food and feed research in the study (EFSA, 2012; Resnik, 2015).

Although 26 years have passed since the launch of the first GMO product in 1994, doubts about the risks and benefits of them have still not been clarified.

EU regulation on GMOs has not been able to keep up with discoveries in the field of biotechnology. There is considerable legal uncertainty about the issue, and regulatory frameworks for GMOs also differ between countries. In summary, both the scientific authorities and the public are confused about the subject. One of the most important issues to be emphasized in the upcoming period is to clarify the effects of GMO products on health and to support research on this issue by individuals, institutions, and governments. The issue should be examined based on health and sustainability without any interest, and necessary legal arrangements should be clarified as soon as possible.

Although direct links cannot be established between GMOs and cancer, many studies clearly show that they have negative indirect effects on health. When new gene products, secondary metabolites, terminator genes, herbicide and pesticide residues from organisms come together, they can interact with each other and create toxicity (Lushchak et al., 2018). In the late 1980s, a Japanese firm produced a tryptophan, an essential amino acid, used to make serotonin in the body, to a bacterium and put it on sale in the USA as a food additive (Richard et al., 2009) Eosinophilia Myalgia Syndrome (EMS), which affects the nervous system and progresses with muscle aches, has occurred within months as a result of the increased tryptophan in the bacteria leading to the formation of a toxic by-product. In 1989, 37 Americans lost their lives and 5000 others suffered severe disability due to EMS (Kohlstadt, 2006).

The short-term effects of pesticides are known as stinging eyes, rashes, blisters, blindness, nausea, dizziness, diarrhea and death while chronic effects of them are cancers, birth defects, reproductive harm, neurological and developmental toxicity, immunotoxicity and impairment of the endocrine system. It has been found that infants and young children are more vulnerable to the toxic effects of pesticides than adults, as agricultural workers and pesticide applicators are also more exposed. The World Health Organization International Cancer Research Agency has evaluated many studies so far and classified the glyphosate used in herbicide production as Group 2A "agents with the possibility of carcinogenic effects in humans" (WHO, 2015). 2,4-D, which is also commonly used in plants, is absorbed from the gastrointestinal tract when taken by mouth and inhibits testicular DNA synthesis. Moreover, it has a mutating effect on animal organisms and is likely to be a carcinogenic substance (Burns et al., 2011)

The possibility of DNA particles from various origins (plants, animals, viruses, bacteria) that are transferred to food products to the circulatory system without being fully digested in the digestive tract after transfer to the human or animal genome, can cause unpredictable consequences. In a study, the mice feeding with double chain M 13 bacteriophage DNA, it was found that DNA fragments did not completely break down, reached blood tissue and other tissues and were covalently bound to mouse DNA (Schubbert et al., 1994).

Antibiotic resistance in GMO products also resulted from transferring bacterial antibiotic resistance genes to distinguish genetically modified cells from the original ones (Davies and Davies, 2010). WHO reported that methods using cell-marker genes are risky and should not be used. Antibiotics are regularly added not only to gene markers in the food and juices of farm animals but also to help animals survive in crowded, unhealthy and stressful conditions. Thus, a perfect environment is created for the growth of antibiotic-resistant bacteria (Davies and Davies, 2010)

In the U.S, two-thirds of antibiotics are sold for use in the livestock industry, not to improve human health. These bacteria are then mixed into the soil through irrigation and fertilization from CAFOs and also spread by air. These resistant bacteria are also spread through contaminated meat and farmer clothing and shoes, combined with other bacterial strains and made them resistant to antibiotics (Davies and Davies, 2010; Lindwall, 2019). Today, antibiotic-resistant bacteria are among the most severe health threats in the world. It is estimated that around 162,000 people die annually as a result of antibiotic-resistant infections in the U.S (IDSA, 2018). WHO, in strong cooperation with FAO and OIE working with the United Nations to tackle the issue at a political level. In 2015, WHO published an in-depth action plan against antibiotic resistance (WHO, 2015).

Since the effects of fertilizer, pesticide and antibiotic use on health are more clear and observable than the effects of GMO products, legal regulations on these issues could be arranged much easier. However, the pressure of agrochemical industry lobbies, governments are often slow to prohibit or even limit the use of these products. Instead, they prefer to hand over the risk to consumers, rural communities, Non-Governmental Organizations (NGOs) and agricultural workers. In this regard, governments should apply the necessary sanctions as soon as possible, without considering any pressure and direction but the public benefits.

Using hormones in plants and animals is another controversial issue. Sex hormones such as estrogens, androgens, and progestogens; synthetic nonsteroidal estrogens and synthetic steroids hormonal action anabolics are used in animals to provide increased body weight gain, feed utilization, better carcass characteristics, and meat quality. Studies show that the proportion of natural hormones (estradiol, testosterone, progesterone) in the meat of the animal to which it is implanted is not a concern for the consumer if it is not more than their normal density. However, metabolic residues in the meat of chemically modified and synthetic anabolics cause specific problems. Natural steroids that are easily metabolized in the liver are dangerous for consumers if they are injected into edible tissues of animals (Velle, 1981; Jeong et al., 2010) The androgenic hormone residues in the meats cause masculinity and menstrual cycle disorders in women; Estrogenic hormone residues can cause femininity, impotence, and infertility in men (Afeiche et al., 2014; Senthil Kumar et al., 2018). In addition to these general hormonal activities, hormone residues have harmful effects such as carcinogen, nervous complications, and vascular stiffness (Health, 1999; Senthil Kumar et al., 2018). The European Community has banned the import and use of hormone meats.

The causes of the health risks mentioned so far stem from the inappropriateness of the processes up to the harvest of animals and plants. However, some practices performed and contamination while food passing through a series of processes including preservation, storage, packaging, and processing after harvest may also be harmful to health. According to WHO, “Substances that are added to food to maintain or improve the safety, freshness, taste, texture, or appearance of food are known as food additives” (WHO, 2018). These substances have become a threat to human and animal health due to reasons such as masking poor quality or spoiled food, making counterfeit food, reducing the nutritional value of the product, being used more than the amount to produce the desired effect, not complying with processing and packaging techniques. In countries where there are no necessary control strategies, allergic, cancer-causing, mutagenic and teratogenic effects of these substances on human health can be neglected (Davidson and Singh, 2018).

There are many studies on the negative effects of food additives. For example in meat products; Nitrate and nitrite, which are used for the development of color and flavor and to prevent microorganisms, may lead to acute and chronic poisoning depending on the dosage, frequency, and shape. Nitrate and nitrite are not carcinogens alone and have the potential to make a carcinogenic form by reacting with other ingredients during cooking or digestion (Ma et al., 2018). Another protective additive that can initiate asthma attacks in patients with asthma is SO_2 (E220) (Vally and Misso, 2012). McCann et al. investigated the effects of food additives on hyperactivity in children and found that artificial colorants increased hyperactivity in both groups in their study of three and eight to nine years (McCann et al., 2007) The furan substance identified as a human carcinogen has been detected in coffee, baby food, and canned adult food in Belgium, Italy, the Netherlands, Spain, Portugal (Crews et al., 2009).

WHO has addressed the following key points regarding food additives (WHO, 2018):

- "Food additives are substances added to food to maintain or improve its safety, freshness, taste, texture, or appearance."
- "Food additives need to be checked for potential harmful effects on human health before they can be used."
- "The Joint FAO/WHO Expert Committee on Food Additives (JECFA), is the international body responsible for evaluating the safety of food additives."
- "Only food additives that have been evaluated and deemed safe by JECFA, on the basis of which maximum use levels have been established by the Codex Alimentarius Commission, can be used in foods that are traded internationally."

As a result of all these, there is no doubt a lot of work for governments to raise public awareness and take necessary legal action. Not only the manufacturers but also the public authorities and individuals should be informed about the products and the additives used in them that are prohibited or should be considered while consuming by legal proceedings. State institutions and organizations need to draw attention to the seriousness of the incident with extensive explanations and campaigns on websites, national channels, and social media about what to look out for to raise public awareness, especially when shopping for food. Also, there is a need for a steady continuation of many remarkable and prominent works, as most issues are ignored and the agenda changes very quickly.

CONCLUSION

The topics discussed in this study are only some of the issues that have been occupying the agricultural community for a long time in terms of environment, food safety and food security. To end our story with a happy ending in the future, the first thing we need to do is to clarify and quickly enforce legal regulations regarding GMO products, food additives, hormones used in products, food processing, and storage techniques, etc. that are or are likely to be a threat to human health. The public should be informed and its awareness should be raised about these issues through campaigns and studies that make a sound through the media, press and social media.

Researches to strengthen the rural economy should be accelerated. Alternative sources of income that will bring additional income to local people besides agricultural activities should be supported by governments, and rural areas should be more attractive for both tourists and investors. Besides, farmers need government grants and assistance to improve the quality of their agricultural activities.

Although the trend of a return to the countryside has begun, urban life is developing now and in the future. In this sense, urban gardening and agriculture should be supported and encouraged to feed the city population. New techniques such as hydroponics and aquaponics, green buildings, vertical farms should be developed through R&D studies and supported by the governments. Also, the participation of city residents in production with applications such as city and balcony gardening and urban agriculture will increase their awareness of being a part of not only consumption but also production. Polycultural agriculture protects and even improves soil structure, reduces the risk of crop loss, enables to obtain the product in every season, reduces pesticide and fertilizer inputs and protects biodiversity. If supported by holistic approaches such as permaculture, energy saving is also added to the system as an input.

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CHAPTER 7

CLIMATE CHANGE AND WATER USE IN AGRICULTURE IN A BEHAVIORAL ECONOMICS PERSPECTIVE

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DOI: https://dx.doi.org/10.5281/zenodo.15092375

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INTRODUCTION

Global climate change is directly linked to increasing greenhouse gas (GHG) emissions, leading to rising temperatures, altered precipitation patterns, and more frequent and severe extreme weather events (IPCC, 2007). These impacts profoundly affect not only environmental systems but also agriculture and food systems. The agricultural sector is both a contributor to climate change and one of its primary victims. Brown and Funk (2008) highlighted the direct impacts of global climate change on agriculture, noting significant effects on food security and production systems. Climate change poses both physical and economic threats to agricultural production processes. Rising temperatures, shifting rainfall patterns, and the increased frequency of extreme weather events constrain agricultural production and create uncertainties in farmers' decision-making processes. This situation imposes significant limitations on production capacity and threatens agricultural sustainability (Fazal and Abdul Wahab, 2013). These effects are particularly pronounced in developing countries, where agricultural activities are heavily dependent on natural climatic conditions. According to a report by FAO (2008), small-scale farming systems in developing countries are especially vulnerable to the impacts of climate change, endangering both food security and livelihoods. Smallholder farmers face significant risks due to changes in rainfall patterns, rising temperatures, and soil degradation. These challenges complicate production planning, limit the adoption of agricultural innovations, and introduce uncertainties into the food supply chain (FAO, 2008). The long-term effects of climate change impact not only production volumes but also the quality of agricultural products, leading to wide-ranging consequences throughout the agricultural value chain. For instance, declining product quality can negatively affect export revenues and reduce competitiveness in agricultural trade. Furthermore, as the frequency and severity of extreme weather events increase, adopting sustainable farming practices becomes more challenging for farmers. These events result in short-term production losses and hinder the transition to innovative agricultural technologies. Such uncertainties particularly restrict the capacity of farmers in developing countries to adapt to climate change (FAO, 2008). For example, the adoption of agricultural irrigation technologies may be delayed due to high initial investment costs and prevailing uncertainties.

Climate change affects not only production processes but also agricultural risk management strategies, exacerbating farmers' economic vulnerabilities. Enhancing farmers' adaptive capacity is critical to ensuring the sustainability of agricultural production and mitigating the impacts of climate-related risks. In this context, advanced planning tools, climate-smart agricultural practices, and innovative technologies offer potential solutions to the challenges faced by the agricultural sector. In conclusion, global climate change poses an increasing threat to the agricultural sector, significantly affecting food security, livelihoods, and agricultural sustainability, particularly in developing countries. Therefore, it is essential to develop policies that enhance the agricultural sector's capacity to adapt to climate change and to provide innovative solutions to strengthen farmers' resilience. These efforts are crucial for ensuring global food security in the future.

1. CLIMATE CRISIS AND WATER USE IN AGRICULTURE

The climate crisis is one of the most significant environmental issues directly affecting the agricultural sector. Rising temperatures, shifting precipitation patterns, and the increasing frequency of extreme weather events have further complicated the management of water resources in agriculture. The rapid growth of the global population and the expanding agricultural demands have placed increasing pressure on water resources. Today, water demand has reached its highest levels, driven by both agricultural production and other human activities. A century ago, freshwater consumption was six times lower than current levels. This dramatic increase is not only due to population growth but also the intensive consumption associated with agricultural irrigation, industrial production, and urbanization. This growing demand for freshwater necessitates the sustainable management of water resources. However, freshwater reserves are depleting faster than their natural renewal rates, creating a cycle that could lead to severe water crises in the future. The pressure on water resources has profound implications, particularly for communities living in arid regions and economies dependent on agricultural production. Climate change further exacerbates this situation by limiting the availability of water resources, making it essential to reassess current water management strategies.

In this context, investing in innovative technologies to conserve freshwater resources, developing sustainable solutions to reduce water demand, and fostering global cooperation on water management are of critical importance. The future of the planet depends on how we respond to the increasing demand for water and how effectively we protect existing resources. Rising global temperatures, irregular precipitation patterns, severe droughts, and extreme weather events are causing significant disruptions in the global water cycle. This poses threats to both the quantity and quality of freshwater resources, which are the foundation of agricultural production. Currently, the agricultural sector accounts for 70% of global freshwater consumption. However, this high usage underscores the urgent need for the sustainable management of water resources. While the growing global population and food demand necessitate increased agricultural productivity, climate change complicates this process further, making sustainable water use an even more critical challenge.

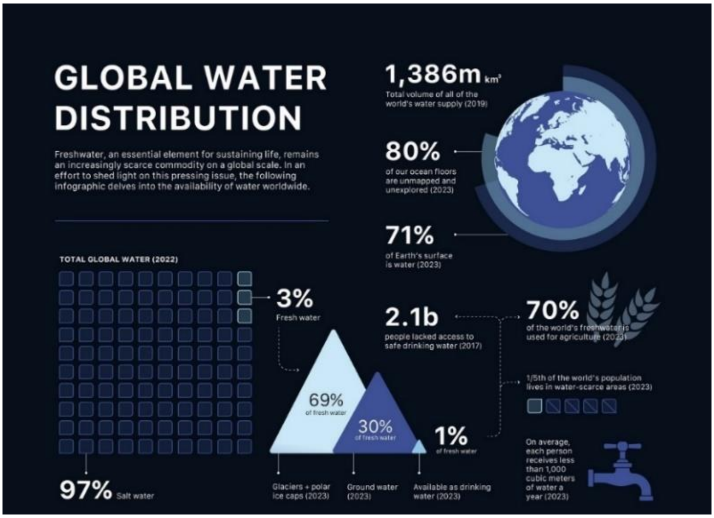

Figure 1: Water Distribution in the World (Source: Kirkland, 2023)

The pressures of the climate crisis necessitate the development of innovative solutions and policies to optimize water use in agricultural production. Tools such as smart irrigation systems and digital monitoring technologies aim not only to conserve resources but also to ensure the sustainability of agricultural production. However, technological advancements alone are not sufficient; raising farmers' awareness and strengthening local implementation capacities also play a critical role. Protecting water resources and improving the efficiency of agricultural water use in response to the climate crisis is not just an environmental issue but also a priority for food security and societal well-being. Actions taken in this context will serve as a cornerstone for leaving a more livable world to future generations. Global climate change is one of the most significant factors directly affecting the distribution and sustainable use of water resources worldwide. While only 3% of the Earth's total water is freshwater, just 1% of it is drinkable and accessible. A large portion of these limited freshwater resources is trapped in glaciers and polar regions, and access to these reserves is becoming increasingly complex due to the impacts of climate change.

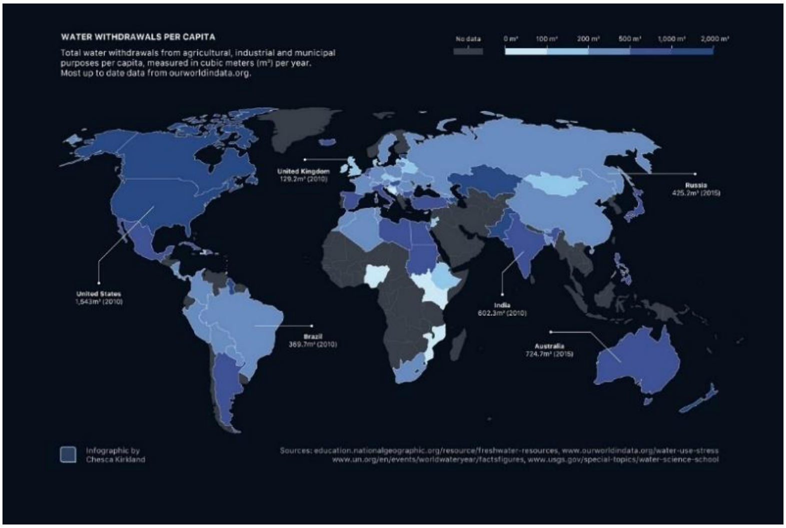

Figure 2 Water Distribution in the World (Source: Kirkland, 2023)

The rise in global temperatures is leading to the melting of glaciers and significant disruptions in the water cycle. Increased evaporation rates and altered precipitation patterns are exacerbating water scarcity, particularly in arid and semi-arid regions. Climate change is also bringing the water used in agricultural production to a critical threshold. Currently, approximately 70% of the world's freshwater is used for agricultural production (Kirkland, 2023). However, growing populations, increasing food demand, and changing climatic conditions necessitate more efficient management of this water usage. Droughts and water stress triggered by climate change pose a significant threat to agricultural productivity and endanger food security. This situation elevates the sustainable management of water resources from a choice to an imperative.

In today's world, technological innovations and opportunities for digitalization hold immense potential for improving agricultural water management. Smart irrigation systems make it possible to achieve higher yields with less water in agricultural processes. Methods that promote water conservation, such as drip irrigation, stand out as viable solutions for maintaining agricultural productivity. Additionally, the development of policies at both local and international levels for preserving water resources is crucial for enabling the agricultural sector to adapt to the climate crisis. Digital monitoring systems and automation technologies are increasingly being utilized to prevent water wastage and protect resources. In rural areas, improving access to these technologies for local farmers is particularly important to mitigate the impacts of climate change. Water management in the context of climate change is a shared responsibility of all stakeholders, from individuals to governments. Considering the pressures of a growing population and shifting climatic conditions, innovative policies must be developed for the efficient and sustainable use of water resources. However, adopting sustainable solutions for agricultural water use and adapting to the climate crisis require examining the behaviors of farmers, water managers, and consumers. For instance, the transition of farmers from traditional irrigation methods to more efficient technologies like drip irrigation is shaped not only by economic incentives but also by habits, knowledge gaps, and social norms. Therefore, this issue will be addressed within the framework of behavioral economics.

2. BEHAVIORAL ECONOMICS

Behavioral economics is an interdisciplinary approach that integrates economics and psychology to better understand human behavior. This approach questions the assumption of rationality in individuals' economic decision-making processes and aims to explain irrational behaviors observed in real-life situations. Classical economics, on the other hand, is based on the assumption that individuals make entirely rational decisions, maximize their utility, and possess complete information (Neumann and Morgenstern, 1944). While this rationality assumption is useful for enhancing the generalizability and predictability of economic models, it falls short of capturing individuals' behaviors in the real world. Behavioral economics contributes significantly to classical economic models by analyzing how irrational behaviors influence decision-making processes (Sunstein, 1998). It considers factors such as cognitive biases, limited information-processing capacities, and emotional influences that affect individuals' decisions. For instance, Kahneman and Tversky's (1979) Prospect Theory demonstrated that individuals tend to weigh losses more heavily than gains. This concept contradicts the assumption of perfect rationality in classical economics and allows for a more realistic understanding of decision-making processes. Behavioral economics has developed numerous concepts and theories to explain individuals' tendencies toward irrational decision-making, including loss aversion, the endowment effect (Thaler, 1980), and the status quo bias (Samuelson and Zeckhauser, 1988). Status quo bias refers to individuals' tendency to maintain their current state and resist change. In situations where proposed changes have both positive and negative aspects, individuals may focus more on the negatives, leading them to reject change. Such behaviors can complicate the adoption of economic policies and delay transitions to energy-efficient or sustainable technologies (Frederiks et al., 2015).

The fundamental difference between classical and behavioral economics lies in how they approach human behavior. Classical economics views individuals as "homo economicus," assuming them to be rational decision-makers. In contrast, behavioral economics offers a broader perspective by accounting for individuals' cognitive limitations, emotional responses, and social contexts (Simon, 1955). This approach aligns with studies emphasizing the importance of understanding the economic consequences of individuals' irrational behaviors and highlighting the complementary relationship between behavioral and classical economics (Kahneman, 2011). Thus, behavioral and classical economics provide complementary approaches to understanding human behavior. While classical economics examines rational behaviors and generalizable economic models, behavioral economics addresses the irrational tendencies and biases individuals exhibit in their decision-making processes (Thaler and Sunstein, 2008).

When evaluated through the lens of Prospect Theory, farmers' preferences regarding adaptation to climate change, their risk perceptions, and decision-making behaviors are significantly influenced by the imbalance between potential gains and losses. According to the theory, individuals assess decisions based on reference points rather than absolute outcomes and are more sensitive to losses. In this context, the yield reductions, increased costs, and resource shortages caused by climate change in agricultural production create a strong perception of loss for farmers. On the other hand, adaptation strategies such as investing in climate-friendly technologies or adopting new agricultural methods may be perceived as high-cost or high-risk in the short term, potentially limiting adaptation behaviors in light of Prospect Theory. However, policies and support mechanisms addressing climate change could reshape farmers' perceptual reference points. For example, incentives for carbon reduction or income guarantees could highlight the potential gains of adaptation strategies, positively influencing farmers' decision-making processes. Therefore, Prospect Theory offers a valuable framework for understanding the agricultural impacts of climate change and designing effective policies (Tversky and Kahneman, 1992).

When the effects of climate change on agriculture are analyzed within the framework of behavioral economics concepts, it becomes evident that factors such as uncertainty, risk perception, and deviations from rationality play a decisive role in farmers' decision-making processes. Prospect Theory provides a valuable framework for understanding these processes; farmers evaluate their decisions based on reference points rather than absolute outcomes and are more sensitive to losses than to gains. The adverse effects of climate change such as yield losses, increased costs, and resource shortages create a strong perception of loss among farmers. On the other hand, adaptation strategies like investing in climate-friendly technologies or adopting new agricultural methods are often perceived as costly and risky in the short term.

This perception can lead to resistance to change due to behavioral biases such as status quo bias and loss aversion. Additionally, due to the impact of the status quo effect, farmers may exaggerate the effects of past extreme weather events, leading to more short-term decision-making (Atış et al., 2024). To counteract these biases, behavioral nudges and proper framing strategies can highlight the benefits of climate-friendly practices. For example, policies such as incentives for carbon reduction, income guarantee programs, or low-risk financing options can shift farmers' perceptual reference points and encourage them to focus on long-term gains. In this context, behavioral economics offers critical guidance for effectively designing and implementing agricultural adaptation strategies to address climate change. From a behavioral economics perspective, biases such as loss aversion, status quo bias, and short-term thinking in farmers' decision-making regarding climate adaptation can pose significant risks to global food security (Kahneman and Tversky, 1979). These biases may limit the adoption of sustainable practices that enhance productivity and mitigate the impacts of climate change. Consequently, increasing production losses over the long term can lead to fluctuations in food supply and broader food insecurity. Therefore, it can be argued that incentives and policies targeting behavioral biases are crucial for preserving global food security at both individual and societal levels (Thaler and Sunstein, 2008).

2.1. Loss Aversion

Sustainable agriculture is closely tied to the principle of "loss aversion" in behavioral economics. Farmers' tendencies to avoid resource losses serve as a significant motivation for adopting sustainable agricultural practices and adaptation efforts against the climate crisis (Brick and Visser, 2015). Most empirical evidence supports the hypothesis of loss aversion, although it may depend on various moderators (Novemsky and Kahneman, 2005). For example, threats such as erosion, water loss, and yield decline promote the implementation of sustainable methods such as drip irrigation, organic matter applications, and integrated pest management. Moreover, raising awareness about the economic and environmental costs of losses can accelerate the adoption of sustainable methods and farmers' efforts to combat climate change. Traditional economic models, particularly Expected Utility Theory (EUT), assume that farmers are entirely rational decision-makers (Neumann & Morgenstern). However, in real-world scenarios, farmers' decision-making processes are influenced by information gaps, risk perceptions, and environmental factors (Shen and Cai, 2005). Loss aversion, frequently discussed in the behavioral economics literature, is a critical concept describing individuals' heightened sensitivity to losses compared to gains of the same magnitude (Wang and Zhao, 2019).

Loss aversion plays a decisive role in farmers' decision-making processes regarding sustainable agricultural practices and adaptation to the climate crisis. For instance, the adoption of low-carbon agricultural technologies (LCAT) is directly related to farmers' perceptions of risks associated with yield, markets, and climate, with market risk perception identified as having the strongest influence (Taghizadeh-Toosi et al., 2022). Traditional agricultural production methods, including intensive tillage, irrigation, and chemical inputs, disrupt soil structure and contribute to carbon emissions. In this context, farmers' risk perceptions may strengthen their inclination toward sustainable practices to mitigate these environmental impacts and combat climate change. Farmers' levels of awareness about climate change and their adaptive behaviors are also shaped by loss aversion and utility preferences. Woods et al. (2017) noted that higher levels of concern among farmers regarding climate change increase their likelihood of adopting adaptation measures. Similarly, He et al. (2019) found that loss aversion behaviors among rural farmers in China increased the adoption of energy-efficient devices. In a study conducted in Kenya, risk-averse behavior positively influenced the adoption of good agricultural practices (GAP), although loss aversion negatively affected this adoption (Kibet et al., 2018). Another study in India found that farmers with higher loss aversion were more inclined to adopt rice varieties with high resilience to adverse conditions (Ward and Singh, 2015). In conclusion, loss aversion and risk perceptions are critical factors in farmers' adoption of sustainable agricultural practices and methods to combat the climate crisis. Behavioral economics theories, particularly Prospect Theory (PT), offer an effective framework for enhancing farmers' capacity to adapt to the climate crisis, especially in the context of agriculture and rural development (Liu and Huang, 2019; Shuping and Yang, 2018). Policies designed to address the climate crisis should take into account farmers' tendencies to minimize losses and aim to promote sustainable agricultural practices accordingly.

2.2. Endowment Effect

The endowment effect refers to individuals' tendency to place greater value on what they already own, perceiving the potential loss of something they own as more painful than the prospect of gaining something they do not own

(Kahneman et al., 1990). This phenomenon is closely associated with the endowment effect, a significant concept in behavioral economics. The endowment effect is defined as the disparity where an individual's willingness to accept (WTA) compensation for a good exceeds their willingness to pay (WTP) for the same good, a concept first introduced by Thaler (1980) as a challenge to the assumption of economic rationality. Sayman and Öncüler (2005) proposed the "distortion method" to measure the endowment effect by examining the difference between WTA and WTP, while Horowitz and McConnell (2002) developed a method based on the WTA/WTP ratio, considering the presence of the endowment effect when this ratio exceeds 1. The endowment effect, with its widespread impact on economic goods and its challenge to economic rationality, has significant implications in the context of agricultural economics and the climate crisis. Farmers often exhibit a strong endowment effect toward their agricultural lands and production methods, which can play both inhibitory and encouraging roles in the transition to sustainable farming practices. For instance, the endowment effect may lead farmers to resist abandoning traditional agricultural methods and adopting new low-carbon agricultural technologies (LCAT) (Zhu and Luo, 2019). However, the same effect could motivate farmers to protect their lands and natural resources, promoting the adoption of sustainable practices to combat climate change. A farmer's perception of land value compared to its market value serves as a critical indicator of the reflections of the endowment and endowment effects in agricultural economics (Knetsch, 1989). Protective behaviors developed by farmers in response to climate change threats such as soil erosion, declining water resources, and reduced crop yields illustrate how these effects can be directed toward fighting the climate crisis. While the endowment effect may make it challenging for farmers to abandon carbon-intensive practices on their lands, it could also encourage the long-term preservation of these lands through sustainable practices.

The endowment effect is strongly tied not only to physical ownership but also to the sense of psychological ownership (Reb and Connolly, 2007). Its influence is particularly pronounced on agricultural lands and methods owned for extended periods, contributing to resistance to change (Strahilevitz and Loewenstein, 1998). In this context, considering the dimensions of the endowment effect is crucial in designing climate change mitigation policies.

Academics have proposed policy recommendations to mitigate the adverse effects of the endowment effect. For instance, improving land capitalization systems, diversifying farmers' income sources, and increasing their mobility are highlighted as key strategies to address these challenges (Zhu and Luo, 2019). Additionally, awareness campaigns emphasizing the long-term economic and environmental benefits of sustainable agricultural practices can activate the positive aspects of the endowment effect. The endowment and endowment effects are critical factors shaping farmers' behaviors in addressing the climate crisis. Their role in the widespread adoption of sustainable agricultural practices presents significant opportunities for integrating behavioral economic theories into agricultural development and climate policies.

2.3. Status Quo Bias

Status quo bias is a behavioral economics concept that refers to individuals' tendency to maintain their current state or resist change. First introduced by Samuelson and Zeckhauser (1988), this concept illustrates individuals' inclination to "do nothing or stick to their current decisions." Kahneman and others (1991) explained status quo bias as a combination of loss aversion and the endowment effect. Loss aversion refers to individuals' tendency to give more weight to losses than to gains, while the endowment effect reflects the tendency to overvalue something one already owns. Within this context, status quo bias reinforces individuals' preference for maintaining their current state and leads to resistance to change, particularly when change proposals involve both positive and negative aspects, with individuals perceiving the negative aspects more strongly (Samuelson and Zeckhauser, 1988; Kahneman et al., 1991).

In the fight against climate change, status quo bias is one of the key behavioral barriers to transitioning to sustainable practices. It causes individuals to maintain their existing habits and energy consumption behaviors, hindering the adoption of sustainable energy technologies and environmental innovations. For example, Frederiks et al. (2015) found that in the context of energy efficiency, status quo bias leads individuals to make economically irrational choices and opt for more expensive, energy-inefficient technologies. This is considered one of the main reasons for the gap in transitioning to cost-effective energy-efficient technologies (e.g., energy-saving bulbs and appliances). Status quo bias is directly linked to loss aversion, as individuals perceive the risk of altering their current state as more threatening than potential gains. It has been particularly noted that organized structures, such as the agricultural sector, tend to reinforce status quo bias and show resistance to change (Hong, 2016). This resistance makes it difficult for farmers to adopt climate-friendly agricultural practices and reduce their carbon footprints. To overcome status quo bias in climate change mitigation, it is crucial to change individuals' perceptions of change and make positive outcomes more visible. For instance, awareness campaigns and economic incentives could emphasize that losses can be compensated for in the long term, even if they are incurred in the short term. Furthermore, policies promoting social norms and collective action can help reduce resistance to change and effectively break status quo bias. Status quo bias is a significant behavioral barrier to combating climate change. To overcome this bias, policies must leverage principles of behavioral economics to reduce resistance to change, reframe individuals' perceptions of loss, and support long-term sustainability goals.

2.4. Present Bias

Present bias, defined as the tendency of individuals to prioritize immediate gratification over future benefits, is a significant concept derived from the self-control theory in behavioral finance (Thaler and Shefrin, 1981). This bias can deeply influence farmers' agricultural practices, investment decisions, and responses to climate change. The theory of time preference supports the idea that individuals often favor short-term rewards over long-term benefits in their intertemporal decision-making processes (Green et al., 1994). Hyperbolic discounting, in particular, describes the tendency of individuals to choose smaller, sooner rewards over larger, later ones (Schreiber and Weber, 2016). In this context, many farmers act impatiently, focusing on the present and delaying the adoption of green agricultural technologies despite the long-term benefits (Duflo et al., 2011). Green agricultural technologies require farmers to provide long-term inputs to their agricultural management processes. Thus, when adopting such technologies, farmers must consider not only the expected benefits but also the sustainability of these benefits in the future (Marenya et al., 2014). However, time preferences often devalue these long-term benefits, reducing the likelihood of technology adoption.

A field study conducted by Mao et al. (2021) involving 1,038 rice farmers in China demonstrated that present bias negatively affects the adoption of green agricultural technologies. The study found lower adoption rates among farmers with stronger present bias. For example, investments in climate-resilient crops or irrigation systems, although capable of significantly enhancing agricultural productivity in the long term, often require substantial upfront costs. This leads farmers to focus on short-term costs, delaying their adoption of such practices. In the context of climate change, the effects of present bias hinder the widespread adoption of sustainable agricultural practices, limiting farmers' capacity to adapt to the climate crisis. Addressing this bias is critical for encouraging long-term, climate-resilient farming solutions and supporting sustainable agricultural development.

2.5. Social Norms

Social norms are unwritten rules and informal understandings that regulate interactions among individuals. These norms define the behavioral codes that indicate what individuals expect from others and what others expect from them (Young, 2014). Normative information is associated with two fundamental forms of social norms: descriptive norms, which reflect the degree to which individuals engage in a particular behavior, and injunctive norms, which represent the extent to which the majority approves or disapproves of a certain behavior (Cialdini et al., 1990). In the context of agriculture, traditional farming methods, while ensuring high productivity and income, rely heavily on chemical inputs such as pesticides and fertilizers. This highlights significant sustainability challenges associated with conventional farming practices (Berg, 2002). The literature emphasizes the critical role of social norms in influencing farmers to adopt environmentally friendly behaviors (Burton, 2004). Social norms have proven to be particularly influential in the adoption of digital technologies and eco-friendly practices. By aligning with social norms, farmers’ adoption of sustainable agricultural techniques can contribute to reducing greenhouse gas emissions from agricultural activities.

The study by Hüttel et al. (2020) demonstrated that social norms within different reference groups positively influenced the adoption of local digital fertilization methods. These findings provide insights into farmers’ organizational decisions and their environmental impacts. Experimental studies reveal that farmers' decisions to adopt social norms are influenced by their perceptions of how other farmers view those norms (Defrancesco et al., 2008). Additionally, farmers living in regions where social norm adoption is high are more likely to align their behaviors with these norms (Allaire et al., 2009). Other experimental approaches show that when the rate of social norm adoption is high, farmers are more likely to continue adhering to these norms or sustain eco-friendly practices even after their contract periods end (Chen et al., 2009). The role of social norms has also been examined in the context of environmentally friendly behaviors outside agriculture. For example, in areas such as energy consumption (Allcott, 2011) and water use (Ferraro et al., 2011), social norms have been shown to shape behavior through mechanisms such as social comparison or conditional cooperation. These studies underscore that social norms are a critical tool for promoting environmentally friendly practices at both individual and societal levels.

3. BEHAVIORAL INSIGHTS

During the 1970s and 1980s, psychologists Daniel Kahneman and Amos Tversky systematically documented various cognitive biases and errors in human judgment and decision-making processes, which often contradicted the predictions of traditional economic models. These biases included loss aversion, framing effects, base rate neglect, and reliance on heuristics such as anchoring, availability, and representativeness. The discovery of consistent patterns in human behavior that diverged from the rational actor model, commonly assumed in economics, challenged traditional economic theories and raised significant questions regarding the design of effective policies (Kahneman, 2011). Discussions on behavior change highlight two primary approaches to shaping and influencing individuals' decisions: the libertarian approach and the paternalistic approach. The libertarian approach allows individuals to freely make their choices by providing them with a broad range of options, aiming to enhance personal autonomy while minimizing external interference. In contrast, the paternalistic approach involves implementing strict measures, such as legal regulations, to enforce behavior change to protect individuals' long-term welfare. This approach often assumes that individuals may harm themselves in the long term due to their short-term preferences. For instance, smoking bans and high tobacco taxes are typical examples of this approach (Thaler and Sunstein, 2008).

Behavioral economics provides alternatives to traditional models to better understand and influence individuals' decision-making processes. Within this context, the concept of libertarian paternalism emerges as a middle ground. It seeks to guide individuals toward healthier or more rational choices without restricting their freedom. Developed by Sunstein and Thaler (2003), this approach proposes regulations that preserve individuals' freedom of choice while simultaneously making their decision-making processes more informed. Libertarian paternalism employs subtle and directive interventions known as "nudges" to facilitate behavior change. These nudges influence decisions by making preferred behaviors more attractive or accessible without limiting the set of available options.

Behavior change often requires more than just knowing what to do; even when individuals have specific intentions to act, they have only about a 47% chance of following through with the intended behavior (Sheeran, 2002). While behavioral insights and nudges are often used interchangeably, they represent distinct concepts with specific definitions and scopes. Nudges, as a concept, refer to a specific type of intervention within the broader framework of behavioral insights, aiming to influence individuals' decision-making processes predictably. This approach involves making subtle adjustments in the context where decisions are made, without restricting individual choice or imposing significant economic incentives. Nudges target behavioral change by considering individuals' natural tendencies and cognitive biases (Lourenço et al., 2016). These insights aim to identify the mechanisms underlying decision-making processes and use this knowledge to inform policies, interventions, and strategies.

Behavioral agricultural economics specifically focuses on examining the decision-making processes of farmers and consumers in complex and uncertain environments (Wuepper et al., 2023). To encourage the adoption of sustainable agricultural practices aligned with climate change mitigation and adaptation goals, innovative policy frameworks incorporating insights from behavioral economics are necessary. These policies could include nudge methods to influence farmers' behaviors effectively. By altering decision-making contexts, such interventions can help reduce barriers to adopting sustainable practices such as conservation tillage, agroforestry, precision farming, and water-efficient irrigation systems. These practices not only reduce greenhouse gas emissions but also improve soil health, conserve water resources, and protect biodiversity. Behavioral nudges can effectively address psychological and informational constraints such as risk aversion, status quo bias, or lack of awareness that farmers might face. Finding ways to promote behavior change for environmental sustainability can also lead to addressing other societal issues. Challenges like inadequate retirement savings, smoking, and obesity share similar decision-making difficulties, with climate change representing a much more extreme example of these challenges (Weber, 2015).

Various approaches exist for incorporating behavioral insights into policy interventions, particularly those focused on changing farmer behavior. The EAST framework, developed by the Behavioural Insights Team in 2014, provides four key principles for promoting behavior change: Easy, Attractive, Social, and Timely (Hallsworth et al., 2016). Another significant framework is MINDSPACE, created by Dolan and colleagues in 2012. This framework categorizes behavioral insights and guides policy applications. The acronym MINDSPACE represents nine main factors that influence human behavior: Messengers, Incentives, Norms, Defaults, Salience, Priming, Affect, Commitment, and Ego. These factors describe the psychological elements affecting individuals' decision-making processes and behaviors, providing a foundation for designing policy interventions (Dolan et al., 2010).

Building on the MINDSPACE framework, Palm-Forster et al. developed a more practical tool in 2019 to influence farmer behavior. Known as Ag-E MINDSPACE, this tool applies behavioral insights specifically to the agricultural sector. It focuses on strategies that encourage farmers to modify their behaviors in alignment with environmental, economic, and social factors (Palm-Forster et al., 2019). In this section, nudge applications based on the MINDSPACE framework are proposed to encourage farmers to adopt sustainable agricultural practices and enhance their capacity to adapt to climate change (Table 1). The recommendations are organized based on their relevance to the topics rather than the order of their appearance in the table (Atış et al., 2024).

Table 1. MINDSPACE Framework

Cue	Behavior
Messenger	We are strongly influenced by the source of information; we tend to trust the credibility of the transmitter rather than critically evaluate the message itself.
Incentives	Our responses to incentives are influenced by predictable mental shortcuts, such as a strong tendency to avoid losses, especially when those losses are unavoidable.
Norms	We are deeply affected by the actions and ideas of others, including the practices they employ.
Defaults	We often tend to follow the default or preset options and often get in our way.
Salience	Our attention is naturally drawn to what is new and what is personally important to us.
Priming	Our behavior is often influenced by subconscious signals.
Affect	Our emotional associations have a profound effect in shaping our actions.
Commitment	We strive to remain consistent with our public commitments and feel obliged to respond to their actions.
Ego	We tend to behave in ways that enhance our self-image and make us feel good.

* Adapted by the author based on Dolan et al. (2012) and Palm-Forster et al. (2019), (Atış et al., 2024)

A significant limitation of traditional economic literature is the absence of a consistent conceptual framework that effectively connects psychological processes to economic decision-making. Farmers often develop a strong attachment to conventional agricultural practices, a phenomenon known as the endowment effect. As a result, when sustainable agricultural practices tailored to address climate change are presented as alternatives, farmers tend to use their existing practices as a reference point. The benefits of sustainable practices-such as mitigating climate change, improving environmental health, enhancing soil and water quality, and boosting biodiversity-are generally perceived as gains by farmers. However, research highlights that farmers often exhibit shortsightedness or myopia in recognizing these benefits (Duflo et al., 2011).

Despite the clear advantages of sustainable practices in combating climate change, it is important to acknowledge that, like most individuals, farmers are inherently loss-averse. Their commitment to current farming practices stems not from ignorance but from the deep integration of these practices into their livelihoods. This commitment, referred to as status quo bias, often makes farmers resistant to altering their established systems. Fundamentally, farmers perceive any deviation from traditional practices as a loss and tend to favor maintaining the status quo. This perception fuels resistance to change and limits the adoption of sustainable practices. Farmers' adoption of sustainable agricultural practices is closely linked to their awareness of these practices. However, existing biases and loss aversion may lead to information avoidance among farmers (Wuepper et al., 2023). This highlights the critical role of access to reliable information, which plays an especially influential role in the adoption of innovations (Rogers, 2003).

Providing farmers with information on soil conservation, new irrigation technologies, and the reduction of fertilizers, pesticides, and fungicides is a key policy tool. Facilitating information acquisition and framing it within the context of nudge interventions can ease the process of farmers modifying their existing management systems (Kahneman et al., 2011). Framing, This concept challenges the neoclassical economic theory, which assumes that decision-making is based solely on rational expectations and considers the presentation format as an irrelevant factor (Thaler, 2015). Framing theory stems from Kahneman and Tversky's (1979) Prospect Theory, which introduced the principle of loss aversion. Loss aversion assumes that decision-makers experience losses more intensely than equivalent gains, leading to asymmetric evaluations. This concept is rooted in reference dependence and diminishing sensitivity and aligns with the broader negativity bias, which suggests that individuals are psychologically more affected by negative stimuli than positive ones (Meyerowitz and Chaiken, 1987). While gain frames have been found to improve attitudes toward recycling (Loroz, 2007), loss frames have been shown to be more successful in influencing recycling behavior (Poortinga and Whitaker, 2018). Similarly, gain frames have demonstrated positive effects on attitudes toward pollution and climate change (Feinberg and Willer, 2011).

In Baek and Yoon's (2017) study, the impact of loss and gain framing was found to vary depending on the emotions evoked. According to the research, loss framing can effectively promote water conservation when combined with feelings of shame, while gain framing paired with guilt can also be impactful. Loss framing, by triggering emotions like shame or guilt, can prompt more immediate behavioral change. In contrast, gain framing offers a positive vision of the future, fostering long-term motivation. Priming interventions are based on expanding the mental scope available at the moment of decision-making (Richardson-Klavehn and Bjork, 1988). Research shows that many farmers perceive their products as being part of environmentally friendly settings (Beedell, 1999). Emotional interventions, on the other hand, are grounded in the fact that emotions strongly influence future decision-making (Kahneman, 2003). Such interventions typically evoke immediate positive emotions (e.g., pride, satisfaction) or negative emotions (e.g., guilt) to influence behavior (Dolan et al., 2012).

Affective nudges are effective tools for encouraging environmentally friendly behaviors. Research in agricultural and environmental health economics suggests that empathy-based nudges can foster positive resilience and promote eco-friendly decision-making (Czap et al., 2019). Salience-Based Interventions, different identities within an individual can influence behavior depending on situational contexts and the salience of a specific identity at a given moment (Hogg et al., 1995). Salience-based interventions are founded on the idea that increasing the focus of attention can significantly enhance decision-making (Kahneman and Thaler, 2006). McGuire et al. (2015) applied this concept in a survey conducted among farmers in Iowa, demonstrating how emphasizing certain aspects of farmers' self-identities can drive the adoption of sustainable technologies. Highlighting these identities and their connection to sustainability can effectively encourage farmers to focus on achieving local sustainable success. Timing interventions aim to improve decision-making processes by creating opportunities for more analytical and System-2-oriented thinking. For instance, sudden visual or olfactory stimuli can distract attention, leading to suboptimal choices during last-minute decisions (Miller et al., 2016).

Administrative tasks, such as those required for agri-environmental schemes (AES) contracts, can be scheduled during less busy times of the year, such as winter, to help farmers better focus on decision-making (Thomas, 2019). Commitment interventions are based on individuals' desire to align their actions with their commitments, fostering consistency and reliability (Katzev and Wang, 1994). These interventions can be effective tools for supporting collective goals, such as climate change mitigation, by leveraging social acceptability and personal responsibility. Ego interventions rely on individuals' motivations to act in ways that align with their self-identity (Dolan et al., 2012). Identifying the self-identity groups farmers associate with and delivering messages tailored to these identities can be a powerful strategy to encourage behavioral changes (Greiner and Gregg, 2011). Social norms, shaped within cultural frameworks, significantly influence societal approaches to issues such as entrepreneurship and sustainability. They are defined as shared standards that gradually develop in social practices and interpersonal communications and are adhered to by most individuals (Cialdini et al., 1990). While social norms are not legally binding, they strongly influence behavior (Huber et al., 2018).

Studies suggest that the cultural legitimacy of entrepreneurship and the motivation to adopt sustainable farming practices are closely linked to social norms. However, when social norms are ineffective as a nudge intervention, alternative approaches such as financial incentives may be necessary (Dessert et al., 2019). Challenges of combining social and market norms, Behavioral changes motivated by social norms and market norms may conflict if they target the same behavior simultaneously. Market norms, such as financial incentives, often dominate and may weaken the impact of social norms. Rebuilding social norms in such situations can be time-consuming and resource-intensive (Atış et al., 2024). Policy implications, norms not only shape individual behavior but can also transform values and beliefs over the long term (Newcomb, 1943). This transformative potential makes norms a crucial tool for achieving lasting changes in priorities and perspectives on climate change and other policy issues. Norms also influence policymakers' attitudes toward climate action and increase the likelihood of public engagement in climate-related political activities, such as contacting government officials, voting for environmentally friendly candidates, or participating in protests (Doherty and Webler, 2016).

Practical strategies, organizing farmers' decision-making environments is critical to promoting the adoption of sustainable agricultural practices. Nudges can make sustainable practices more visible, accessible, and present in farmers' surroundings, fostering behavior change. For example, innovative technologies like soil moisture sensors or smart irrigation systems can be effectively introduced to environmentally conscious individuals. Widening access to such innovations can increase their long-term adoption rates.

Farmer cooperatives or networks can also facilitate information sharing and promote awareness by tailoring programs to the farmers' current knowledge levels and needs. Workshops that consider regional differences can ease farmers' transition to sustainable practices. Addressing barriers that limit farmers' access to sustainable technologies is equally important. Some farmers may perceive the procedures required for new practices as complex or time-consuming, leading to reluctance. Overcoming such barriers may involve introducing low-cost, practical micro-incentives, simplifying bureaucratic processes, and providing easily accessible educational materials. Pre-selected options (defaults) can reduce confusion during decision-making. For instance, setting default options for irrigation systems can influence farmers' behaviors, encouraging water-saving practices. These strategies not only simplify farmers' decision-making processes but also support environmental sustainability goals.

4. CONCLUSION

Global climate change, directly associated with the increase in greenhouse gas emissions, significantly affects environmental systems, particularly the agricultural sector, through rising temperatures, altered precipitation patterns, and more frequent extreme weather events. These impacts pose a severe threat to water use in agriculture. The agricultural sector is both a contributor to climate change and one of its most significant victims. Climate change disrupts agricultural production processes by causing water resources to decline due to rising temperatures and irregular rainfall. Small-scale farming systems in developing countries, which heavily rely on natural water resources, are among the most affected by these changes. Increased uncertainty in rainfall patterns and more frequent drought events lead to higher irrigation demands, complicating both the sustainable use of water resources and farmers' production planning. Additionally, factors such as soil degradation and reduced irrigation efficiency further complicate water management in agriculture. Beyond the reduction in water resources, their effective and equitable distribution contributes to uncertainties in the global food supply chain. As a result, long-term planning and sustainability goals in the agricultural sector are increasingly under threat. From a behavioral economics perspective, farmers' risk perceptions and status quo biases significantly influence the adoption of water-saving technologies in agriculture. For example, the prioritization of short-term costs can delay the transition to innovative practices such as drip irrigation and water harvesting, exacerbating both economic and environmental losses. By utilizing behavioral nudges, farmers' decision-making processes regarding water use can be improved, accelerating the adoption of practices that ensure more efficient water usage.

In conclusion, climate change represents one of the most significant threats to water resource management in agriculture. These impacts jeopardize not only agricultural production but also global food security and economic stability. To address this crisis, policies promoting water conservation and innovative technologies must be developed. Approaches that enhance farmers' adaptive capacities and target psychological barriers will support the sustainability of water management in agriculture. Achieving long-term goals will require coordinated efforts addressing environmental, social, and economic dimensions.

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ISBN: 978-625-378-210-8