INTERNATIONAL STUDIES AND EVALUATIONS IN THE FIELD OF

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CONTENTS

CHAPTER 1

HEALTH AND SAFETY OF WORKERS IN AGRICULTURE

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1 Introduction

The number of employees is also increasing due to the increase in population in the world and in Turkey. This increase reveals the importance of the concept of occupational health and safety (OHS). The measures taken regarding occupational health and safety aim not only to reduce the number of occupational accidents, but also to minimize the damages resulting from occupational accidents. (Keffane, 2015).

Healthy and safe working conditions are not only desirable for employees, but also contribute significantly to labor productivity and stimulate economic growth. Studies on occupational health and safety can positively affect the competitiveness and productivity of businesses by reducing the costs arising from work accidents and occupational diseases and increasing employee motivation. In addition, the decrease in work accidents and occupational diseases relieves the pressure on public and private sector social protection and insurance systems (TUIK, 2023). Work accidents; It is an important problem that affects employers, employees and the country's economy. Therefore, occupational health and safety procedures must be strictly followed in workplaces. Otherwise, permanent incapacity and deaths occur as a result of work accidents, economic losses and workday losses occur. Work accidents and occupational diseases refer to undesirable negativities that occur during the execution of work. While occupational accident is defined in the Occupational Health and Safety Law No. 6331 as "an event that occurs in the workplace or due to the execution of work, causing death or causing a mental or physical disability to the unity of the body" (Yıldırak et al. 2002). The International Labor Organization defines work accident as; It defines a work accident as an unexpected and unplanned event occurring outside or in connection with work, including acts of violence, that causes injury, illness or death to one or more workers. Work accidents are divided into two as fatal and injured, depending on their occurrence. Work accidents with injuries are grouped according to loss of working days and permanent disability (Türk, 2006).

Occupational Health and Safety Law and Occupational Health and Safety in Agriculture

Occupational Health and Safety Law No. 6331 was accepted on 20 June 2012 and came into force by being published in the Official Gazette No. 28339. While there has been an improvement process in almost every production sector except the agricultural sector with the OHSL No. 6331, there has not yet been a serious change in the agricultural sector. No improvement arrangements were made.

A circular was published by the Ministry of Food, Agriculture and Livestock on 14/03/2013, and in this circular, it was requested to pay attention to the basic OHS rules in agricultural enterprises and to determine the risk level of the enterprise by performing a risk analysis. However, due to the insufficient labor laws for employees in agriculture, the health and safety of the employees were requested. Legal regulations, practices and research regarding safety remain extremely limited The reason for this is the Labor Law No. 4857, which is valid in the field. While the law mentioned in (Anonymous, 2003) enforces occupational health and safety provisions in agricultural and forestry enterprises employing more than 50 workers, it excludes agricultural enterprises employing 50 or less than 50 workers from the scope of this law.

This issue has been relatively corrected in the OHSL No. 6331 and it has been decided that "the provisions of the Occupational Health and Safety Law will be applied in all enterprises, except for places that produce goods and services on their own behalf and without employing employees." in other words, if the agricultural enterprise is a family enterprise, this enterprise is excluded from the scope of OHSL No. 6331, while Occupational Health and Safety provisions will be applied to all agricultural enterprises that are not family enterprises. Agricultural enterprises in Turkey can be described as small-scale family enterprises, since their average land size is 5.9 hectares and they are mostly managed as family enterprises. (Anonymous, 2014b) Unfortunately, since more than 80% of agricultural enterprises in Turkey are family enterprises, these enterprises Since it is outside the scope of Occupational Health and Safety Law No. 6331, there are some deficiencies. One of the most important shortcomings is the lack of any notification obligation regarding accidents (Taş, 2018).

Afterwards, businesses with low employment were also included within the scope of the Occupational Health and Safety Law.The main reasons why agricultural workers have not reached the desired level in terms of occupational health and safety are similar to almost all underdeveloped and developing countries.

These similarities can be summarized as follows:

• People working in agriculture mostly have common problems due to organizations that are unorganized or do not work well.

• Insufficient education levels of employees in this sector (the new generation is more educated coming, but their numbers are still low).

• The number of working women and child workers is higher than in other sectors,

• High seasonal or displacement rate among employees

(Orel et al. 2009).

The agricultural sector is one of the most important employment areas after the service sector all over the world. It is the most important sector in terms of women's labor, especially in some countries including Turkey. In addition, agricultural labor is a very important and special sector in terms of occupational health and safety, as it is the most important field where children are commonly employed.

According to the European Union Statistical Office (EUROSTAT), the agricultural sector is considered the second most dangerous sector after the construction sector. Nearly half of the world's workforce (an estimated 1.3 billion workers) is engaged in agriculture. The International Labor Organization points out the agricultural sector as one of the most dangerous branches of work and reports that many agricultural workers suffer from occupational diseases and accidents at work every year (ILO).

It is reported that 170 thousand agricultural workers die every year and millions more are seriously injured or poisoned by chemicals. Considering the large number of unrecorded deaths and injuries in this sector, it can be thought that the real extent of the damage may be more serious.According to the data of the Turkish Statistical Institute, 14.8% of those employed in 2023, with 4 million 695 thousand people, are in the agricultural sector (Tüik, 2023). When considered together with their families, it becomes clear that a significant part of the population is involved in agricultural labor.

Women work significantly in the agricultural sector. They participate in every stage of agricultural labor by doing temporary or seasonal agricultural work, especially in families with little or no land (Yıldırak et al. 2002). According to the results of the Address-Based Population Registration System (ABPRS), as of the end of 2023, the population of Turkey was 85 million 372 thousand 377 people, 22 million 206 thousand 34 of which were children. 51.3% of the child population was boys and 48.7% was girls. According to the United Nations definition, the child population, including the 0-17 age group, constituted 48.5% of the total population in 1970, while this rate became 41.8% in 1990 and 26.0% in 2023. (TUİK, 2024).

Employing children in agricultural labor is also an important situation. More than half of working children work in agriculture, often in dangerous conditions. Children and young people are more affected by the risks of this sector. It has been reported that the sector with the highest fatal work accident rate among young workers in Europe is agriculture, and more than 30% of accidents on farms consist of accidents involving children and adolescents (EU-OSHA, 2006). In Turkey, especially in rural areas, children are employed in agriculture. According to the Turkish Statistical Institute, 392 thousand children (41% of the total working children) work in agriculture (TUIK, 2006).

The majority of agricultural workers (86%) work without social security. This situation creates a serious inequality in terms of agricultural workers' access to health services. There are deficiencies that distinguish those working in agriculture from those working in other sectors in terms of basic occupational health services. For example; One of the important deficiencies is that almost all workers in agriculture do not have access to preventive occupational health services. In addition to the problems listed above, other important difficulties for seasonal agricultural workers increase inequality in working life, while significantly endangering their health and safety. Seasonal workers travel illegally in trucks in large numbers, which poses life-threatening risks. Every year, many seasonal agricultural workers in our country lose their lives or are injured in traffic accidents.

Risks in the Agriculture Sector

It is the most important EU directive in the context of OSH for all EU members and candidates, requiring all employers to carry out risk assessments and inform employees.

The International Labor Organization's convention no. 184 (ILO, 2001) and recommendation no. 192 (ILO, 2001) foresee the development of national systems and policies in the health and safety of agricultural workers. It establishes principles for protection and prevention in key areas for agriculture (machine safety and ergonomics, production and transportation, management of chemicals, prevention of livestock and biological risks, and establishment of agricultural facilities).

The risks that await employees in the sector in terms of occupational health and safety are as follows:

It is possible to classify.

1. Mechanical Risks

2. Electrical Risks

3. Ergonomics Issues

4. Chemical Risks

5. Biological Risks

6. Risks Related to Housing and Feeding Environment

Occupational Health Problems of Agricultural Workers

Diseases, injuries and deaths caused by chemicals used in agriculture, inappropriate working conditions and tools used are commonly observed in agricultural labor.

In addition to chemicals, biological and physical factors also cause various diseases in many organs. Depending on the work, many organs and systems may be affected in agricultural workers and various health problems may arise. It is possible to affect the respiratory system and the skin with organic and inorganic dusts and chemicals. Chemicals have a role in the formation of some neurological disorders and some cancers with their toxic and carcinogenic effects.

Various diseases may occur in the musculoskeletal system due to mechanical stress. Accidents are a very important problem in agricultural labour. Additionally, social and economic difficulties can cause psychosocial problems (Perry, 2008).

Respiratory system affected

Dust, gases and particles resulting from agricultural activities negatively affect the respiratory system. Workers encounter agricultural dust and gases in fields and gardens, barns and silos during harvest time, and these dusts usually reach the person in a mixed structure.

These are organic dusts such as fungus, mold, bacteria and animal waste; inorganic powders such as silica; chemicals such as artificial fertilizers and pesticides; It consists of gases such as nitrogen oxide gases and exhaust smoke, and they exist together in various proportions. Therefore, assessing exposure to agricultural factors can be difficult (Linaker and Smedley, 2002).

Respiratory diseases caused by agricultural activities are in a wide spectrum and are caused by exposure to factors, especially general viral and bacterial respiratory infections (Kirkhorn and Garry, 2000). When evaluating respiratory complaints of agricultural workers, their work history should be taken carefully and it should be examined which substances the complaints may be related to. It is important to associate the course of the disease with the changes in the working process (Barış and Atabey, 2009). It should not be overlooked that organic dust will have typical effects on people engaged in animal husbandry and especially poultry farming. (Rylander et al,1995). Hypersensitivity pneumonia (farmer's lung) occurs with exposure to antigenic agents found in moldy grass, hay, grain and feed. It shows seasonal characteristics. Complaints are common in cold and humid climates where fungal growth is easy and during the winter months when crops are stored for animal feed. Acute complaints may develop in the form of shortness of breath, cough, fever and chills (Linaker and Smedley, 2002), (Kirkhorn and Garry, 2000). Exposure to factors such as crop residues in the threshing floor, mold, fungi, endotoxins released by pathogenic bacteria when bacteria die and cell walls break down, mycotoxins, and gram-negative bacteria can cause toxic organic dust syndrome. This syndrome is an acute inflammatory reaction of the airways. Symptoms such as shortness of breath, fever, cough and fatigue, which occur 4-6 hours after exposure, are similar to the acute form of hypersensitivity pneumonia (farmer's lung).

However, unlike this, the symptoms usually resolve spontaneously within 36 hours without the need for treatment. In both cases, education of agricultural workers is important. In this line of business, it is generally almost impossible to remove the agent from the agent to prevent contact. Dust control and particularly sensitive people should be ensured to use personal protective equipment such as respiratory protectors.

Occupational infectious diseases involving the respiratory system are also important in agricultural work.

Especially in developing countries, bovine tuberculosis is an important public health problem and can occur in many mammals and humans (O'Reilly and Daborn, 1995). In addition, psittacosis, which is seen in poultry farmers and is caused by Chlamydya psittaci, and Q fever, which is caused by Coxiella burnetii, which can be transmitted from infected sheep, goats and cattle to humans, should be mentioned in this group of diseases.

Affecting the skin

Contact dermatitis occurs through contact with fertilizers, pesticides and other chemicals and is common among agricultural workers. Dermatoses caused by heat, sunlight and arthropods can also be considered among dermatological problems. It should not be forgotten that skin cancer is a risk as a result of continuous and unprotected exposure to sunlight.

Toxic and carcinogenic effects

Many chemicals are used in agricultural labor and can have toxic and carcinogenic effects. The most important of these are pesticides used as herbicides, phagocytes and insecticides and are widely used in agriculture. Its widespread and uncontrolled use is a big problem, especially in underdeveloped countries.With the concentration, commercialization and globalization of agriculture in low- and middle-income countries, pesticide use has become widespread in small agricultural enterprises and has become a billion-dollar business (Konradsen, 2007). However, only 20% of agricultural chemicals used worldwide are used in developing countries. On the other hand, almost all of the deaths due to acute pesticide poisoning are in these countries. The most important reason for this is the uncontrolled use of dangerous pesticides and without taking precautions (Kesavachandran et al, 2009). Exposure to pesticides can occur during the preparation, transportation and application of the chemical. This chemical enters the body through the skin, eyes, mouth and breathing. The use of pesticides affects not only the agricultural worker but also his family (Shealy et al, 1997). Acute effects are seen as nausea, vomiting, headache, abdominal pain, skin and eye problems. Neurotoxic effects may occur as a result of long-term exposure (Bjorling-Poulsen et al, 2008).

In a study evaluating the cognitive capacity of agricultural workers, occupational exposure to pesticides was identified as a significant risk for the development of Parkinson's and Alzheimer's disease (Baldi, 2003). In recent studies, it has been shown that the likelihood of Parkinson's disease increases in those who live or work close to agricultural lands where fungicides are used (Wang, 2011). Although definitive evidence has not been produced to demonstrate a causal relationship between working in agriculture and cancer development, exposure to some types of pesticides may lead to diseases such as Non-Hodgkin's lymphoma, leukemia, tongue and prostate (Blair and Freeman, 2009), multiple myeloma, soft tissue sarcoma, Hodgkin's disease, It has been associated with pancreatic, ovarian, breast and testicular cancer (McCauley, 2006).

A comprehensive study monitoring agricultural workers and their relatives in terms of pesticide use, lifestyle and nutritional characteristics showed that the risk of prostate cancer was high in farmers and pesticide applicators. The same research also shows that the frequency of skin and ovarian cancer is high in women (Alavanja et al, 2005). The negative effects of chemicals used in agriculture on reproductive health are beginning to be better understood. There is increasing evidence showing that pesticide use in agriculture causes reproductive dysfunction in women (Yu, 2011).

Musculoskeletal system

Agricultural workers often work in unsuitable ergonomic conditions. heavy lifting, Many physical strains such as carrying, standing for long periods of time, and working in repetitive and inappropriate positions for a long time can cause many musculoskeletal disorders such as low back pain, disc herniation, carpal tunnel syndrome, tendinitis. In order to implement measures to improve ergonomic conditions, it is very important to ensure the participation of agricultural workers in the planning and implementation stages and to take into account the psychosocial and sociocultural characteristics of the region (Fathallah, 2010).

Accidents

Agricultural workers face serious accident risks due to the use of machines. In a study compiling all publications and data on accidents in agriculture. Fatal accidents are listed as drowning, electric shock, impact-related injuries, hydrogen sulfide poisoning and head injuries. It is stated that non-fatal injuries frequently occur due to slips, trips and falls, strains and sprains, use of machinery, chemicals and fires (Myers, 2010). Tractor rollovers are one of the most common causes of injuries and can lead to serious injuries and deaths. In Turkey, this problem is an issue that agricultural workers frequently experience but has not been studied much. Serious hand injuries have been described in hazelnut workers in Turkey (Tuncel, 2009). Studies on risk reduction have not provided evidence that training intervention reduces the frequency of injuries in agricultural workers.

Psychosocial problems

Economic difficulties can be a serious source of stress for agricultural workers. Especially landless peasants, migrants and seasonal workers experience the negative effects of poverty and insecurity. Having to find other income-generating jobs during periods of unemployment, long working hours in seasonal agricultural work and lack of rest time cause excessive workload. These effects can cause depression, anxiety, alcohol use, and suicidal thoughts.

Conclusion

The agricultural sector is unique in nature. It has serious differences from other business lines in terms of working conditions, living standards, and business environment. It is one of the rare sectors that is generally run as a family business and where work and home life cannot be strictly separated. Since the disease and injury rates of employees in the agricultural sector are high compared to other sectors, this information and risk analysis It is very important that the work is done. The living conditions of farmers, who are constantly suffering despite the energy and expense spent, should be improved and measures should be taken to prevent especially the young population from escaping from agriculture. If OHS-related problems are added to these problems, we may have difficulty finding people to work in agricultural production.

The most important problems that are inevitable in the future are potable water and safe water supply.

Considering that it will be about food supply, in terms of continuity of agricultural production,The problems that workers in the field of agriculture will encounter in terms of occupational health and safety are the most government, employers and agriculture to try to minimize and improve working conditions employees come together and solve problems within the framework of mutual understanding and tolerance is of great importance. However, unfortunately, all legal regulations made to increase employee welfare and safety in the agricultural sector, which is among the sectors with the highest rates of informality and child labor, have not affected the living standards of agricultural sector employees in active working life. Currently, due to long working hours, working tempo, lack of competent personnel, socioeconomic and political factors, low earnings, widespread employment of child workers and most importantly, the integration of agriculture into all life by seeing it as a way of life rather than a profession, therefore the lack of social security. Insecurity against work accidents is one of the problems awaiting solution.

The Turkish Ministry of Labor and Social Security has prepared a strategy and action plan to improve the working and social lives of seasonal migratory agricultural workers (ÇSGB, 2024). In order to achieve the planned goals, intense effort is required. It is necessary to create a service model for the health and safety of agricultural workers in rural areas and integrate it with basic health services. Critical points for this may be the following (Bakırcı, 2008):

• Ensuring intersectoral cooperation

•Expanding inclusion for agricultural workers and ensuring access to health services

•There is a relatively well-organized health system in rural areas. Investigating how primary health services can be integrated and whether this is possible

• Determining which institutions can work on safety issues in agriculture and how

• Establishing national policies - providing the legal infrastructure. Additionally, the International Labor Organization has defined and reported very detailed codes of practice to support awareness of risks in agriculture, protection of health and ensuring safety (ILO, 2010). This developed practice guide is an important guiding resource for those working on the health and safety of agricultural workers in Turkey. It is necessary to further develop these practices and reduce work accidents and fatal work accidents to zero by protecting the health of workers in agriculture and other sectors.

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CHAPTER 2

FARMERS' COLLECTIVE ACTION: AGRICULTURAL COOPERATIVES

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1. Introduction

Organization can be defined in general terms as living and acting together, working together and institutionalization. The level of development of a country's political and economic structure is related to effective organization. The widespread and strong organization in a society is accepted as an indicator of development. Organization is also developed in economically developed countries. There is a linear relationship between organization and development. Organization helps farmers use inputs and labor more efficiently in all processes from the first stage of production to the marketing of their products (Karlı et al., 2018).

In Türkiye, reasons such as structural problems in rural areas and being powerless against buyers and sellers have led farmers to establish different purpose organizations such as professional chambers, cooperatives, unions and associations in order to protect their economic and professional interests (Semerci, 2022). Among these organizations, cooperatives are a major factor in reducing the number of intermediaries between the farmer and the consumer. For every product that reaches the consumer from the farmer, values such as production factors such as profit, wage, interest, and rent are added at every stage of the distribution channel, and the cost of the product increases as it changes hands more and more until it reaches the end consumer. Thus, the price the consumer will pay also increases. With cooperatives, the number of intermediaries can be reduced and consumer protection can be ensured (Everest and Yercan, 2016; Turhan and Vural, 2016).

In Türkiye, markets for agricultural products mostly operate irregularly. For example, producers may suffer losses because product prices do not cover costs during periods of surplus production. However, if farmers establish organizations at local, regional and national levels and become cooperatives, they will be able to obtain higher prices and also serve to ensure consumer satisfaction (Aytüre, 2014). Kooperatifse can eliminate intermediaries who operate with high profit levels, especially in marketing. Intermediaries dominate agricultural product markets in Türkiye. The product changes hands 4-5 times before reaching the consumer. However, in developed countries, this number does not exceed 2-3 and the intermediaries are mostly farmer organizations (Everest, 2009; Kadanalı and Dağdemir, 2013).

However, structural problems in Turkish agriculture are undoubtedly closely related to the potential of cooperatives. The fragmentation of land and the small size of the farms in Türkiye are important obstacles to the development of modern agriculture. Land fragmentation means decreased productivity and, as a result, decreased production. On the other hand, it is difficult for smallholder farmers to cope with structural changes in the agri-food markets and to benefit from the changing market environment (Pakdemirli, 2019)

Many studies have been conducted on the level of agricultural organization in Türkiye and the tendency of farmers to become members of cooperatives. (Koçtürk and Özbilgin, 2003; Karlı et al., 2006; Yercan, 2007; Terin and Çelik Ateş, 2010; Şahin et al., 2013; Sağlam and İnan, 2014; Karakaya and Kızıloğlu, 2014; Semerci, 2015; Doğan ve Yercan, 2016; Aydın Can et al., 2017; Yercan and Kınıklı, 2018; Başaran and Irmak, 2018; Kaya et al., 2019; Değer et al., 2020; Sevinç, 2021; Özgirgin et al., 2021; Kılıç Topuz et al., 2022; Yücel Engindeniz and Yercan, 2024). However, these studies need to be continued, developments in the level of cooperatives should be closely monitored, the factors that are effective in success should be revealed, and solutions should be produced for the problems encountered.

In this study, the importance of cooperatives as a collective action of farmers in agriculture is emphasized, agricultural cooperatives operating in the world and in Türkiye are examined and some suggestions are presented for the development of cooperatives. The study uses statistics published by institutions such as the Turkish Statistical Institute (TURKSTAT), the Ministry of Agriculture and Forestry (MAF), and the International Cooperative Alliance (ICA) and the results of previous research.

2. The Importance and Necessity of Organization in Agriculture

Although organization is a very broad concept, it is basically defined as the desire to live together, to act together and to cooperate (Kızılaslan and Doğan, 2013; Karlı et al, 2018; Altuntas, 2021). Organization is also described as a structure where individuals with similar problems come together to solve their problems. In this way, individuals solve their problems and can form pressure groups to direct the policies to be implemented regarding individuals.

Today, farmers need independent structures, in other words organizations, to be informed in order to be effective and efficient in their production patterns, to need a series of technical consultancies, to reduce the risks and uncertainties they have endured, to help farmers in the supply of inputs required for agricultural production, to guide them.

Organized structures provide advantages such as getting a greater share of added value to farmers, reducing agricultural input costs, better pricing, ease of access to technical information, and increasing bargaining power (Sayın and Sayın, 2004). It is seen that in economically developed countries that are aware of such advantages, there are strong and autonomous organizational structures that specialize in a certain subject, care about R&D activities and intensify their work, can integrate with the industry, and even conduct lobbying activities in the formation of agricultural policies of that country.

In Türkiye, the agricultural organization structure is subject to different classifications according to various criteria. When the agricultural organization structure is considered as producer and breeder organization, it is summarized under four main headings as infrastructure and service institutions, financing institutions, professional organizations and economic and social purpose institutions (Can and Sakarya, 2012). In another form of examination, the subject is addressed under two headings as public organization and producer organization. According to this distinction, the relevant ministries are included in the public organization. Farmer organization is examined under two subheadings as professional organization (Chambers of Agriculture, Farmer Associations, Syndicate) and economic organization (Agricultural Cooperatives, Unions, Farmer Unions) (Yercan, 2007).

3. Objectives and Principles of Cooperatives

Cooperatives are perfect means of solidarity that combines material and spiritual powers to meet the needs that people have difficulty in meeting. In Article 1 of the Cooperatives Law No. 1163, amended by Law No. 3476, Cooperatives are defined as follows: They are organizations with changeable partners and changeable capital established by real and public legal entities, special administrations, municipalities, villages, societies and associations in order to provide and protect the specific economic interests of their partners and especially their needs related to their profession and livelihood through mutual assistance, solidarity and surety, having a legal personality.

The basis of cooperatives is the sense of assistance, solidarity and the aim of achieving work. For this purpose, people have come together under various names to overcome difficulties with hand and heart unity.

The benefits of cooperatives can be listed as follows. As stated in the proverbs "Unity is strength" and "One hand has nothing but the voice of two hands", cooperatives are a focus of power and a pressure tool for economic activities. They are a perfect solidarity organization that performs tasks that individuals cannot handle individually. They are an organization that creates balance in neutralizing the losses of those who suffer from income distribution. It is possible to meet material and spiritual needs at the feet of the partners with the least expense and cost. The stages between the farmer and the consumer are either completely eliminated or minimized through cooperatives. It helps labor and the product find its real value. It acts as an insurance in the formation of the price and the elimination of the farmer's losses. It prevents selfishness and serves to make mutual efforts in favor of others without taking into account their own interests. With these functions, cooperatives are humane and moral organizations.

Through cooperatives, waste is prevented, costs are reduced, production increases and efficiency increases. Cooperatives are a school of democracy. They are institutions that respond to the needs of the society in a shorter time and provide the best opportunity to serve people thanks to being elected and leaving office. Consumers have access to reliable and controlled food products. Cooperatives prevent excessive price increases in the market. In this way, protection of the consumer is served. Cooperatives also play an important role in increasing employment and preventing unemployment.

There are 7 cooperative principles accepted by the International Cooperative Alliance (ICA) in 1995 and these principles are still applied today (Şen and Çoban, 2008; Mülayim, 2019).

Voluntary and Free Entry Principle: Cooperatives are organizations open to everyone who volunteers to take on the responsibility of being a member. The cooperative is open to everyone regardless of gender, race, social status, political and religious discrimination.

Democratic Management Principle: Cooperatives are managed by their members. Managers come to power through elections. Each member has equal voting rights.

Partner Economic Participation Principle: Cooperative members become partners in the cooperative by paying a limited fee when entering the cooperative. These fees are used for the common interests of the cooperative. Members always have the right to control the cooperative's fund within the framework of the contract provisions.

Autonomy and Independence Principle: Cooperatives are autonomous and independent organizations managed by their members. They always maintain their autonomous structures in agreements made with other organizations.

Development of Education, Training and Information Principle: Cooperatives are organizations that have the function of providing education and information in order to help their members, elected representatives and managers and employees develop.

Principle of Cooperation Between Cooperatives: Cooperative members cooperate to make cooperative activities more efficient and establish local, regional, national and international unions.

Principle of Social Responsibility: Cooperatives are organizations that act with a sense of social responsibility in their work related to their fields of activity.

4. Agricultural Cooperatives in the World

The oldest records about cooperatives belong to the Fenwick Weavers' Association, which was formed by local weavers in Fenwick, Scotland in 1761. The real pioneers of modern cooperatives are the consumer cooperative established in 1844 by 28 craftsmen working in a cotton mill in the town of Rochdale in the north of England, under the name of the Rochdale Fair Pioneers

Association. These craftsmen opened a consumer store in the town and laid the foundations of cooperatives by determining a number of principles (İnan, 2008). This movement, also known as the Rochdale Pioneers, triggered the rapid development of cooperatives in Europe (ICA, 2023). Although the cooperative approach that emerged in England is considered a pioneer, it was stated that small tradesmen and craftsmen should also be supported in addition to agricultural production with the public fund established in France in 1830 before that date. In France, it is considered a pioneer in this field due to the prominence of production cooperatives. In Germany, the cooperative movement began with Herman Schultze-Delitzsch's establishment of a raw material purchasing cooperative in 1849 and reached a turning point with the establishment of the Raiffeisen Bank in 1864. This bank provided appropriate credit services and savings opportunities for those living in rural areas (Altuntas, 2021). In Israel, the Kibbutz established in 1909 and the first Moshav Ovdim villages established in 1921 were successful practices in which production and consumption activities were carried out according to a collective understanding and agricultural cooperatives were carried out based on socialist principles. In Russia, with the 1917 revolution, agricultural enterprise types called Sovkhoz and Kolkhoz emerged with changes in land ownership and business order, and agricultural activities were carried out collectively. While Sovkhozes meant state farms, Kolkhozes continued their activities as a structure that granted partial ownership rights in land, animals and equipment.

The establishment of cooperatives in Denmark in the 1880s is closely linked to both cheap imported grain and the decline of tariff protection. Similarly, the establishment of cooperatives in France and the Netherlands has been shown to be farmers' response to the agricultural economic crisis of the late 19th century. In 1877, farmers in the Netherlands formed their first cooperative to purchase quality chemical fertilizers. In the 1880s, French farmers banded together in a syndicate to jointly purchase fertilizers in order to counter the dominance of middlemen in the market (Pakdemirli, 2019).

Cooperatives did not remain only on a national level 115 years ago, but also laid the foundations for cooperation at an international level. European cooperative leaders who came together at the London Cooperative Congress with the participation of 200 representatives from 14 countries between 19-22 August 1895, came together under the roof of ICA as a result of the decision they made. Delegates from a total of 12 countries, including Belgium, France, Denmark, the Netherlands, Hungary, Switzerland, the USA, Australia, India, Argentina, Serbia and Italy, and guest representatives from Austria and Russia attended. The ICA's center is in Brussels. According to 2023 data, the organization is comprised of 315 organizations from 107 countries. The 3 million cooperatives under the umbrella of the organization's member organizations have more than 1.2 billion members. There are cooperatives operating in various sectors within the ICA. These cooperatives are included in the sector organizations under the umbrella of the ICA and carry out activities. These are primarily active in agriculture, banking, fishing, health, housing, industry, insurance, education, labor, transportation, energy, tourism, consumption and many other branches (ICA, 2023).

ICA is conducting a project titled "Top-300" to show the contributions of cooperatives to national economies and is preparing the World Cooperative Monitor (WCM) report. WCM presents the top 300 cooperatives and sectoral rankings according to two different criteria. The first is the ranking according to turnover, and the second is the ranking according to the ratio of turnover to Gross Domestic Product (GDP) per capita. The data collected for WCM's 2023 report is for the 2021 fiscal year. The main sources of the data are annual reports and sustainability reports, existing economic databases, data collected by national associations, research institutes and other organizations, and data collected directly from enterprises through surveys.

According to the top 300 rankings by turnover, the total turnover of cooperatives in 2021 is 2,409.41 billion US Dollars. When the distribution of cooperatives by sector is examined, it is seen that most of them operate in the agriculture and food sector (105 cooperatives) and the insurance sector (96 cooperatives), followed by the wholesale and retail trade sector (57 cooperatives). While the agricultural sector stands out with 103 cooperatives in the top 300 in terms of turnover according to GDP per capita, there are 87 cooperatives in the insurance sector, followed by the wholesale and retail trade sector (56 cooperatives) (Table 1).

Table 1. *Cooperatives with the Highest Turnover in the World by Sector*

Sector	Annual turnover		Annual turnover/GDP per capita	
	Number of cooperatives	%	Number of cooperatives	%
Agriculture and food	105	35.00	103	34.33
Insurance	96	32.00	87	29.00
Wholesale and retail trade	57	19.00	56	18.67
Financial services	27	9.00	39	13.00
Industry	9	3.00	5	1.67
Education and health	3	1.00	8	2.67
Others	3	1.00	2	0.66
Total	300	100.00	300	100.00

Source: ICA, 2023

When the top 300 cooperatives in terms of annual turnover are examined, it is seen that 166 (55.33%) are in European countries, 94 (31.33%) are in countries in the Americas, and 40 (13.34%) are in Asia-Pacific countries. The countries with the most cooperatives in Europe are France (40), Germany (31), the Netherlands (17), and Italy (13), respectively. The USA (73) is the country with the most cooperatives (ICA, 2023). Information on the top 10 cooperatives with the highest turnover in the world is given in Table 2. As can be seen, the top three cooperatives with the highest turnover are in France and Germany. It is seen that these cooperatives, which are in the first places, operate in the fields of financial services and wholesale and retail trade.

When the annual turnover of cooperatives in European countries is examined, France comes first. This is followed by Germany, Italy, and the Netherlands, respectively. In Türkiye, although the number of cooperatives is high, their annual turnover is quite low compared to other European countries. Türkiye ranks second in Europe after Italy in terms of the number of cooperatives. France and Spain follow these countries. However, Türkiye lags behind in terms of the number of members. France, Germany, the Netherlands, and Italy are in the first places. It is seen that Türkiye is not in the first places in terms of the number of employees in cooperatives. In this respect, Italy, Germany, Poland, Spain, and France are the most important countries, respectively (CoopsEurope, 2022; Kınıklı, 2022).

Table 2. *Top 10 Cooperatives with the Highest Turnover in the World*

Cooperatives	Country	Sectors	Turnover (Billion $)	Employment contribution (person)
Groupe Credit Agricole	France	Financial services	117.01	147,000
REWE Group	Germany	Wholesale and retail trade	82.03	257,996
Groupe BPCE	France	Financial services	64.06	99,900
Nonghyup (National Agricultural Cooperative Federation - NACF)	South Korea	Agriculture and food	61.17	27,865
ACDLEC-E.Leclerc	France	Wholesale and retail trade	60.56	138,000
Cooperative Financial Network Germany-BWR	Germany	Financial services	59.82	170,614
Talanx Group	Germany	Insurance	53.82	23,316
Edeka Zentrale	Germany	Wholesale and retail trade	51.97	83,534
Groupe Credit Mutuel	France	Financial services	49.36	83,141
Nippon Life	Japan	Insurance	49.07	92,737

Source: ICA, 2023.

Information on the cooperatives with the highest turnover in the agricultural and food sector is given in Table 3. Accordingly, the cooperative named "Nonghyup" operating in South Korea ranks first with a turnover of $61.17 billion. It was determined that some other cooperatives operating in Japan, USA, Germany, New Zealand, Brazil and the Netherlands also have high annual turnover.

In the European Union, cooperatives have an important place in the economic sphere, and the market share of agricultural cooperatives is around 40%. In countries such as Denmark, Finland, Sweden, Ireland, the Netherlands and France, this rate is over 50% (Pakdemirli, 2019).

Table 3. *The 10 Agricultural and Food Cooperatives with the Highest Turnover in the World*

Cooperatives	Country	Turnover (Billion $)	Employment contribution (person)
Nonghyup (National Agricultural Cooperative Federation - NACF)	South Korea	61.17	27,865
National Federation of Agricultural Cooperative Associations - ZENNOH	Japan	38.91	26,632
CHS Inc.	USA	38.45	9,941
Bay Wa	Germany	23.46	21 185
Dairy Farmers of America	USA	19.30	-
Land O'Lakes	USA	16.00	9 000
Fonterra Cooperative Group	New Zealand	14.92	19 608
Hokuren	Japan	14.30	1 806
Copersucar SA	Brazil	13.88	637
Friesland Campina	Netherlands	13.60	22 961

Source: ICA, 2023.

5. Structural Characteristics of Agriculture in Türkiye and the Need for Cooperatives

Table 4 shows the number and size of farms according to the general agricultural census results (1980, 1991 and 2001) and the Farmer Registration System (2023). As can be seen from the table, the number of farms has gradually decreased. When the farm land sizes are examined, according to 2023 data, approximately 83% of the farms have a land size of less than 100 decares, while they cultivate 39% of the total land.

The average farm size was determined as 6.23 ha in 1980, 5.91 ha in 1991, 6.10 ha in 2001, and 6.96 ha in 2023. The fact that the proportional decrease in the number of farms was greater than the proportional decrease in land size in the 1980-2023 period caused the average farm scale to increase from 6.23 hectares to 6.96 hectares. In other words, the increase in the average farm scale shows that small-scale farm lands are excluded from agricultural activities (Dinçer, 2023).

Table 4. *Number of Farms and Land Size in Türkiye by Year*

Farm size (decares)	Number of farms (1,000)				Land size (1,000 ha)			
	1980	1991	2001	2023	1980	1991	2001	2023
<50	2,267	2,660	1,959	1,452	4,556	5,189	3,934	2,969
50-99	738	713	560	408	4,839	4,675	3,813	3,078
100-499	616	557	481	364	10,633	9,570	8,596	7,386
500-999	26	24	17	19	1,786	1,498	1,122	1,306
≥1,000	4	13	5	3	905	2,518	970	887
Toplam	3,651	3,967	3,022	2,246	22,764	23,451	18,435	15,626

Source: TURKSTAT, 2024a; MAF, 2024a.

In Türkiye, farmers have been registered in the Farm Registration System since 2002. The lands registered by farmers and the change in the number of farmers are given in Table 5. As can be seen, although the number of farmers has decreased in recent years, the average farm size has increased.

Table 5. *Changes in the Number of Farmers and Farm Size in Türkiye According to the Farmer Registration System*

Years	Number of farmers	Total land (1,000 ha)	Average farm size (ha)
2002	2,588,666	16,496	6.37
2003	2,765,287	16,735	6.05
2004	2,745,424	16,710	6.09
2005	2,679,737	16,583	6.19
2006	2,609,723	16,493	6.32
2007	2,613,234	16,728	6.40
2008	2,380,284	15,769	6.62
2009	2,328,731	15,436	6.63
2010	2,318,506	15,631	6.74
2011	2,292,380	15,205	6.63
2012	2,214,537	15,345	6.93
2013	2,183,270	14,729	6.75
2014	2,206,874	14,928	6.76
2015	2,197,319	14,800	6.73
2016	2,267,176	14,786	6.52

2017	2,121,428	14,850	7.00
2018	2,152,003	15,064	7.00
2019	2,083,022	14,789	7.10
2020	2,127,957	15,180	7.13
2021	2,171,748	15,160	6.98
2022	2,172,974	15,330	7.05
2023	2,245,526	15,626	6.96

Source: MAF, 2024a.

According to the results of the Agricultural Structure Survey conducted by TURKSTAT in 2016, the average number of parcels in farms was determined as 5.9 and the average parcel size was determined as 12.9 decares. As the size of the farm increases, the number and size of the parcels also increase (Table 6).

Table 6. *Number of parcels and average parcel size in farms in Türkiye*

Farms size (decares)	Number of parcels of agricultural land per farm	Average parcel size of agricultural land (decares)
Total	5.9	12.9
<5	1.5	1.6
5 - 9	2.4	2.7
10 - 19	3.4	3.8
20 - 49	4.7	6.4
50 - 99	6.9	9.4
100 - 199	10.1	12.9
200 - 499	13.7	20.6
500 - 999	21.1	30.3
≥1000	36.9	60.3

Source: TURKSTAT, 2024b.

According to the results of the Survey-2016, 79.5% of the farms only cultivate their own land. 17.1% of the farms cultivate both their own land and others land. 3% of the farms cultivate only by rented land, 0.3% only cultivate only on share basis land, and the remaining 0.1% cultivate land in other ways (TURKSTAT, 2024b).

According to the results of the Survey-2016, of the lands cultivated by efarms, 69.3% are cereals and other crops, 11.9% are fruits and other perennials, 2.2% are vegetables, strawberries and flowers, and 0.1% are poplar and willow. The remaining 16.5% are fallow lands, unutilized potentially productive lands, pastures, wood and forest, non-agricultural lands and other lands (TURKSTAT, 2024b).

According to the results of the Survey-2016, 60% of the farms have less than 50 head of bovine animals (cattle and buffaloes). 91% of the farms have 50 head or more of sheep and goats (TURKSTAT, 2024b).

According to the results of the Survey-2016, when the distribution of farms according to economic size is examined, it is seen that 85.5% of them have an economic size below 83,250 TL. 12.7% have an economic size between 83,250 - 333,000 TL, and 1.7% have an economic size above 333,000 TL (TURKSTAT, 2024b).

Small farms in agriculture have some important problems compared to large farms. First of all, they cannot increase the efficiency of the farm because they cannot use the production tools (machinery, buildings) used by large farms intensively. Secondly, as the workforce and specialization increase in large farms, they use the advantages of large-scale production, this is not possible for small farms. Thirdly, they cannot access the credits required for production as easily as large farms. For these reasons, agricultural organizations and cooperatives are important and necessary, especially for the sustainability of small farms.

6. Agricultural Cooperatives in Türkiye

In the modern sense, the beginning of the Turkish cooperative movement is the National Funds, which Mithat Pasha founded in 1863. The reason why National Funds is considered the beginning of the cooperative movement is that after the management income is deducted from the income obtained, one third of the remaining money is given to the partners as a return (Çıkın and Karacan, 1994). The remaining money is spent on works such as fountains, schools and road construction, which are within the scope of providing benefit to the society, which is another important principle for cooperatives. Ziraat Bank, one of the most important banks in Türkiye today, was established with the capital of National Funds. Therefore, Mithat Pasha is the initiator of the Turkish cooperative movement and also the founder of Ziraat Bank (Özer Topaloğlu and Sönmez, 2023).

During the Atatürk period, the Agricultural Unions Law came into force in 1924, the Ankara Civil Servants Consumption Cooperative in 1925, the Agricultural Sales Cooperatives and Unions Law No. 2834 in 1935, and the Agricultural Cat Cooperatives Law No. 2836. With the death of Atatürk and the beginning of World War II, it is seen that the cooperative movement stagnated. In the 1960-1980 period, it is seen that important legal studies were carried out regarding cooperatives. In the 51st article of the 1961 Constitution, cooperatives were mentioned in a constitution for the first time with the statement, "The state shall take measures to ensure the development of cooperatives". In the second half of the 1960s, it is seen that especially village development cooperatives were established in Türkiye. It is seen that developments regarding cooperatives took place after the Cooperatives Law No. 1163 dated 1969 and many different types of cooperatives became widespread. The 1st Cooperative Congress held on 7-18 March 1990 was a turning point in terms of completing the upper organization of Turkish cooperatives and subsequently, the Turkish National Cooperatives Union was established on 30.11.1991 (Koçtürk, 2006; Irmaklıoğlu and Irk, 2022).

With the entry into force of the Agricultural Law in 2006, the organization of agricultural producers constituted one of its most fundamental objectives. In addition, the entry into force of the Turkish Cooperative Strategy and Action Plan in Turkey in 2012 and 2019 is important for Turkish cooperatives. The audit principles of the cooperative law numbered 1163 were changed with the Law on Amendments to the Cooperative Law numbered 7339 and Certain Laws dated 2021 and numbered 7339.

In Türkiye, cooperatives can be classified differently according to their purposes, fields of activity and the laws they are established. Agricultural cooperatives continue their activities under three different laws (1163, 1581 and 4572) and two different ministries (Ministry of Agriculture and Forestry and Ministry of Commerce) (Kınıklı, 2022). Agricultural Development Cooperatives, Irrigation Cooperatives, Fishery Cooperatives and Sugar Beet Growers Cooperatives continue their activities under Law No. 1163 and are affiliated with the Ministry of Agriculture and Forestry.

Agricultural Credit Cooperatives are also affiliated with the Ministry of Agriculture and Forestry, but continue their activities under Law No. 1581. Unlike these cooperatives, Agricultural Sales Cooperatives are affiliated with the Ministry of Commerce and continue their activities under Law No. 4572. Other cooperatives affiliated with the Ministry of Commerce are; Tobacco Agricultural Sales Cooperatives and Fresh Fruit and Vegetable Marketing Cooperatives. Tobacco Agricultural Sales Cooperatives continue their activities according to Law No. 1196, and Fresh Fruit and Vegetable Marketing Cooperatives continue their activities according to Law No. 1163. The number and number of partners of these two cooperatives are small.

In Türkiye; agricultural cooperatives constitute 18% of the total number of cooperatives and 57% of the number of cooperative members. Information on the number of agricultural cooperatives operating in Türkiye and the number of members is presented in Table 7. As can be seen, the cooperatives with the largest number are Agricultural Development Cooperatives (6,597). Agricultural Development Cooperatives constitute 56% of agricultural cooperatives (11,709). These cooperatives are affiliated to Village-Cooperative, Agriculture, Animal Husbandry, Forestry and Tea Regional Unions according to their fields of activity. When examined in terms of the number of members, it is seen that the cooperatives with the largest number of members are Sugar Beet Growers

Cooperatives (1,399,339). Sugar Beet Growers Cooperatives constitute 38% of the total number of members of agricultural cooperatives (3,672,010).

Agricultural Development Cooperatives develop the production of all kinds of crops, animal husbandry and forestry of the members and carry out activities such as procurement, supply, management, marketing and evaluation regarding their needs. They help the members to develop economically and socially and provide job opportunities. They benefit from natural resources to increase the economic power of the members and take measures to ensure the development of handicrafts and home arts and agricultural industry.

Irrigation Cooperatives establish agricultural irrigation facilities such as land leveling, field head canals, in-field irrigation and drainage, or operate and have established irrigation facilities operated, maintained or have them operated, to use the water to be taken from irrigation facilities supplied or to be supplied by the state or to be extracted from agricultural fields in any way.

Fishery Cooperatives provide services to their partners in the production, processing, storage and marketing of all kinds of fishery products, and provide the fishing gear, equipment and supplies their partners need.

Sugar Beet Growers Cooperatives take the necessary measures regarding soil preparation, planting, growing and protecting sugar beets and other agricultural products, and increasing their yield per decare, and help their partners obtain useful information.

In Türkiye, the purchase shares of agricultural products by agricultural cooperatives vary between 3% and 40%. When examined according to products, this rate is seen as 21.28% in sunflower, 4.10% in cotton, 2.45% in olive, 2.07% in olive oil, 0.55% in hazelnut, 2.96% in dried fig, 11.75% in rose flower and 39.33% in mohair (Karlı et al., 2018).

Table 7. *Agricultural Cooperatives Operating in Türkiye (As of 29.07.2024)*

	Unit cooperatives			Cooperative regional unions				Cooperative central unions (**)			
Law	Cooperative type	Number of cooperative	Number of partners	Cooperative type	Number of partner unions	Number of partner cooperatives	Number of partners	Number of central unions	Number of partner unions	Number of partner cooperatives	Number of partners
1163	Agricultural Development	6,597	731,195	Village-cooperatives	16	1,423	166,444	1	19	1,277	146,332
				Agriculture	12	543	62,250	1	21	952	109,005
				Animal Husbandry	34	1,734	179,301	1	34	1,806	194,000
				Forestry	17	828	100,124	1	29	2,440	303,029
				Tea	5	35	65,752	1	5	35	65,752
1163	Irrigation	2,484	319,761	Irrigation	14	673	93,228	1	17	617	88,930
1163	Fishery	594	31,029	Fishery	17	232	14,304	1	17	199	11,403
1163	Sugar Beet Growers	31	1,399,339	Sugar Beet Growers	1	31	1,399,339	-	-	-	-
	Sub-total	**9,706**	**2,481,324**	**Sub-total**	**116**	**5,499**	**2,080,742**	**7**	**142**	**7,326**	**918,451**
1581	Agricultural Credit	1,618	853,869	Agricultural Credit	17	1,618	853,869	1	17	1,618	853,869
	Sub-total	**11,324**	**3,335,193**	**Sub-total**	**133**	**7,117**	**2,934,611**	**8**	**159**	**8,944**	**1,772,320**
4572	Agricultural Sales (*)	338	332,925	Agricultural Sales	13	281	308,346	-	-	-	-
1196	Tobacco Agriculture Sales (*)	18	939	Tobacco Agriculture Sales	1	9	124	-	-	-	-
1163	Fresh Fruit and Vegetable Marketing (*)	29	2,953	Fresh Fruit and Vegetable Marketing	-	-	-	-	-	-	-
	General Total	**11,709**	**3,672,010**	**Total**	**147**	**7,407**	**3,243,081**	**8**	**159**	**8,944**	**1,772,320**

(*) It is under the responsibility of the Ministry of Trade. (**) These are cooperative unions within the Agricultural Purpose Cooperative Central Unions.

Source: MAF, 2024b.

6. Conclusion

There are sufficient numbers of cooperatives and farmer organizations in Türkiye. However, the numerical adequacy of these organizations is not compatible with the power and effectiveness of their economic activities. For example, the shares of agricultural cooperatives in Türkiye in various agricultural product purchases vary between 3% and 40%, with an average of approximately 10%. In the EU, the average share of agricultural cooperatives in agricultural product purchases is around 50%. This situation is an indication that agricultural organizations in Türkiye cannot work as effectively as in developed countries. The reflection of this situation on the primary pillar, the farmers, is the disruptions and problems in that product market.

According to the research, the main problems of agricultural cooperatives in Türkiye are evaluated as conceptual, educational, legal, administrative-managerial and economic problems (Güreşçi, 2017; Güreşçi and Gönç, 2017; Yercan and Kınıklı, 2019). According to the results of a research conducted in Manisa province, according to 65.63% of the farmers who are cooperative partners, the main problem in the cooperative is the management problem (Özcan, 2022). According to the results of a research conducted in Niğde province, the most important problem according to the cooperative partners is the control problem (Gümüş, 2022).

Although there are sufficient farmers organizations in the agricultural sector in Türkiye, the desired success cannot be achieved due to the lack of information and low level of awareness at the farmer level; lack of trust in farmer organizations, the inability of organizations to produce solutions to the problems of farmers, their inability to be effective in both input and product marketing and social issues, and the failure of organization managers. In order to solve these problems, training activities should be carried out for farmers in rural areas and the awareness levels of farmers on organization should be increased. At the same time, it is important that the people who will take part in farmer organizations have a leadership structure and have knowledge about the functioning of the organizations. Therefore, in organization training activities for rural areas; the short, medium and long term needs to be determined and put into practice.

Cooperatives make significant contributions to both the development of the agricultural sector and rural development. The development of cooperatives can contribute positively to the national economy and increase their role in marketing. However, cooperatives are trying to create a market and create a brand with their own means. This situation is affected by the deficiencies in management and the abundance of organizations that cannot work effectively. Therefore, state support for cooperatives to enter the market should be provided through public institutions and local governments. In addition, initiatives should be made to ensure that public institutions and local governments prefer cooperative products when meeting their needs. In fact, successful applications of this are seen in Izmir province

It is also important to increase the service quality in cooperatives and to provide better service to their members. For this reason, studies that reveal the extent to which existing cooperatives have improved in terms of service quality and sample cooperatives should be used. In this way, it will be possible to take precautions in advance and carry out developmental studies.

As a result; cooperatives have become a widely used business model in many countries today. Cooperatives provide economic and social contributions in different regions. It is seen that cooperatives are effective in production and marketing, especially in developed countries. In developing countries, cooperatives should be used more, especially in marketing agricultural products. In Türkiye, cooperatives can make important contributions in terms of protecting farmers and consumers. Increasing the number of cooperatives in this direction, cooperating with existing cooperatives, increasing supply and employment opportunities and directing consumers to cooperative products will make important contributions to the regional economy and rural development.

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CHAPTER 3

COPING WITH DROUGHT: SUSTAINABLE FARMING PRACTICES IN A CHANGING CLIMATE

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1. **Introduction**

Feeding a growing population amid climate change demands innovative solutions. Enter cover crops: nature's multitaskers. They manage nutrients, conserve soil and water, and boost climate resilience. Yet irrigation remains agriculture's Achilles' heel, limiting production as temperatures rise. Smart irrigation systems offer hope. Tailored to regional needs, they protect soil, biodiversity, and the environment.

Practitioners, food managers, and researchers play vital roles in this transition. They must actively promote and implement these advanced irrigation methods across diverse geographical areas. By doing so, they ensure both resource conservation and continued food production.

Ultimately, embracing smart irrigation is key to agriculture's future in a changing climate.

The geographical fragmentation of water resources has turned a vital necessity into a complex global challenge. The 276 transboundary basins, shared by 148 countries, support 60% of the world's freshwater flow, making them a critical lifeline for millions of people. Another 300 aquifer systems, spanning across international borders, supply water to 2 billion people, further emphasizing the need for cooperation. The repercussions of inadequate water management are far-reaching, affecting not only the environment and economies but also human well-being and global stability. To mitigate these risks, countries must prioritize collaborative water resource management, investing in sustainable infrastructure, transparent governance, and innovative technologies. By doing so, they can ensure that this finite resource is harnessed in a way that benefits all, as underscored by the World Bank Group (2024).

In today's world, where water demand is surging, scarcity is escalating, and uncertainty is growing, it is vital that clients prioritize investments in institution-building, information management, and infrastructure development. This will ensure the optimal use of water resources, reducing the risks of scarcity and crisis. For instance, the efficient allocation of water resources requires robust institutions, such as those in Singapore, which have enabled the country to achieve water self-sufficiency.

In addition, effective information systems are crucial for monitoring water resources, informing decision-making, and predicting weather patterns. In the United States, for example, the National Drought Mitigation Center's monitoring systems have helped farmers and policymakers respond to droughts more effectively. Moreover, innovative technologies can significantly enhance water productivity, conserve resources, and develop new water sources. Israel's pioneering work in water recycling, for instance, has enabled the country to reuse over 80% of its wastewater.

The development of natural infrastructure, such as watersheds and aquifers, is also critical. In Australia, the protection of natural water storage systems has helped maintain ecosystem health and mitigate the impacts of droughts. Furthermore, investing in non-conventional water sources, such as desalination and wastewater reuse, can provide additional water supplies. In Namibia, for example, a desalination plant has increased the country's water supply, supporting economic growth and development.

Ultimately, the global water security challenge can be overcome by adopting a comprehensive approach that addresses institution-building, information management, infrastructure development, and innovative technologies. By adapting these strategies to local contexts and needs, we can strengthen global water security and create a more sustainable future for all (Wold Bank Org. 2024).

What if the world's irrigation needs triple by 2100? This alarming scenario stems from multiple converging factors. The relentless colonization and agricultural expansion of new lands strain already scarce water resources, depleting aquifers and rivers. Climate change, responsible for 14% of the increased demand, exacerbates the problem by altering rainfall patterns and evaporation rates. The swelling population, in turn, drives land use shifts, such as the conversion of natural habitats to arable land, further amplifying the effect. Moreover, the growing demand for bioenergy crops adds pressure on water resources, as these crops are often thirsty and require extensive irrigation. As soil moisture fluctuates wildly, farmers are increasingly reliant on irrigation systems to ensure crop survival. Technical reports predict a significant, upward spiral in water usage, while models incorporating resource constraints forecast dramatic increases that will strain global water supplies. The interplay of these factors shapes global irrigation demands, which are set to skyrocket. This trend creates mounting pressure on water supplies worldwide, presenting a complex, daunting challenge for future food security and resource management. Innovative solutions, such as precision irrigation systems and drought-resistant crops, are desperately needed to balance agricultural needs with sustainable water use, ensuring that the world's growing population has access to nutritious food without compromising the planet's precious water resources.

As the global water crisis worsens, regions like East and Central Asia, the Middle East, and parts of the Americas are bracing themselves for irrigation restrictions. The main culprit behind this looming crisis is the reckless depletion of groundwater resources, brought on by years of over-irrigation. For instance, the Indian state of Punjab, known for its lush green fields, has seen its groundwater levels plummet by over 70% in the past two decades (Turner et al. 2019). Similarly, the Middle East, which relies heavily on groundwater for irrigation, is struggling to maintain its food production due to rapidly depleting aquifers. The situation is no different in the Americas, where the agricultural hub of California has witnessed a staggering 60% decline in its groundwater levels since the 1960s. As the world's population continues to grow, these irrigation restrictions will have far-reaching consequences, including food shortages, economic instability, and even social unrest. It is imperative that policymakers and farmers alike take immediate action to adopt sustainable irrigation practices and conserve this precious resource before it's too late.

Drought's grip tightens on global agriculture. Wheat yields may plummet 12%. Maize faces a 6.3% decline. Rice could see a staggering 19.4% drop. Other crops aren't spared, with 15.1% losses looming. Soybeans face the harshest future a potential 16.1% yield reduction by 2100(Grossiord et al. 2020). But that's not all. Rising temperatures increase water vapor deficits, potentially boosting plant mortality. This double threat compounds yield losses across crops. Current models can't keep up. They fail to capture crop responses to high CO_2 under extreme conditions. This blind spot leads to underestimating climate change's true impact on agriculture. As volatility rises, our understanding falters, leaving global food security hanging in the balance (Deryng et al. 2016;Schewe et al. 2019).

Faced with intensifying droughts, water managers seek robust solutions. This paper examines effective moisture conservation systems. We prioritize actionable methods for immediate deployment. Our analysis covers soil moisture retention techniques and irrigation water optimization. By exploring these approaches, we aim to equip decision-makers with practical tools. Implementing these strategies promptly can significantly mitigate drought impacts. Our review underscores the urgency of adopting these water-saving measures.

2. Materials and Methods

This review article sets out to explore the critical issue of mitigating the impact of climate change on irrigation in agricultural production. It seeks to answer two key questions: Firstly, what alternative irrigation methods are viable alternatives to traditional practices? Secondly, how can we enhance the adaptive capacity of irrigation systems in different climate zones?

To provide a comprehensive response to these questions, this article synthesizes the latest research on climate resilience in irrigated agriculture, highlighting the specific challenges and opportunities for implementation. It draws on a wide range of academic studies and expert opinions to provide a thorough overview of the current state of knowledge in this field.

In addition, the article examines the crucial role of economic analysis in enabling irrigated agriculture to adapt more effectively to climate-related stress. It discusses the importance of assessing the costs and benefits of different adaptation strategies, and highlights the need for policymakers and farmers to consider the economic implications of their decisions.

The article also identifies and describes effective practices that have been successfully implemented in improving climate resilience in irrigated agriculture. These include the use of drought-tolerant crops, precision irrigation systems, and conservation agriculture. By highlighting these examples, the article aims to provide practical guidance for stakeholders seeking to address the challenges posed by climate change to agricultural production.

3. Results

3.1. Techniques for water conservation

3.1.2. Terracing

Erosion threatens farmland. The solution? Terracing. By sculpting hillsides into steps, farmers slow water's descent. This ancient technique boosts absorption, preserving precious soil. The result: sustainable agriculture on once-vulnerable slopes. Terraced plots can vary in shape and size and typically consist of a flat area and a near-vertical riser protected by a wall of dry stone, soil, grass, or trees. The height of the riser or wall can range from several decimeters to a few meters, with a continuous or intermittent structure comprising single walls or a complex series of walls. In the context of climate change, terraces represent a form of adaptation that can assist in situations where there is an increase in precipitation, as well as a decrease in precipitation. This is achieved through processes such as increased infiltration and reduced runoff, which have been demonstrated to have a robust evidence base and high level of agreement. Nevertheless, there are several obstacles to the continued maintenance and construction of new terraces, including the high costs associated with labor and/or capital (Arnáez et al., 2015) Furthermore, there is a loss of local knowledge regarding the maintenance and construction of new terraces (Chen, Wei, and Chen 2017). The propensity of farmers to invest in mechanical soil conservation methods varies with land tenure; farmers with secure tenure arrangements are more willing to invest in durable practices such as terraces (Lovo 2016). Where the slope is less severe, erosion can be controlled by contour banks, and the keyline approach(Duncan 2016) to soil and water conservation.

Figure 1. Terracing infrastructures

1.1.1. Contour plowing

Adjusting crop rows to follow the natural slope with contour plowing minimizes runoff and improves water retention. Contour plowing has been demonstrated to mitigate the adverse effects of floods, storms, and landslides on crops by reducing soil erosion by up to 50 percent, controlling water runoff, increasing moisture seepage and holding capacity, and improving soil quality and structure. Contour ploughing is a soil conservation technology that is employed throughout Grenada to mitigate the adverse effects of natural hazards on soil quality and composition. The practice of contour ploughing involves following the natural contours of the land when tilling the soil, planting, and cultivating. (FAO, 2008)The aforementioned characteristics render the structure more resilient to weather-related hazards, including flash floods. This renders the structure more resilient to weather-related damage, including flash floods. Furthermore, the preservation of soil conditions and the achievement of higher yields will have a beneficial impact on the livelihood of farmers. The implementation of contour plowing allows for a more efficient utilization of land resources. By adhering to the natural contours of the land when tilling the soil, planting, and cultivating, this practice serves to mitigate the impact of climate change on crops by enhancing soil quality and composition.

Figure 2. Contour plowing infrastructures

1.1.2. Cover crops

Soil-shielding plants, known as cover crops, guard against erosion and water depletion while enriching the earth beneath. This paper will examine the potential of using agricultural land cover crops for climate adaption and change mitigation. Cover crops represent a pivotal instrument with the potential to enhance crop yields, safeguard the quality of surface and groundwater, mitigate erosion, sequester atmospheric carbon, and promote soil quality and health across tropical regions. However, there are numerous research gaps, and further investigation is required to ascertain the potential benefits of cover crops for soil, human, and animal health. Additionally, there is a need for an open-access data repository that synthesizes research on cover crops in the tropics. Although cover crops do utilize and transpire some water, as do all crops, the overall impact of maintaining a continuous ground cover of roots throughout the year is an enhanced water infiltration and retention in the soil, a reduction in water runoff, and a decrease in evaporation. The presence of living cover crops has the potential to significantly influence soil temperature. The amplitude of diurnal temperature fluctuations is reduced by the presence of cover crops, resulting in a less variable temperature profile. The application of cover crop mulches serves to safeguard the soil from the detrimental effects of cold nighttime temperatures, thereby mitigating the rate of cooling. This may confer a benefit in regions with high temperatures, but may also result in reduced growth rates in regions with cooler climates. The implementation of winter cover crops serves to moderate temperatures during the winter season. Soil temperatures are higher in the vicinity of standing crops than in areas where the soil is flat. The use of row cleaners has been demonstrated to be an effective method for the management of residues, with the potential to enhance soil temperatures in no-till fields. Additionally, the implementation of cover crops has been demonstrated to enhance soil infiltration by facilitating the formation of macropores, which are expansive channels within the soil matrix. These macropores frequently emerge within the confines of preexisting root channels and are often the consequence of the activities of soil fauna, such as earthworms. The maintenance of adequate pore space allows for the rapid infiltration of water via a greater number of connected pathways. However, the impact of cover crops on water movement may vary considerably depending on the characteristics of the field, including slope and soil type, the specific cover crop species and its biomass and root structure, and the duration of use.

Figure 3. Cover crops applications

1.1.3. Organic mulches

Straw, compost, and other organic materials form protective mulches, preserving vital soil hydration. Mulching transforms soil health and plant vitality. This technique layers plant residues on soil surfaces, offering multiple benefits. It conserves moisture, controls temperature, and prevents erosion. Organic mulches improve soil structure and boost water retention. Moisture conservation is crucial. Mulch shields soil from sun and wind, reducing evaporation by up to 50%. It acts as an insulator, moderating temperatures in all conditions. This protection is vital in arid regions and during droughts. Temperature control follows. Mulch cools soil on hot days and warms it on cold nights. It enhances beneficial microbial activity, naturally fighting diseases and pests. The layer also prevents surface compaction and reduces runoff. Soil improvement is significant. Mulch slowly releases nutrients as it decomposes. It increases water-holding capacity and enhances drainage. The cover also effectively controls weeds. Practical benefits abound. Mulching simplifies garden maintenance and eases weeding. It's economically and aesthetically advantageous for any landscape. From small gardens to vast orchards, mulching is key to thriving plants and healthy soil. (Liu, Zhang, and Zhang 2002). Agricultural waste mulching boosts soil water retention. Straw and compost form a protective layer, reducing evaporation. Grass clippings enhance this effect, preserving moisture. Leaves contribute similarly, improving hydration. Researchers confirm these materials' efficacy in soil management. This technique aids crop growth and promotes sustainable farming practices (Baumhardt and Jones 2002; Kar and Singh 2004; Shengxiu and Ling 1992; Steiner 1989). Efficient water usage drives down production costs effectively.

Figure 4. Organic mulches applications

1.1.4. Inorganic mulches

Water retention improves with inorganic mulches like plastic or stone. These materials effectively conserve moisture in gardens. Inorganic mulches can be natural (like river rocks and gravel) or synthetic (like landscape tarp and rubber), but they were never alive, so they don't decompose. This means you don't have to replace them as frequently as organic mulches, but it also means they don't return nutrients to the soil. Black plastic doesn't allow for the flow of air or moisture, so it's important to cut holes in the plastic sheeting to prevent root rot. Bury it underneath a more decorative, organic mulch (like wood chips or pine needles) to keep it in place and improve your soil's resistance to compaction. Stones, gravels, and plastics form the backbone of inorganic mulching. These materials, devoid of organic matter, serve multiple purposes in landscaping and agriculture. While they excel at suppressing weed growth, their impact on soil varies. Rocks and pebbles, though inert, can absorb and reflect heat—a boon in arid climates. Conversely, biodegradable and photo-degradable plastic mulches break down over time, enhancing soil quality. Unlike their organic counterparts, inorganic mulches don't decompose rapidly, offering long-lasting ground cover solutions for diverse environmental conditions.

Figure 5. Inorganic mulches applications

1.1. Water conservation applications

1.1.1. Rainwater harvesting

Harvested rainwater can provide a source of alternative water to federal facilities. Alternative waters are sustainable sources of water, not supplied from fresh surface water or groundwater, that offset the demand for freshwater. Rainwater harvesting captures, diverts, and stores rainwater from rooftops for later use. Rainwater harvesting provides a source of clean fresh water in places where water is scarce, polluted, or only seasonally available. In addition, harvesting and storing rainwater can be a less expensive way (compared to desalination or piping water long distances) to guarantee safe, clean water for drinking and home use, as well as gardening, watering livestock, or agriculture.

1.1.1.1. Rooftop collection systems

Rainwater falls on rooftops. Clever systems spring into action. Gutters and pipes guide the flow. Storage tanks fill up below. A basic system that collects rainwater from a roof via downspouts and a barrel or tank is ideal for outdoor use—for watering plants or other outdoor chores. This is generally known as “rooftop rainwater harvesting,” and these systems don’t require much more maintenance than typical gutter-cleaning upkeep. If you have a rain barrel at the bottom of the spout with a removable lid, make sure the lid is fastened tightly to prevent animals from climbing inside and drowning; check it regularly.

Figure 6. Rooftop collection systems

1.1.1.2. Ground catchment systems

These systems expand the surface area for rainwater catchment by using the land as a catchment area. Another system is "surface runoff harvesting", where surplus rain on the ground is collected through a slightly more complex series of aquifers. You may want to use this approach if you're collecting rainwater for household use—for sinks, showers, washing machines, and toilets (or outdoors for a swimming pool).

Figure 7. Ground catchment systems

1.1.1.3. Ponds and reservoirs

The occurrence of precipitation can result in the accumulation of water in ponds. This phenomenon is typical of farm and ranch ponds, which are often situated at a low elevation to facilitate the collection of runoff from higher points within the watershed. Additionally, farm ponds may be replenished with water from irrigation systems. Furthermore, the water levels of these ponds can be maintained by drawing water from streams when precipitation occurs, thereby ensuring the continued flow of streams during the dry season.

The recharging of groundwater by ponds allows for the retention of water within the system for a longer period of time. This results in an increased availability of water within the watershed, facilitating seepage into streams at a later point in the summer. The construction of ponds in valleys that have been subjected to overdrafting serves to facilitate the management of the watershed.

Furthermore, ponds can be utilized for the purpose of storing water from irrigation. The sediment can be allowed to settle and then returned to the fields. The reuse of water can reduce the necessity for the diversion or pumping of additional water. The energy required for pumping from a pond is less than that needed for groundwater pumping. A sediment trap is connected to a pond via a flow mechanism.

1.1.1.4. On-farm ponds

Miniature reservoirs on farmland capture precipitation and surface flow, providing water reserves. Ponds provide water for human and animal consumption, irrigation of high-value crops and vegetables, and other uses that contribute to the overall value of the farm. The typical size of a farm pond ranges between 30 and 500 square meters, depending on the resources a farmer has available. Furthermore, larger natural bodies of water, such as small lakes, can also be considered farm ponds. The physical proximity of ponds to the farmer's residence is crucial for effective management. Those that are fully incorporated are the most beneficial to the overall operation of the farm. The existence of ponds on a farm gives the ability to raise fish and other aquatic organisms, thereby providing diversification of the farm's income sources and reducing overall risk (FAO, 2009; Miller 2009).

Figure 8. On-farm ponds systems

1.1.1.5. **Check dams**

The presence of these barriers allows aquifers to recharge, thereby replenishing underground reserves. The water flow was then captured and allowed to seep into the soil below. The construction of check dams represents an effective method for the trapping of sediment in river basins and other locations worldwide that are prone to severe soil erosion. It is essential to quantify the amount of sediment trapped by check dams in order to assess their impact and inform the design of new structures (Sun and Wu 2023).

Soil water is a fundamental element for plant growth and vitality, as well as a critical component of the hydrological cycle. (Wang et al., 2021) The text is incomplete and therefore meaningless. As a primary conduit among precipitation, soil water, and groundwater exchange, soil infiltration plays an indispensable role in the hydrologic cycle. Furthermore, soil infiltration capacity serves as a crucial metric for assessing soil water retention and erosion resistance. (Gwak & Kim, 2017) The text is incomplete and therefore meaningless. Soil infiltration represents a principal mechanism for the replenishment of groundwater resources. In particular, the Loess Plateau relies on multiple intense rainstorms during the rainy season to replenish soil moisture, which serves as the primary source of groundwater recharge in this region (Suo et al. 2018; Wang et al. 2013).

Figure 9. Check dams systems

1.2. Water management practices

1.2.1. Crop rotation

Crop rotation is a practice that involves growing different crops in a specific sequence on the same piece of land over time. This technique offers several benefits for optimizing crop performance and water use efficiency. For example, alternating between water-demanding crops and more drought-tolerant crops allows the soil to replenish moisture levels during periods of lower water demand (Rabotyagov, Jha, and Campbell 2010).

Crop rotation also helps break pest and disease cycles, reducing the need for chemical interventions and further enhancing crop health. Planting different crops in succession can aid in preserving soil structure and optimizing water use. Economic pressures drive farmers to alter crop rotations, awakening dormant ecosystems. Fields transform, impacting both profits and watersheds. As agriculture shifts, water quality improves, and the set of conservation practices optimally selected for leastcost improvements in water quality (Rabotyagov, Jha, and Campbell 2010).

The five crop rotations used in the study reduced water use by 7- 12 percent and groundwater use by 21-31 percent compared to conventional methods. Rotations with sweet potatoes and peanuts increased yields by up to nearly 32 percent, profits by up to 70 percent, and water productivity by 24-68 percent compared to WM. Crop rotation with shallow-rooted plants like sweet potato, soybean, peanut, and millet improved soil water storage at the start of the wheat planting season by 3–9% compared to WM. These shallow-rooted crops mainly directed their roots into the top 80 cm of soil water, complementing the deeper roots of wheat. This improved the leaf area index and aboveground biomass of the subsequent wheat and corn crops, and increased total grain yield by 4-11%. Adding shallow-rooted crops before wheat and maize in the WM rotation helps save water, boosts crop yields, and slows down the decline in groundwater in the NCP. (Wang et al., 2024).

The incorporation of shallow-rooted crops has the potential to significantly enhance water efficiency in cereal systems. The integration of sweet potato, soybean, peanut, spring maize, and millet into crop rotations has been demonstrated to reduce evapotranspiration by 7 to 12 percent and groundwater use by 21 to 31 percent. The implementation of diversified systems has been observed to enhance soil water storage by a range of 3 to 9 percent for wheat, thereby facilitating the conservation of deep moisture. The economic advantages of sweet potato and peanut-based rotations are considerable. The application of strategic crop rotation techniques has been observed to result in yield increases of between 4 and 11 percent. Roots with a shallower depth of penetration absorb moisture at a depth of 80 cm or more, while wheat accesses deeper reserves. This vertical synergy optimizes the utilization of water, which is of particular importance in arid regions. The North China Plain study illustrates a correlation between increased production and decreased water consumption. Farmers achieve enhanced yields and profitability while simultaneously conserving a scarce resource: groundwater.

Crop diversification represents a mutually beneficial solution for water-scarce regions globally. It promises sustainable agriculture, whereby productivity is balanced with the preservation of resources. This novel approach has the potential to revolutionize agricultural practices in regions prone to drought on a global scale. (Wang et al. 2024).

1.2.2. **Technology and innovation in water management**

With the combination of agriculture soil science and technology, we're ushering in an era of smarter, more efficient farming:

1.2.2.1. **Moisture sensors**

The soil-based sensors track soil moisture, delivering instant data to optimize crop irrigation efficiency. Water stress can devastate crops, slashing yields and quality. Smart irrigation technology offers a solution. By monitoring site-specific data, these systems precisely meet crop needs. They prevent excessive stress while conserving precious resources. Recent innovations have made this tech more accessible and competitive. Farmers now wield precise control over water use, tailoring irrigation to each crop's requirements. The result? A more sustainable and productive approach to agriculture. Efficient, energy-saving systems are now a reality. They revolutionize water management, transforming how we grow food. With smart irrigation, farmers optimize plant productivity and quality while preserving our most vital resource (Paulo et al. 2023).

Soil moisture sensors are crucial for optimizing irrigation. They guide farmers on water application timing, method, and quantity, maximizing crop yields. These devices maintain ideal soil moisture across diverse field conditions. Sensor selection depends on location, soil type, crop variety, existing moisture levels, and budget constraints. By precisely monitoring soil water content, these tools enable efficient resource use and improved agricultural productivity(Kumar et al. 2024). Knowing exactly when, how, and how much water to apply is vital in agriculture. For instance, in regions with water scarcity, precise irrigation schedules can significantly reduce water waste. On the other hand, in areas with abundant water resources, optimized irrigation can lead to increased crop yields. Maintaining field capacity, which is the ideal amount of water held in the soil, is essential for healthy plant growth.

Figure 10. Moisture sensors

This can only be achieved by using soil moisture sensors, as they provide real-time data on soil moisture levels. The type of soil moisture sensor used depends on various factors, including the location, financial resources of farmers or researchers, soil type, crop being grown, and the initial moisture level in the soil. For example, in arid regions, farmers may opt for more advanced sensors that provide frequent updates on soil moisture levels, while in wetter climates, simpler sensors may suffice. Similarly, researchers with limited budgets may choose more affordable sensors, whereas those with ample resources may invest in more sophisticated sensors that provide more detailed data. By using soil moisture sensors, farmers and researchers can create tailored irrigation schedules that cater to the specific needs of their crops, resulting in improved yields and reduced water consumption.

1.3.3.2. Automated drip systems

The advent of new technologies has precipitated a period of accelerated advancement in the agricultural sector, mirroring developments in numerous other domains. In order to meet the increasing food needs of a growing population while ensuring the efficient use of natural freshwater resources, studies have commenced to investigate potential solutions. In this context, the development and implementation of automated irrigation systems in agricultural production have assumed greater significance (Arık and Korkut 2022). Water consumption for agricultural applications had been an area of great concern; with the increasing pressure from population development and climatic variations on water resources.

1.1.1.3. Portable testing kits

Instant water testing kits provide real-time feedback on contaminants. Automation Products offers farmers remote field irrigation, eliminating on-site visits. Smart scheduling and monitoring simplify irrigation management, making the process effortless and efficient. These tools revolutionize water quality control and crop watering, empowering farmers with convenience and precision.

Figure 11. Automated drip systems

1.1.1.4. Data-driven management

Data-driven farming revolutionizes water management. Smart devices provide real-time feedback, enabling proactive resource control. Modern irrigation faces dual challenges: boosting output while conserving water and adapting to climate change. Stakeholders must create comprehensive, affordable databases to maximize efficiency. Upgrading traditional systems with flexible delivery and cutting-edge measurement unlocks their full potential. This tech-savvy approach enhances soil health and crop yields through advanced analytics. It mirrors regenerative farming, improving nutrient retention and stress resistance. The result? Water conservation and a healthier ecosystem, all while optimizing agricultural practices for sustainability and productivity.

Climate change demands smarter farming. Enter data processing systems: game-changers for modern agriculture. These powerful tools rapidly analyze farm information, enabling swift, informed decisions. Now, farmers implement data-driven solutions to boost efficiency and sustainability. From optimizing water use to predicting pest outbreaks, the technology transforms every aspect of farming. As environmental pressures mount, this digital paradigm shift ensures agriculture can adapt and thrive, meeting global food demands while preserving resources for future generations.

Figure 12. Smart data-driven systems

4. Conclusion

Irrigation strategies are widely acknowledged as a crucial adaptive mechanism to combat the far-reaching impacts of climate change. The primary objective of these strategies is to conserve water while maximising crop yields and water productivity, thereby increasing agricultural output per unit of water used. By doing so, irrigation strategies can effectively counter the devastating effects of climate change, such as drought, soil salinisation, and reduced crop yields. To achieve this, irrigation strategies and technologies are employed to manage the volume, rate, and timing of water application, ensuring that it aligns with the water-holding capacity of the soil and its salt levels. These strategies are tailored to specific irrigation methods, cropping patterns, and soil types, and their efficacy is evident in reducing water losses through evaporation and seepage. Moreover, sustainable agricultural water management practices involve improving and repairing the physical infrastructure of irrigation networks, as well as enhancing operational management and maintenance. To ensure the optimal use of limited water resources, it is essential to adopt innovative solutions such as irrigation technologies, vegetation cover, mulching, water tanks, water harvesting systems, and measures to improve water quality. Furthermore, the development of drought-resistant agricultural varieties is critical in addressing the persisting food and water deficits worldwide. The use of computer models, which can calculate soil water balance using irrigation smart systems and observational data, has revolutionised the way irrigation strategies are developed and evaluated, making it possible to create superior irrigation schedules and promoting water-saving practices.

Computer models offer an accessible approach to crafting and assessing irrigation strategies. They compute soil water balance and create optimized watering schedules using weather data and root zone information. A wide array of sophisticated models exists, enabling farmers and researchers to fine-tune irrigation practices efficiently. These digital tools streamline the complex task of balancing water needs across diverse agricultural scenarios.

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CHAPTER 4

SUGAR BEET (BETA VULGARIS L.) CULTIVATION AND PRODUCTION POTENTIAL

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1. Introduction

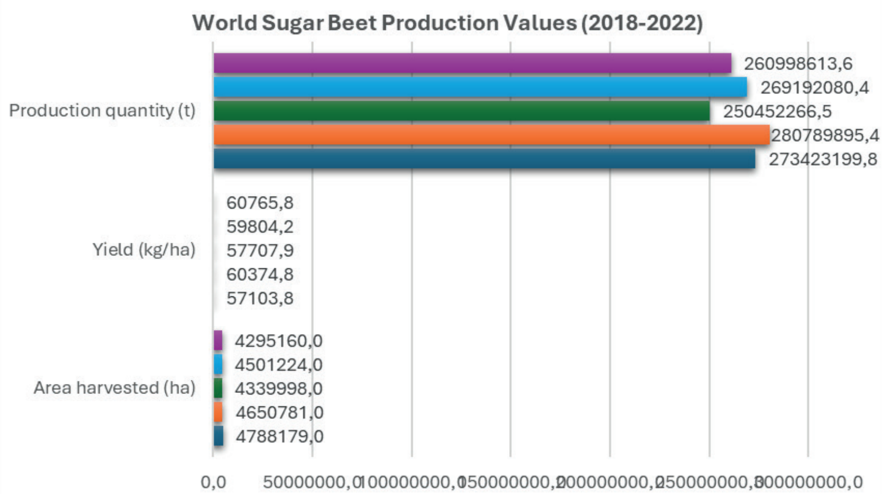
Sugar beet (*Beta vulgaris* L.) is cultivated for the sucrose sweetener, generally referred to as table sugar. Sucrose is a disaccharide consisting of glucose and fructose synthesized in leaf and transported to the rest of the plant (Koch 2004; Ruan 2014; Li et al. 2017). In sugar beet, sucrose accumulates in the main root, whereas in sugarcane, it concentrates in the stem. Sugar cane (*Saccharum officinarum* L.) and sugar beet are significant sources of table sugar in commerce. Sugar beet is the second most significant source of refined table sugar after sugarcane, contributing to approximately 30-40% of global sugar production (Zhang et al. 2016, Ghaffari et al. 2019). In addition to being the driving force of the sugar industry, processed by-products and other residues are utilized to produce food additives, bioethanol, biodegradable plastics, and biofertilizers (Magaña et al. 2011, Ghaffari et al. 2021).

Sugar beet, although a two-year species, has a growth period of 5-6 months when grown as a commercially viable crop. It manufactures and supplies sugar, which can also be processed for industrial use. Sugar beet is an effective energy converter, improving its utilization by both animals and people. It is an agricultural crop developed through selective breeding (Pathak and Kapur, 2013). Although it is a temperate plant, it has expanded from subtropical to tropical regions over time. Above-ground germination is realized in the first year and leads to the emergence of rosettes on the leaves and the accumulation of sucrose in the roots. The plant has 2n=18 chromosomes and is classified as a diploid plant. During the second year, the reproductive phase begins, which utilizes the sugar stored in the roots (Elliott and Weston 1995). Sugar beet plant has several unique characteristics compared to other sugar crops such as sugar cane: (1) it is a salt tolerant plant, able to withstand saline conditions up to 9.5 mhos/cm. (2) it takes up sodium ions, making it more suitable for arid regions. (3) it belongs to C3 plants. (4) cold treatment is vital for flowering. (5) Functions as a two-year crop for seed production and an annual crop for root production. (6) Selective breeding increased the sugar level in roots to 18-20% from as low as 3-4% on a fresh weight basis (Shrivastava et al. 2013).

The primary reason why sugar beet (*Beta vulgaris* L.) holds a leading position in the agricultural policies of our country and many others around the world is its role as an industrial crop. Nearly all of the by-products from sugar beet processing, such as ethanol, bagasse, and molasses, are considered strategic products. Molasses and bagasse are utilized in animal feed formulations and serve as key raw materials in the production of spirits. In addition to these uses, sugar is also a crucial ingredient for various products such as antibiotics, yeast, and bioethanol (Sunulu and Sunulu, 2016).

Sugar beet (*Beta vulgaris* L.) is cultivated between 30 ° south latitude and 60 ° north latitude, and sugar beet is produced in our country because it is located between these belts (Er and Uranbey, 1998). Sugar beet cultivation is an agricultural production that requires more labor force than other cultivated plants. It is not possible to obtain high yields even if the climate and soil conditions are favorable, unless importance is given to processes such as preparation of sugar beet cultivation lands for planting, variety selection, planting time, maintenance and alternation (Doğanay, 2007).

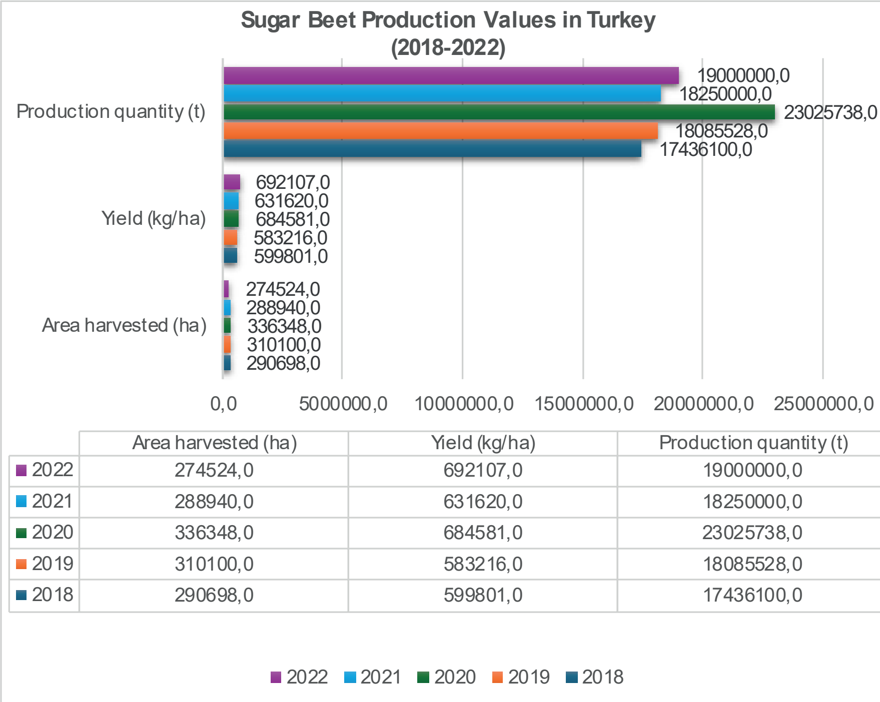
Looking at the world sugar beet production values, 2019 had the highest production amount in five years. In terms of yield average, 2022 was determined as the year in which the highest yield was obtained with 60765.8 kg/ha (Fig. 1). It can be predicted that the yield has shown an increasing trend in recent years and this is due to the acquisition of new varieties, technological advances, better equipped farmers and full utilization of resources.



	Area harvested (ha)	Yield (kg/ha)	Production quantity (t)
2022	4295160,0	60765,8	260998613,6
2021	4501224,0	59804,2	269192080,4
2020	4339998,0	57707,9	250452266,5
2019	4650781,0	60374,8	280789895,4
2018	4788179,0	57103,8	273423199,8

2022 2021 2020 2019 2018

Fig. 1. World Sugar Beet Production Values (2018-2022).



	Area harvested (ha)	Yield (kg/ha)	Production quantity (t)
2022	274524,0	692107,0	19000000,0
2021	288940,0	631620,0	18250000,0
2020	336348,0	684581,0	23025738,0
2019	310100,0	583216,0	18085528,0
2018	290698,0	599801,0	17436100,0

Fig 2. Sugar Beet Production Values in Turkey (2018-2022)

If we consider sugar beet production values on the basis of our country, the harvested area has varied over the years, and the highest average value came to the fore in 2020 with an area of 33634.0 ha. Yield has shown an increasing trend over the years. The highest yield was obtained in 2022 with 692107.0 kg/da. Although sugar beet production has fluctuated in recent years in our country, it is seen that it has reached the highest levels in terms of yield (Fig. 2).

In order to obtain high yields in sugar beet agriculture, it is necessary to know the climate requirements of the plant, its soil requirements, which crops it is in crop rotation with, as well as the timely and appropriate doses of plant nutrients needed by the plant during the growing season, which variety will be better adapted to the region, as well as the procedures to be carried out from planting to harvest at the right time and with appropriate techniques.

2. Climate and Soil Requirements

Sugar beet is an agricultural crop which can be cultivated in various climatic zones between latitudes 30 south and 60 north. It has no specific climate requirements and can be grown in environmental conditions ranging from misty, wet European climates to sunny continental climates. Severe environmental factors encountered during the growing period can negatively impact the growth and development of the plant.

During the growth process of sugar beet, the variation of sunny and cloudy days positively influences the beet yield. Specifically, the continuity of sunny weather conditions boosts the sugar content in the beet, while cloudy and overcast weather leads to a reduction in sugar content (Arıoğlu, 2014).

Sugar beet can be cultivated on most types of soil, except for excessively wet, poorly drained, stony soils, and dense clay soils, where soil preparation and harvesting are difficult. Sugar beet does not flourish in highly acidic soils. Soils with a pH range of 6.0-8.0 are ideal for its growth; however, it can also thrive in soils with a pH of up to 9.5 or in areas with high salinity (Rahman et al., 2006). Soil hardening during the germination stage prevents the roots from penetrating deeper, leading to the formation of forked roots and lowered yields. Loamy and sandy loam soils, rich in organic matter and well-drained, are considered the optimal growing conditions for sugar beet (Rahman et al., 2006).

3. Crop Rotation

Since the planting method of sugar beet is based on rotation, it has transformed what used to be a single species planting system into a multi-species planting system. Sugar beet is the pioneer of planned agricultural production, rotation and agricultural inputs in Turkey. Rotational planting of this crop increases the productivity of other crops planted after it. For example, when wheat is planted after sugar beet, wheat yields increase by about 20%.

In addition, sugar beet, also known as hoe plant, ensures that tillage operations are carried out regularly, contributes to the development of these areas by encouraging inputs such as irrigation, plant protection, fertilization and mechanization, and establishes the crop rotation habit as it is planted in accordance with the rotation system (Turhan 1991; Kara 2011).

4. Nutrient Requirements and Fertilization

Sugar beet plants take a large amount of nutrients from the soil during the growth process. According to researches, when 4 tons of stem and 2 tons of leaf products are obtained from a decare, 15 kg of nitrogen (N), 6 kg of phosphorus pentoxide (P_2O_5), 18 kg of potassium oxide (K_2O) and 8 kg of calcium oxide (CaO) are taken by the plants from a decare of land (İncekara, 1965).

The plant nutrients needed by sugar beet must be met on time by fertilization; otherwise the expected high yield cannot be obtained. In order to create an effective fertilization program in sugar beet, soil analysis is absolutely necessary. Soil analysis should be done every year for nitrogen fertilizer and every 3-4 years for potash and phosphorus fertilization.

A comprehensive fertilization strategy should be planned in advance by evaluating the nutrient content of the soil so that fertilizer amounts can be adjusted accordingly (Draycott and Christenson, 2003). Approximately 50% of certain elements like potassium, phosphorus, and nitrogen should be applied prior to planting, with the remaining nitrogen applied once the young plants have developed four to eight true leaves. Boron, among the micronutrients, plays a crucial role in the growth of sugar beet; it helps in cell wall formation, carbohydrate metabolism and participates in the movement of sugar.

According to the results of Dordas et al. (2007), average seed weight, number of seeds per plant, and seed yield per plant improved after foliar boron application. They also noticed fewer malformed plants. Typically, this element is applied during the 4-6 or 6-8 leaf stages (Kockelmann et al., 2010).

5. Variety Selection and Seed

Sugar beet, a two-year plant, develops its root body below the soil and leaves above the soil in the first year. In the second year, it undergoes vernalization and produces stems, branches, flowers and seeds (Er and Uranbey, 1998). In seed sugar beet production, a two-stage production method is applied in order to shorten this two-year process. In the first stage, seedlings of parental lines are grown to create hybrid varieties, and in the second stage, these seedlings are surprised and seed production is realized (Arıoğlu, 1998).

The first condition for obtaining high yield and quality products in sugar beet farming is the selection of the right variety. However, the concepts of "good variety" and "good seed" should not be confused. The characteristics sought in varieties for high beet production in terms of yield and quality can be listed as follows:

a. High root and leaf yield,

b. High sugar content,

c. Low Na, K and α-amino nitrogen content,

d. High purity Usare rate,

e. Easy processability,

f. Resistance to stubbornness,

g. Resistance to diseases and pests,

h. High monogerm rate,

ı. Suitability for machine harvesting.

Sugar beet seed should have the following characteristics depending on whether it is monogerm or multigerm:

a) Seed must be clean and not mixed with other varieties,

b) The seed should be fresh and plump,

c) It should be well ripe and have the typical seed color,

d) The moisture content of the seed must be below 15%,

e) The germination rate of the seed must be above 75%,

f) Necessary treatment and spraying against diseases and pests must have been carried out,

g) Monogerm seeds should be calibrated (naked) between 3.25-4.50 mm (Arıoğlu, 2014).

6. Tillage and Seedbed Preparation

Soil tillage is the preparation of a field using agricultural machinery in accordance with the specific requirements of the crop to be grown. It includes mechanized tasks performed with the objectives of seedbed preparing, weed management, providing a proper environment for plant growth, and minimizing erosion, as well as diseases and pests. Soil tillage operations are broadly classified into four categories:

- Turning the soil over (double plowing),
- Loosening the soil (rakes and cultivators) without turning it over,
- Tillage by stirring the soil (rotary tillers),
- Pressing the substrate for leveling and compaction ("land rollers").

Improper, untimely or excessive tillage practices can lead to deterioration of soil properties, wasting both time as well as energy. In sugar beet cultivation, the impact of pre-planting soil treatments on productivity can be up to 70% (Bee et al. 2004). Among the tools and machines suitable for tillage operations are the following:

- Equipment for heavy disc harrows
- Wide blade plows
- rotovators, inter-row cultivator
- Chisel plow
- Cylinder

In our country, sugar beet production is realized in irrigated and dry areas. Therefore, tillage practices differ depending on the growing conditions. In rainy and irrigated areas, the first tillage is done by turning the soil upside down with a plow. The area to be planted with sugar beet is cultivated to a depth of 20-25 cm with a plow in the fall, depending on the condition of the pre-plant. If there is an opportunity in the fall, it is useful to do one more tillage. However, unnecessary over tillage in the fall should be avoided.

In arid regions, the soil does not need to be turned over with a plow. It is sufficient to cultivate the soil with plow-like tools. For this purpose, cultivator type equipment should be used and the soil should be cultivated in the fall without turning over. The field, which has been cultivated in this way over the winter, is prepared for sowing in the spring (between February and April).

In the spring, according to the soil's condition, the field is mixed with a cultivator. Base fertilizers are spread and then the soil is thoroughly crumbled with a disc harrow. After this process, a roller or tapan is pulled to prepare the seedbed properly and the field is ready for planting. In spring, unnecessary tillage should be avoided. Otherwise, the soil structure will deteriorate and moisture loss will occur. The plow should never be used in spring plowing. In plowing operations, the soil loses moisture and seeds have difficulty in germination. In a well-prepared seedbed, there should be a 2-3 cm layer of loose soil on the top layer, a harder layer underneath and a deeper layer of loose soil.

7. Plant sowing

In sugar beet production, the sowing process is one of the most important agricultural methods that affect the yield and quality of the product to be obtained. It is not possible to obtain maximum yield with a planting that is not done on time and in accordance with technical rules. For this reason, sugar beet planting is a process that requires great care.

The purpose of planting in sugar beet production is to ensure the plant density required for high and high quality root yield and to regulate the vegetation period in the most efficient way, as well as to minimize labor. In order to be successful in sugar beet planting, it is necessary to correctly adjust the planting time, planting method, plant density and planting depth.

Sowing dates refer to the impact of all environmental factors on the growth and yield of crops, which can differ significantly from one region to another. Germination of sugar beet plants is crucial for their development, yield, and root quality. For most crops, phenological progression is closely linked to the accumulation of temperature above a certain threshold or base temperature, beyond which plants exhibit minimal growth. This threshold temperature varies across different plant species (Ash, 1995; Bellin et al., 2007). Sugar beet germinates more quickly when the soil moisture in the seedbed is between 20-23% and air and soil temperatures range from 15-25°C (Khan, 1992; Copeland et al., 2001; Sroller and Svachula, 1990; Spaar et al., 2004).

No matter how high the germination rate of sugar beet seed is, since the sowing is done superficially, the germination rates of the seeds used vary between 42% and 57%. Therefore, this situation should be taken into consideration when determining the amount of seed to be used according to the sowing frequency.

In sugar beet planting in our country, the distance between rows is 45 cm and the distance between rows is 20-25 cm. During sowing, too much seed is used per decare and then the row spacing is adjusted by thinning (the rate of double plants in the field should not be above 10%). Depending on the type of beet seed used, 1000-1100 g/ha of seed is used for multigerm, 800-850 g/ha for technical monogerm seed and 350-400 g/ha for genetic monogerm seed. Since genetic monogerm seed is generally (80%) used in our country, sowing is done at 45x5 cm or 45x8 cm spacing, and then the row spacing is thinned to 20-25 cm. The distance between rows should never fall below 15 cm.

8. Plant Maintenance

Sugar beet plant maintenance includes weed control, irrigation, disease and pest control.

a. **Weed Control**

Weed control is vital for sugar beet to achieve the desired yield and quality because weeds compete with plants and negatively affect yield. Most importantly, failure to control weeds can result in serious yield losses. Seadh et al. reported (2013), different weed flora significantly reduced beet yield, total soluble sugar, sucrose as well as apparent purity (%) in beet juice compared to the control group. In sugar beet fields, 250 weed species were identified, among which 60 species, of which 30% were narrow-leaved and 70% broad-leaved weeds, were identified as important pests (May and Wilson 2006; Bhadra et al. 2020).

However, weed management options in sugar beet vary depending on many factors such as geographical location, planting date, weed species, labor costs, weeding equipment, irrigation conditions.

Cultural measures are taken in weed control. These include crop rotation, mulching and tractor hoeing. At the same time, chemical control is a form of control other than cultural measures.

Weeds that cause problems in sugar beet can be eliminated by hand removal, hoeing and herbicides. In our country, weed problems in sugar beet cultivated areas vary depending on the region. In recent years, the problem of sugar beet weeds has become more and more of a problem in sugar beet cultivated areas. The frass absorbs the sap of the beet plant and prevents its growth and development, which eventually leads to a decrease in beet yield. When frass is detected in the field, it must be eradicated immediately. Otherwise, it spreads rapidly and can cover the whole field (Arıoğlu, 2014).

b. **Irrigation**

Sugar beet has a deep root system that is able to efficiently draw water from the soil. Sugar beet yields are reduced in both extreme circumstances, under water stagnation as well as drought. In drought conditions or rainfall-based agriculture, the amount of water available to plants is very limited, leading to poor plant development and yield loss. When water stagnates in the field, aeration problems arise and this leads to a greater threat of disease, resulting in poor crop growth and yield loss.

A shortage of water during the initial growth phase leads to a substantial decline in sugar beet production (Abdollahian-Noghabi, 1999). Generally, the volume of water absorbed by sugar beet constitutes about 1% of the total water evaporated throughout the growing period. In these circumstances, irrigation can be regarded as a substitute for water lost through evaporation from the plant and soil.

Sugar beet crops are sensitive to water shortage during germination and the first 3-4 weeks following emergence, particularly when rainfall is inadequate. When precipitation is delayed and irrigation is insufficient, achieving optimal yields becomes challenging, and yield reductions are comparable to those caused by late planting (Hassanli et al., 2010).

Sugar beet produces significant amounts of dry matter under appropriate climatic conditions, mainly when adequate rainfall as well as irrigation is present. Beetroot daily water use varies between 1.1-1.5 m^3 during the leaf growth stage, 5.6-8.2 m^3 during root development and 6.1-6.8 m^3 during the sugar storage stage. As the average daily temperature increases by 1°C, these values increase by 2.5-3 m^3 per day (Tortopoğlu, 1994; Vazifedousta et al., 2008).

Sugar beet water consumption is highest in June, July and August and the plant is susceptible to water scarcity during these months. Irrigation can begin during these periods, along with thinning-weeding and the application of remaining nitrogen fertilizer. Because of the high water holding capacity of clay or heavy textured soils, the frequency of irrigation is naturally lower compared to lighter soils. Daytime irrigation should be avoided to minimize water loss and enhance productivity. Depending on soil structure and rainfall, 20-80 mm of water should be applied at 10-15 day intervals in July and August for high yield and quality (Carlson and Bauder, 2020; FAO, 2020).

c. **Disease and Pest Control**

Plants interact with microorganisms in their surroundings. Various microorganisms can be colonized on plants and form a variety of relationships that can be mutualistic (mutually beneficial), neutral (no benefit or harm) or pathogenic (harmful) (Compant et al., 2010; Raaijmakers et al., 2009).

Sugar beet (Beta vulgaris L.) is usually grown in agriculture to produce sucrose, which is stored in the roots (Trebbi and McGrath, 2004). As with other agricultural products, one of the most important factors affecting sugar beet production is plant density per unit area. In order to achieve a root yield of 60-70 tons per hectare, a plant number between 72,000 and 96,000 plants per hectare is ideal (Pervin and Islam, 2015). Nevertheless, various fungal pathogens can negatively affect this plant density and diseases such as damping-off diseases, especially at the seedling stage, can cause significant economic losses at all stages of plant development.

Important diseases seen in sugar beet; Cercospora Leaf Spot-(CLS), Ramularia Leaf Spot-(RLS), Alternaria Leaf Spot-(ALS), Phoma leaf spot disease (PLS), Rust Disease (Uromyces beticola), Powdery mildew disease, Bacterial leaf spot/blight disease, Beet curly top virus (BCTV), Sugar beet yellows virus (BYV), Seedling diseases (Seedling collapse diseases), Rhizoctonia root and crown rot, Wet rot of sugar beet roots, Sclerotium root rot, Fusarium root rot, Charcoal rot, Tuberculosis disease (Xanthomona beticola-Tuberculosis Disease), Crown Gall, Root soft rot disease (Erwinia carotovora subsp betavasculorum-Root Soft Rot Disease), Rhizomania

Important pests are Sugar Beet; Moth (*Scrobipalpa ocellatella*), Leafworms, Greyworms (*Agrotis ipsilon* and *A. segetum*), Shield Bugs (*Cassida* spp.), Hairy Caterpillar (*Spilosoma obliqua*), Millipedes (*Blaniulus spp.*), Sugar Beet Telkworms, Sugar Beet Springworms, Sugar Beet Rootworm (*Tetanops myopaeformis*), June Beetle (*Phyllophaga* sp. and *Lachnostema* sp.), Root Aphids (*Pemfigus populivenae*), Sugar Beet Cyst Nematode (*Heterodera schachtii*), Root-knot nematodes (*Meloidogyne* spp.).

An integrated approach is needed to control diseases and pests in sugar beet. This approach involves a combination of several methods:

Integrated Pest Management (IPM): Pests and diseases can be controlled through a combination of chemical, biological and cultural methods.

Biological Control: The use of natural enemies (e.g. fungi, bacteria) can help prevent the spread of diseases.

Cultural Measures: Cultural practices such as soil cultivation, proper irrigation techniques and crop rotation can help prevent the spread of diseases.

Chemical Control: When diseases reach serious levels, appropriate pesticides and fungicides can be used. However, care should be taken not to disturb the natural balance of these chemicals.

However, practices such as mixed cropping and crop rotation improve soil health, while the use of resistant and local varieties increases the resilience of agricultural systems. At the same time, the release and conservation of natural enemies (predators and parasites) supports the biological balance in the ecosystem. Optimizing the timing of sowing and harvesting maintains plant health, while weed control reduces crop competition and increases productivity. Proper application of irrigation and fertilization techniques ensures that plants receive the nutrients they need efficiently. In addition, using environmentally friendly pesticides that protect natural enemies and minimize the side effects of chemical pesticides is an important part of an integrated pest management (IPM) system. Such sustainable practices minimize pest impacts while ensuring biodiversity conservation and the long-term health of agro-ecosystems. Thus, human health, environmental health and soil fertility are prioritized and ecological balance is maintained (Gu et al., 2008; Scherr and McNeely, 2008; Mousa and Ueno, 2019).

9. Harvesting

Sugar beet prefers a moderate, humid environment with dry, sunny spells just before harvesting. In its first year of growth, sugar beet produces sugar and stores it in its root, which is nearly fully buried in the soil and ranges in length from 15 cm to 35 cm. It is gathered after the first year. If the growth cycle is allowed to continue, it enters the reproductive phase and the following year, it uses all the sugar stored in the stem to produce seeds. Therefore, it is planted in spring and harvested in the fall or early winter. Sugar beet plays a crucial role in crop rotation cycles. In industrialized countries, sugar beet is harvested mechanically. A single machine equipped with a "topper" or "defoliator" at the front and a "lifter" at the rear performs several tasks. A soil cleaning machine removes dirt from the sugar beet before it is transferred to the processing plant. Shipping sugar beets is challenging and needs to be done quickly because the sugar content decreases rapidly after the beets are uprooted. Sugar processing plants operate continuously for between two and three months after harvest. Sugar beet harvesting takes about three months. For every ton of sugar beet, between 20% and 30% waste is produced, whereas less than 5% waste is generated for every ton of sugar cane (Handbook, 2009).

During the sugar beet harvest, mechanical damage and root breakage occur when loading onto transport vehicles after harvest and during unloading by beet unloading machines at reception centers. Losses in sugar beets begin during the dismantling stage and continue until processing at the factory. The main losses during sugar beet harvesting and post-harvest operations (cleaning, loading, unloading) are surface injuries on the root, root fractures, and cracks on the surface of the beet. In beet harvesting, deep cutting of the head and root breakage, leaving parts behind in the soil, cause the greatest losses (Çolak, 2007).

10. Siloing

Beet ensiling is very difficult due to its high water content. The internal temperature of the silo rises with the increase in air temperature and the respiration rate accelerates. In windy and low humidity weather, the beet in the silo loses water and wilts, leading to weight and sugar losses (Kenter and

Hoffmann 2009; Kleuker and Hoffmann 2022; Schnepel and Hoffmann 2014).

Factors affecting silo losses in beets include genetic traits, ensiling conditions, length of ensiling period, injuries during harvest, rotting, pathogen attacks and respiration rate, and climatic conditions during the ensiling period (Al-Jbawi et al. 2015; Kleuker and Hoffmann 2022; Schnepel and Hoffmann 2014; Schnepel and Hoffmann 2016). If the head of the beet is not cut properly and remains leafy, respiration continues and this causes yield loss (Arıoğlu 2014). In silos, the highest number of diseases are detected in beets with injuries on the root stems, followed by beets with heads that are not cut properly (Sürel and Boyraz 2009).

Environmental factors are very important for the successful storage of sugar beet, with temperature and humidity being the main ones. Storage conditions play a critical role in minimizing losses; the ideal temperature range should be between 4-6 °C and humidity between 95-98%. In sugar beet, at 2 °C, in an atmosphere of 6% CO_2 and 5% O_2, bacterial and fungal growth and root germination are inhibited and sucrose and raffinose formation is stopped. By rapidly reducing the harvested beet to the appropriate temperature range without cold damage, the respiration rate is slowed down and microbial activities can be delayed (Batu 2002).

It may not be possible to process all of the sugar beets harvested every day. In order to preserve the physical and chemical properties of the harvested beet and to minimize damage, the beet must be stored in piles at the reception centers. This process is known as siloing and the stacks are called silos. Siloing is of great importance for the sugar industry. For this reason, depending on the factory capacity and the amount of beet, the campaign starts in September and continues until the end of January.

Before general dismantling, factories have the capacity to process only small beet silos per day. After the general dismantling starts, all beets are taken from the farmers and stored and processed in silos. Bilgin (1974) stated that 50-70% of the harvested beet can be processed after waiting in silos for 30 to 100 days, during which time silo losses occur due to respiration, evaporation and decay (Özcan K, 2018).

Akınerdem (2003) stated that the sugar loss of beets in a silo varies according to the position of the beet in the silo, and the loss rate can be up to 40% in beets in the edge regions. Considering that the ratio of beet to total beet on the surface of a silo is 17% on average, it is emphasized that losses will decrease with the reduction of the silo surface and significant losses can be experienced in short-term siloing in the field, so beets should be transported quickly to places where long-term siloing is done.

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CHAPTER 5

MULTISPECTRAL CAMERA INTEGRATION IN UNMANNED AERIAL VEHICLES AND FORESTRY APPLICATIONS

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INTRODUCTION

In an era of accelerating demand and consumption, the depletion of our natural resources is occurring at an alarming rate. Consequently, the sustainable management of the environment and natural resources is becoming an increasingly crucial and indispensable aspect. Forests represent a significant natural resource. A forest is defined as a natural ecosystem comprising trees and other flora and fauna, in addition to soil, water, climate, and other environmental factors, both living and non-living.

Forests are a natural resource that provides humanity with a multitude of economic, ecological, and socio-cultural benefits. These include food, fuel, shelter, clean air and water, medicine, income, employment, recreation, and landscapes. Forests play a pivotal role in the conservation of biodiversity and the mitigation of global climate change. The monitoring of forest areas, the prevention of fires, the preservation of biodiversity, and the implementation of sustainable forest management are of paramount importance.In light of these developments, the protection and monitoring of forests has become a matter of increasing urgency. Developed countries have implemented a range of technological solutions to enhance the efficiency of forest monitoring and management activities. While traditional methods rely on direct observation, advanced techniques employ remote sensing systems.

In the present era, remote sensing represents a dependable avenue for the acquisition of data pertinent to the monitoring of forest ecosystems. The utilisation of diverse remote sensing methodologies is on the rise. Contemporary remote sensing technologies furnish sophisticated instruments for the observation of forest health, thereby establishing a foundation for sustainable forest management and protection.

The utilisation of satellite imagery is a common practice in remote sensing studies. However, due to inherent limitations such as the inability of satellites to capture images from a specific location at all times and the sampling intervals employed, these studies often prove inadequate when high temporal and spatial resolution, precision and accuracy are required.

Fieldwork constitutes the foundation of forestry studies. During fieldwork, a number of challenges, including topography, vegetation cover and road networks, present significant obstacles. To overcome these challenges, photogrammetry and remote sensing methods are employed. Unmanned aerial vehicles (UAVs) equipped with multispectral cameras are highly effective in providing the data required for these methods.

Unmanned aerial vehicles (UAVs) are typically well-suited for rapid data collection over limited areas and for cost-effective, precise mapping, making them adaptable for diverse applications (Ahmad et al., 2013). The utilisation of

UAV-based spectral imaging presents considerable benefits in high-resolution remote sensing applications. Nevertheless, the number of sensors that can be mounted on a UAV is constrained, and the selection of the optimal combination of spectral bands is a challenging yet pivotal process for traditional UAV-based multispectral imaging systems (Ishida et al., 2018).The spectral range, spatial, and temporal resolution of UAVs are significantly affected (Peña et al., 2015). The use of UAVs equipped with small thermal or spectral sensors has emerged as a promising alternative for modeling, mapping and monitoring of rangeland and forestry applications. (Salamí et al., 2014).

Unmanned aerial vehicles (UAVs) have become a popular and versatile platform for acquiring high-quality aerial images (Christensen, 2015; Otero et al., 2018). In comparison to traditional aircraft and satellite research techniques, unmanned aerial vehicles (UAVs) are capable of operating at significantly lower altitudes, enabling the capture of ultra-high spatial resolution images (Torresan et al., 2017; Goodbody et al., 2017). UAV products frequently utilise cm-level resolution and are characterised by high accuracy (Colomina et al., 2017).

In recent years, the utilisation UAV's in forestry has increased exponentially because of the advantages they offer, including low cost, repeatability and flexibility. This is particularly evident in tasks such as predicting forest inventory parameters. Furthermore, they are employed in the monitoring of forest change and recovery (Wallace et al., 2012; Panagiotidis et al., 2017; Wallace et al., 2012; Zahawi et al., 2015).

Unmanned aerial vehicles (UAVs) facilitate the acquisition of multi-temporal and high-spatial-resolution images on demand. Furthermore, photogrammetric point clouds derived from UAV images are characterised by high detail and accuracy (Saarinen et al., 2018; White et al., 2015; Goodbody et al., 2018). The combination of low cost, flexibility and repeatability has led to a rapid increase in the use of UAVs in forestry in recent years.

This study aims to examine the use of multi-band cameras on UAV' and their applications in forestry from a broad perspective. The second section of the study presents an overview of the concepts of UAVs and multi-band cameras. The third section discusses the use of UAVs with multi-band cameras in forestry applications. The final section presents a discussion of the results of the study.

UAV AND MULTISPECTRAL CAMERA

An unmanned aerial vehicle (UAV) can be defined as an aircraft comprising integrated systems that are remotely or autonomously pilotable without the presence of a human operator on board. The UAV is capable of communicating with an operator who controls it and transmitting images captured by the vehicle, along with information regarding its position, speed, altitude, and other pertinent data to a designated location. Additionally, the UAV is equipped with the capacity to transmit data such as remaining fuel or battery level, engine temperature, air temperature, wind direction, and speed (Kule, 2015).

Unmanned aerial vehicles (UAVs) can vary in size, shape, and weight depending on their intended mission capabilities and objectives. While they typically carry cameras as sensing systems, they can also be equipped with a variety of sensors that allow them to perform different measurements (Avdan et al., 2014).

As is the case with the majority of technological developments, the creation of unmanned aerial vehicles (UAVs) was initially driven by military necessity (Alptekin et al., 2020; Cömert et al., 2021). The deployment of UAVs in civil contexts and scientific research has facilitated significant advances in their operational capabilities (Doğan and Yakar, 2018).

The advent of technological progress has given rise to a new branch of photogrammetry, namely UAV photogrammetry. This term defines a photogrammetric measurement platform that is controlled remotely or semi-autonomously. The technology in question works with platforms equipped with photogrammetric measurement systems, small to medium-sized camera systems, and includes thermal and infrared cameras as well as lidar systems (Eisenbeiss, 2009). The advancement of unmanned aerial vehicle (UAV) technology has been accelerated by the miniaturisation and development of cameras that can be mounted on these devices. UAV technology, which makes temporal resolution and high spatial more feasible, provides advantages for agricultural and forestry applications that require high-resolution imagery (Zhang and Kovacs, 2012; Matese et al., 2015).

Unmanned aerial vehicle (UAV) systems have become increasingly prevalent in a multitude of fields in recent years. The integration of high-performance cameras into UAVs has enabled the collection of data even in challenging conditions. These cameras can encompass a range of capabilities, including visible light, multispectral, thermal, oblique, optical zoom, and web cameras (Cilek et al., 2020; Villi et al, 2022). This study focuses on multispectral cameras, which are specialised cameras that can capture images in different wavelengths (red, blue, green, red edge, and near-infrared). In contrast to traditional cameras, multispectral cameras are capable of collecting information in a range of wavelengths, thereby revealing details that are not visible to the naked eye. They provide cost-effective, high spectral resolution. The integration of these cameras into UAVs offers numerous advantages in forestry applications.

The multispectral Parrot Sequoia camera generates four 1.2-megapixel images at the following wavelengths: and near-infrared (NIR) (790 nm), red edge (735 nm), red (660 nm) and green (550 nm) (Parrot Drone SAS, Paris, France) (Parrot, 2019). The MicaSense RedEdge-M sensor produces five 1.2-megapixel images at the following wavelengths: NIR (840 nm), red edge (717 nm), red (668 nm), green (560 nm) and blue (475 nm) (MicaSense, Inc., Seattle, WA, USA).

Figure 1. Parrot Sequoia multispektral camera system and Spectral bands: blue, green, red, red edge, near- infrared (Url-1).

The low error rate of images obtained with multispectral cameras reduces the error rate of subsequent analyses. Therefore, it is of the utmost importance to perform the requisite calibrations and adjustments correctly before commencing the capture of images with a multispectral camera.

The Parrot Sequoia multispectral camera system is comprised of two distinct components (Figure 1). The initial component is a camera apparatus comprising four distinct spectral bands and an RGB sensor, which captures images utilising a synchronised global shutter system. The subsequent element is a sunlight sensor integrated with the camera. This sensor is situated on the superior aspect of the device and captures and records the light emanating directly from the sun, adjusting for the prevailing lighting conditions, and automatically calibrates the camera outputs for absolute measurements. This guarantees that the multispectral images produced by the camera have high radiometric resolution and accuracy.

The MicaSense RedEdge multispectral camera is equipped with a GPS receiver, light sensor, and IMU sensors, all of which require calibration for direction and angle in an environment free of magnetic interference (Figure 2). Furthermore, as the camera captures images in five different bands, irradiance calibration must be conducted for each band. To achieve this, calibration images should be taken during times when the sun is directly overhead, utilising a reflectance panel.

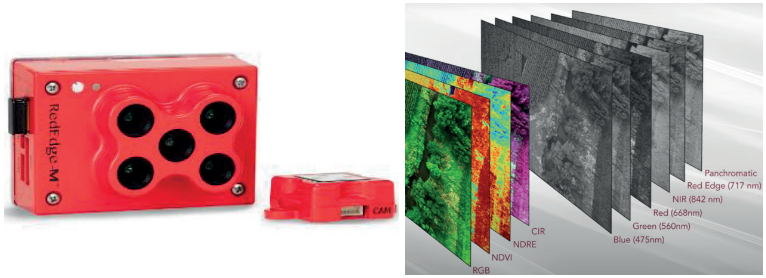

Figure 2. Micasence RedEdge- M camera system and Spectral bands: blue, green, red, red edge, near- infrared (Url-2).

UAV-BASED MULTISPECTRAL CAMERAS AND FORESTRY APPLICATIONS

Forests are of vital importance to global ecosystems, and their role in reducing the negative impacts of climate change is significant. They provide natural habitats for a great many animal and plant species, act as important carbon sinks, and support effective hydrological cycles. Unmanned aerial vehicles (UAVs) have emerged as a valuable data source with potential applications in a range of forest management scenarios. To date, studies have employed the use of UAVs and multispectral cameras for the assessment of forest health. UAV-based multispectral images have been employed to identify detect tree crowns, individual tree species and predict the structural characteristics of forests (Salo et al., 2012,Gini et al., 2014; Puliti et al., 2017; Dempewolf et al., 2017).

In a study conducted by Melin et al. (2017), it was demonstrated that the utilisation of spectral images with geometric accuracy and spatial resolution had a beneficial impact on the prediction of the structural characteristics of forests.

In a study executed by Goodbody et al. (2018), a number of (UAV)-based spectral indices (including the GLI,NDVI and GRVI) were employed to forecast the cumulative leaf drop in a northern forest. The findings stated that spectral measurements demonstrated a superior capacity to predict cumulative leaf drop in comparison to structural measurements. The root mean square error (rRMSE) for spectral measurements was 14.5%, whereas that for structural measurements was 21.5%.

In a pioneering study, Lehmann et al. (2015) employed unmanned aerial vehicles (UAVs) to assess insect infestation levels in forest ecosystems. Utilising multispectral images and object-based image analysis, the researchers were able to effectively detect infestations in oak forests.

Näsi et al. (2015) pioneered the use of UAV-based multispectral imagery for the identification of distinct infestation stages of the European spruce bark beetle (Ips typographus L.). The UAV data were collected at an altitude of 100 m above ground level with a ground sampling distance (GSD) of 10 cm using a multispectral camera.

In a study conducted by Klouček et al. (2019), UAV equipped with CIR and RGB cameras was employed to capture multiband time-series data from a bark beetle outbreak region in the northern Czech Republic. The findings revealed that the UAV-based sensor system yielded valuable insights into the diverse stages of bark beetle infestation across different seasons, including the ability to detect early signs of infestation.

Dash et al. (2017) conducted an experiment in which herbicide was injected into mature plantation trees and time-series multispectral UAV images were used to monitor changes in canopy colour and density. The study confirmed the effectiveness of high-resolution, time-series UAV data in the value of characteristic stress in trees and determined spectral indices.

In a further study by Dash et al. (2017), a controlled experiment was conducted on a mature Pinus radiata plantation to test the accuracy of multispectral image time-series data obtained from UAV platforms and satellite images in detecting herbicide-induced stress.

Multispectral imaging is a valuable tool for monitoring plant vitality and detecting stress conditions. In such studies, data from the red, green, near-infrared, and red edge bands captured by multispectral cameras mounted on UAVs are converted into vegetation indices using different algorithms, which facilitate the straightforward detection of plant health and stress. The most commonly employed vegetation index in remote sensing studies is the NDVI (Rouse et al., 1973). NDVI is also one of the principal indices utilised to examine plant phenological development. Its most common applications include predicting plant water stress, plant health, metabolic processes, as well as determining biomass and crop yield (Berni et al., 2009; Zarco Tejada et al., 2012).

In their 2018 study, Franklin and Ahmed employed multispectral UAV imagery to investigate the classification of deciduous forest species, including trembling aspen (Populus T.) in Canadian hardwood forest.

In challenging terrains, UAVs can be used for wildlife monitoring and detecting, counting, or classifying endemic species. Thapa et al. (2018) used UAVs to detect and count an endangered crocodile species in the Nepal region. They conducted 12 different flights at an altitude of 80 meters with a fixed-wing UAV, collecting a total of 7,708 photos. Their analysis of these images allowed them to calculate the number of endemic species per kilometer.

In their 2009 study, Adam and Mutanga confirmed the significance of the red edge and near-infrared regions of the electromagnetic spectrum in species detection and discrimination. They observed that green leaves exhibit the greatest diversity in these regions and validated the role of the red edge and infrared regions in plant species identification.

In their 2014 study, Somers and Asner employed spectral and temporal data to enhance the spectral separation between tree species present in each pixel. In investigations pertaining to the spectral differentiation of plant species, the red edge spectrum has been identified as a particularly efficacious tool. The red edge spectrum is responsive to vegetation structure parameters, and plants with large leaves and a high Leaf Area Index render the red edge region an optimal choice for species discrimination (Jia et al., 2011).

DISCUSSION AND CONCLUSIONS

Over the past decade, the advancement of UAV technology has led to a significant increase in the utilisation of UAV-based multispectral cameras in a range of civil applications, including forestry activities. The use of UAV-based multispectral cameras has become widespread in forestry operations, including mapping, land use detection, biomass estimation, tree species classification, silvicultural applications, monitoring of tree stress levels, and plant health assessment. These activities can be effectively detected using multispectral cameras mounted on UAVs, which is crucial for increasing efficiency in forestry and for the more effective utilisation of natural resources.

A multispectral camera is a technology that is capable of detecting light at various wavelengths, thereby enabling the identification of different characteristics of objects. One of the most significant advantages of multispectral cameras is their capacity to distinguish between healthy and unhealthy plants by detecting light reflected by plants at different wavelengths. This allows for the more effective detection of tree diseases and the enhancement of productivity in forested areas.

Forests constitute a significant portion of the Earth's terrestrial surface and are frequently situated in mountainous regions, rendering them challenging to traverse on foot due to the prevalence of dense vegetation. The health of trees and forests is threatened by a number of factors, including the presence of harmful insects, fungal diseases and nutrient deficiencies. UAV-based multispectral imaging provides a solution for the monitoring of forest health. This technology allows access to remote areas and enables the early, accurate detection of stress and disease symptoms, which can be monitored using both visible and invisible spectral bands.The utilisation of data from disparate bands, particularly the red-edge band, enables the generation of indices that elucidate the specific chlorophyll concentrations in arboreal specimens and facilitate their comparison over time, due to the high temporal resolution of these sensors.

Insects have the potential to pose a significant threat to forests globally, with the capacity to devastate entire ecosystems if not identified and addressed in a timely manner. The use of traditional methods may prove ineffective in the observation of an infestation in remote regions. It is challenging to quantify the spread and severity of insect infestations in trees through physical observation of the forest. While satellite images can provide a comprehensive overview and identify broad areas of interest, obtaining the detailed information necessary to accurately determine the location and extent of an infestation remains a challenge. Invasive plant species have the potential to alter the ecological balance of the ecosystem they colonise by outcompeting native species. UAV-based multispectral imagery can effectively capture both native and invasive species, providing valuable data on the size and extent of an infestation.

The classification of tree species in forests is a crucial yet challenging task, often requiring significant resources. A multitude of ecological applications, including the designation of conservation status, the monitoring of protected areas, the observation of habitats, and the restoration of damaged ecosystems, necessitate the production of comprehensive forest inventory reports. UAV's equipped with multispectral sensors offer environmentalists and foresters the ability to conduct extensive studies and detect changes over time, whether on a daily, weekly, or monthly basis.

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The issue of reforestation is a primary focus for numerous public forestry organisations and private companies. However, the increasing frequency of uncontrolled wildfires in many parts of the world has highlighted the need for a greater emphasis on reforestation efforts. UAV technology can facilitate not only the improvement of natural vegetation but also the monitoring of the health and successful replanting of young trees. Research on newly planted or rehabilitated areas can assist foresters in monitoring young saplings or determining whether further intervention is necessary, thereby making these efforts more cost-effective and increasing the likelihood of success.

A growing body of evidence suggests that the utilisation of (UAV)-based multispectral cameras is becoming increasingly prevalent, offering significant advantages in terms of time and cost efficiency. While satellites have traditionally been used for large-scale aerial surveys, their resolution has always constituted a limitation. Satellite imagery, which typically provides resolution at the metre level, is difficult to use for field studies that require detailed mapping. However, UAV-based multispectral cameras can offer sub-metre and, depending on the flight altitude and sensor usage, even centimetre-level resolution.

The integration of multispectral cameras into UAV's facilitates expeditious and precise scanning of forested regions, thereby enabling foresters to make more rapid and accurate decisions. With the growing prevalence of UAV technology in forestry, the significance of multispectral cameras is becoming increasingly evident.In the contemporary era, it is evident that forestry practices will become increasingly intertwined with computer science and novel technologies in the forthcoming years. Consequently, there is a pressing need for researchers to engage in more interdisciplinary collaboration.

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CHAPTER 6

EFFECTS OF GLOBAL WARMING AND CLIMATE CHANGE ON WATER RESOURCES

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Introduction

Climate has tended to change throughout the history of the earth. The mentioned change occurred as a result of natural effects until the industrial revolution in 19 th century ; It has been determined that human influence played a significant role in subsequent changes. After the mentioned date, global climate change and the resulting; For example, problems such as environmental pollution, desertification, erosion, marine pollution, extinction of animal and plant species and soil degradation have begun to be experienced intensively. Today, agriculture and water resources are at the forefront of the segments most affected by the problems in question, especially climate change. Emissions of greenhouse gases (CO_2, CH4, N_2O) are the primary cause of global warming.

The emission of these gases, especially CO_2, is important. Accumulations of CO_2 in the atmosphere have been around since 1750.

It increased by 30%. It is predicted that CO_2 accumulation, which was approximately 280 ppmv before the industrial era and 370 ppmv in 1999, will reach 700 ppmv by the end of the 21st century. Anthropogenic CO_2 emissions are to blame for the rise in atmospheric CO_2. The use of fossil fuels is responsible for about 75% of emissions (IPCC, 2008). Increases in greenhouse gas accumulations resulting from human activities and released into the atmosphere weaken the cooling efficiency of the Earth through long-wave heating and cause it to warm further with positive radiative forcing. This positive contribution to the energy balance of the atmosphere is called the greenhouse effect. The magnitude of global warming resulting from the increasing greenhouse effect depends on the increase amount of each greenhouse gas, the thermal properties of the gases, their atmospheric lifetime and the accumulation of other greenhouse gases (Kanber et al. 2007).

Global warming is the term used to describe the increase in temperature on Earth and in the lower atmosphere caused by the natural greenhouse effect being strengthened by urbanization. This is because of the rapid accumulation of greenhouse gases released into the atmosphere by various human activities, such as the burning of fossil fuels, deforestation, and industrial processes (Anonymous, 2005).It is certain that global warming will have significant impacts on water supply, and increased rainfall variability will create significant problems in the agricultural sector. A warmer climate will accelerate the hydrological cycle and increase global amounts of precipitation and evapotranspiration (ET).

Like runoff from mountain snowmelt, the temporal distribution of precipitation may differ from historical patterns. It is clear that some of these changes are already occurring, but their regional effects are not well known. Hydrological uncertainties; This is due to the fact that relatively small changes in precipitation and temperature, especially in arid and semi-arid regions, have rather large effects on both the surface flux and the volume and timing of ET.In short, the outlook for global warming confronts irrigators and society as a whole with significant new uncertainties and problems. All of these factors have created a water demand crisis that is only getting worse (Hoffman and Evans, 2007).

The average weather conditions seen over a long period of time in any location on Earth, along with the temporal distribution of their frequency of occurrence, observed extreme values, severe events, and all forms of variability, are collectively referred to as the climate (Türkes, 2007). In addition to the natural climate change seen during similar time periods, climate change is defined as the change in climate brought about by human activities that either directly or indirectly alter the composition of the global atmosphere (Selçuk, İ. Ş, 2009). Global climate change is the concept that expresses the rapid change of the world climate in a very short period such as the last 15-20 years, as opposed to the long geological periods, by affecting other climate elements such as air movements, precipitation and humidity as a result of global warming (Yönten, 2007).

Natural disasters like hurricanes, floods, and heavy rains will become more frequent and severe in some parts of the world due to climate change. In other parts of the world, there will be severe droughts and the related desertification events. These events will negatively affect entire ecosystems. Most of the time, the concepts of global warming and climate change are used interchangeably; But there is a difference between the two concepts. Climate change refers to variations in seasonal temperature, precipitation, and humidity levels in a particular area, whereas global warming refers to the rise in the average global temperature that may cause climate change. In other words, according to Yamanoğlu (2006), global warming is more about the rise in minimum temperatures than it is about the rise in daily, monthly, and annual maximum temperatures. It has been proven by scientific observations that global temperature increases have occurred in the 21st century, and it is accepted that this warming will cause climate change in a short period of a few decades (Anonymous, 2001a). The doubling of CO_2 in the atmosphere after the industrial revolution indicates that there will be possible climate changes until 2030. The first noticeable change will be temperature increases. It is stated that the warming in surface temperatures increases almost every year compared to the previous year and breaks global temperature records. It is seen that the average global temperature has increased by 0.5-0.8 °C since 1860. Based on the view that the temperature increase in the last 50 years has had noticeable effects on human life, scientists state that the point of no return is approaching.

Reduced water supplies, forest fires, droughts, and related ecological disturbances are all consequences of global warming. Cities will experience water shortages as a result of the decline in river basin annual flows; urban and agricultural water demands will rise. Agriculture will suffer from the depletion of water resources brought on by climate change. The rise in the average annual temperature will accelerate desertification, salinization, and erosion in addition to the growth of arid and semi-arid regions. Seasonal snow and snow cover will cover a smaller area, and the duration of snow cover will be shorter. Water resources, agriculture, transportation, and energy will all suffer from the altered flow time and volume brought on by snowmelt. Furthermore, glacier melting, sea level rise, and climate zone shifts are all consequences of global warming (Türkes et al. 2000).

Global Water Potential

The total surface of the world is 510 million km^2, and approximately 71% of it is covered with water. The total amount of water in the world is 1.4 billion km^3, 97.5% of which is salt water in the oceans and seas and 2.5% is fresh water in rivers and lakes. Since 90% of such scarce fresh water resources are located in the poles and underground, it is understood how small the amount of fresh water that human beings can easily benefit from is (Denhez, 2007). A significant portion of the usable fresh water in the world is necessary for the continuity of ecosystems (Kibaroglu, 2008). Salt water in the seas does not have the qualities to meet the needs of humans, and only 10% of the water on land is classified as usable fresh water. This is 0.3% of the total water potential, or 5 500 km^3. When this value is compared with the annual flow rate of 37 000 km^3 of all rivers, it becomes a significant value of 15%. This result reveals that it will create major problems in meeting the increasing water demand in the future (Küçükklavuz, 2009). Every year, 500 thousand km^3 of water evaporates and mixes with the atmosphere. While the continents lose 70 thousand km^3 of water through evaporation, they receive 110 thousand km^3 of water through precipitation. Approximately 40 km^3 of this precipitation flows through rivers and reaches the seas and lakes in closed basins. Only 9 000 km^3 of this precipitation can be used technically and economically (Koluman, 2003).

Fresh water use occurs in three areas: agriculture, industry and housing, and there is great water competition between sectors. Share of water use in agriculture in the 20th century. While it was 90.5% in the beginning, it decreased to 69% today, and increased to 23% in the industry and energy sectors and 8% in residences (Aytemiz and Kodaman, 2006). 73% of the world's total water consumption is used for irrigation. While irrigated agricultural areas were 253 million hectares in 1995, it is expected to reach 290 million hectares in 2010 and 330 million hectares in 2025 (Ateş, 2008). As a result of population growth, 45 times more water is used today compared to 300 years ago. While total water consumption was 1 000 km^3 in 1940, it doubled in 1960 to 2 000 km^3, doubled again in 1990 to 4 130 km^3, and reached 5 200 km^3 in 2000 (Dündar, 2007). Every year, we use an astounding 4.3 trillion cubic meters of freshwater worldwide. Humanity has already used up more than 2.9 trillion cubic meters of this valuable resource as of the start of 2023. (www.irrigreen.com).

Climate Change's Impact on Water Resources and Water Use Water resources, forest fires, and associated ecological disturbances will all decline as a result of global warming. Throughout the year, there are numerous variations in the flows of rivers, streams, and streams. Natural disasters like droughts and floods are occurring more frequently, and river flow patterns are shifting. Over time, river flows move both forward and backward. Additionally, depending on local precipitation regimes, groundwater recharge rises or falls and stream flows vary greatly. Water requirements will rise and urban water shortages will start as a result of river basins' declining yearly flows. Agriculture will suffer from the depletion of water resources brought on by climate change. The rise in the average annual temperature will speed up desertification, salinization, and erosion in addition to the growth of arid and semi-arid regions. Seasonal snow and snow cover will cover a smaller area, and the duration of snow cover will be shorter. Water resources, agriculture, transportation, and energy will all suffer from the changed flow time and volume brought on by snowmelt. Sea levels will rise, glaciers will melt, and climate zones will shift as a result of global warming. The economy, society, and environment are all significantly and widely impacted by changes in the cycling movement of water between land, sea, and air, which raises concerns about the effects of global warming. For instance, it is evident that the presence of water influences the features of many land and aquatic ecosystems (Şen, 2005).As a result, the quantity and quality of water resources are deteriorating day by day. Although personal demand is falling in some countries, the pressure on available resources is increasing. Accordingly, the goals and processes of water management also change. Water is essential to human life and a variety of activities. Plantations that are used for agricultural production provide the clearest indication of this. However, water is also of vital importance in areas such as industry, electricity generation, transportation and wastewater management. However, the availability of clean water has a positive impact on economic development as well. Changes in precipitation characteristics are the cause of climate change's effects on water resources. The primary cause of temporal and spatial variability in water balance is precipitation. Climate-related changes in precipitation can have significant effects on water resources and hydrology. The daily, seasonal, annual, and decadal cycles of precipitation all have an impact on the hydrological variability that occurs over time in a given water basin. For instance, different versions in short-term rainfall amounts (such as heavy rainfall) and in rainfall intensities from year to year affect the frequency of floods. Moreover, there is compelling evidence that rainfall will generally increase as a consequence of global. Once again, different versions in the seasonal distribution of precipitation are the cause of the frequency of drought. Snowfall decreases with rising This event means that in areas where a very small part of the precipitation falls in the form of snow, there will no longer be any snow. It is clear that the reduction or complete cessation of snowfall will have very important consequences for hydrological cycles. Since one of the most important systems of the hydrological cycle is the atmosphere, it is clear that changes in atmospheric conditions caused by climate change will lead to significant changes in the hydrological processes of basins such as precipitation, evapotranspiration and flow, both in space and time scale. These changes will not only be limited to the current long-term averages, but will also be seen in the frequency, magnitude and spatial distribution of extreme events. Studies on global warming show that climate change will play a restrictive role in water resources (Fıstıkoglu and Biberoglu, 2008).

The hydrogeological cycle, water supplies, and their distribution and management at the local, regional, and global levels are all significantly impacted by climate change. These effects are predicted to develop gradually over many years. Water supply will undoubtedly be significantly impacted by global warming, and the agricultural industry will face serious challenges due to increased rainfall variability. Global precipitation and evapotranspiration (ET) will rise as a result of a warmer climate, which will also speed up the hydrological cycle. In summary, irrigators and society at large face serious new uncertainties and issues related to precipitation as a result of global warming (Kanber et al. 2010). Snowfall decreases with rising temperatures.

Effects of Global Warming and Climate Change on Drought, Precipitation, Underground Water Resources, Soil Moisture, Changes in Snow Cover and Glaciers, Water Quality, Productivity and Quality of Agricultural Products.

Climate Change and Drought Drought and water issues will become apparent as a result of the global temperature rise rise in temperature and drop in precipitation. Drought, defined as a natural phenomenon that causes negative effects on land and water resources and disruption of hydrological balance as a result of rainfall falling significantly below normal recorded levels, has become more complicated with the phenomenon of global warming and climate change. Drought; They classify drought as meteorological, hydrological, agricultural and socio-economic drought (Anonymous, 1997).

Increased evaporation, drought, and erratic rainfall are all consequences of the atmosphere's warming trend. As a result of the decrease of in beneficial rainfall distribution decided to bring on by worldwide, humanity is at risk of experiencing repetitive droughts.With global warming, many countries that are among the water-rich countries will begin to be among the water-poor countries. As water resources gradually dry out, the danger of dehydration will increase. There are several indicators of water supply shortage. This includes the amount of water available per person, the ratio of volume of water potentially available/volume of water withdrawn for use. When withdrawals exceed 20% of total renewable resources, water shortages become a limitation to development. If the volume of water withdrawn exceeds 40% of this amount, there is a big problem. Likewise, if a country or region does not have 1700 m3/year of water per person, there may be a water shortage problem (Falkenmark and Lindh, 1976; Şen, 2005). In order for a country to be considered water rich, it must have an average water potential of 10 000 m^3 per person per year. Countries with a water potential of less than 1000 m^3 are considered water poor countries (Atalık, 2006).

Per capita water consumption in the world is 800 m^3 per year, 1.3 billion people, approximately one-third of the population, live without clean water, and approximately 2 billion people live without adequate and healthy living conditions due to the availability of clean water. 19 countries, most of which are in the Middle East and Africa, are classified as countries experiencing water scarcity or water stress. It is estimated that this number will increase to 5 billion in 2025 due to climate change and population growth. However, even without climate change, increases in demand resulting from population growth and economic growth will cause this number to double by 2025 (Anonymous, 2001b; Babuş, 2005).

In the 1990s, 26 countries with a combined population of 300 million were directly impacted by water scarcity, which has grown to be a major problem (Filinte , 2007; Uzmen, 2007; Ateş, 2008) by 2050, there will be 9.3 billion people on the planet, and 60 countries will experience water scarcity as a result of climate change. By 2025, 60% of the world's population will reside in water-stressed nations that are not affected by climate change, compared to about one-third in 1990 who lived in nations that used more than 20% of their water resources. It can be deduced from variations in river flow. The potential for energy production will change as water resources decline. While the energy production potential of rivers will decrease by 20-50% in the Mediterranean region of Europe in the 2070s, it is predicted to increase by 15-30% in Northern and Eastern Europe (Küçükklavuz, 2009).

Rainfalls

Changes in precipitation characteristics are the cause of climate change's effects on water resources. The primary cause of variations in water balance over time and space is precipitation. Climate-related changes in precipitation can have significant effects on water resources and hydrology. The daily, seasonal, annual, and decadal cycles of precipitation all have an impact on the hydrological variability that takes place over time in a water basin. For instance, variations in short-term rainfall amounts and annual variations in rainfall intensities contribute to the frequency of floods. Additionally, there is proof that as global warming increases, shower frequency will rise. Changes in the seasonal distribution of precipitation also contribute to the frequency of Increasing temperatures cause snowfall to decrease. It is clear that a decrease or complete cessation of snowfall will have important consequences for hydrological cycles.

The distribution of precipitation is altered by climate change. Different regions of the world and seasons exhibit distinct distributions of precipitation. Precipitation falls in tropical and sub-tropical areas of both hemispheres during the fall and winter months, but it rises in the middle and high latitudes of the Northern Hemisphere. Some equatorial regions near the pole and Southeast Asia are predicted to experience the biggest changes in precipitation on land as a result of climate change. R. (Kanber et al. 2010). The world will become more humid as a result of more water evaporating from seas and oceans due to global warming. There will be more precipitation as a result. Over the past century, the amount of precipitation that falls on the continents has increased by 1%. (Denhez, 2007). It has been estimated that during the 20th century, precipitation on the continents in the middle and higher latitudes increased by 5–10%. The frequency of heavy rainfall increased by 2–4%. However, there was a 3% decrease in precipitation that fell on land in subtropical regions. (Marda. and Şahin, 2007). Specifically, precipitation decreased in some Mediterranean and north and west African countries. In certain continents, like Asia and Africa, the severity of heat and drought has increased during the past ten years. (Aksay et al. 2005). Surface Flow; Climate change has caused potential changes on surface runoff, and as a result, floods and droughts have occurred. Due to the risky trends emerging in hydrological data, it can be said that the flow changes that occur from year to year are due to changes in precipitation rather than changes in temperature.

Underground Water Supplies In rural areas, particularly in arid and semi-arid regions, groundwater serves as the primary source of utility and drinking water. Rainfall, rivers, and lakes all contribute to the aquifer's nutrition. It has long been known that variations in precipitation, not variations in temperature, are the cause of the flow variations that take place from year to year. Coastal aquifers will experience salt water intrusion due to sea level rise. The groundwater's hydraulic gradient determines how much of this interference there is. The most vulnerable are shallow coastal aquifers. The volume of collectable water has decreased due to the decrease in precipitation brought on by sea level rise, which will also result (Amadoreet al 1996 ; Şen, 2005).

The moisture content of soil For agriculture, soil moisture storage is essential, and the rate of evaporation also affects the production of surface runoff water and the feeding of groundwater. Both the rate of climate change and the characteristics of the soil influence the observed local impacts of global warming on soil moisture. Potential variations in the soil moisture gap will depend on the soil's ability to retain water. The sensitivity to climate change is high when the capacity is low. Through water absorption or cracking properties, climate change can also impact soil properties, revealing the soil's capacity to store moisture. These facts reveal the moisture storage properties of the soil. The infiltration and water retention capacity of many soil types is affected by the frequency and intensity of frost (Şen, Z, 2005).

Changes in Snow Cover and Glaciers

From high mountain peaks to continental ice fields, the world's glaciers are melting quickly. Glaciers are extremely sensitive to changes in the climate system, which has a big effect on how the climate system is balanced. Glaciers, ice sheets, and permafrost are melting as a result of rising temperatures brought on by global warming. Over the past 50 years, the Arctic's sea ice has gotten much thinner, and in the last 30 years, its area has shrunk by 10%. By 2100, sea ice in the North Pole is predicted to drop by 22–33%. (Babuş, 2005).

Sea Level

In addition to causing soil loss, sea level rise also causes clean water resources close to the coast to merge with the sea, causing major changes to coastlines. Numerous factors influence it, most notably the rise in temperature, the type and volume of precipitation, and the melting of sea ice. The concentrations of these gases in the atmosphere have changed due to greenhouse gas emissions. It is anticipated that the rise in global temperature during the same time period will contribute significantly to sea level rise. The 20th century saw a higher sea level rise than the 19th century, by 0.1 to 0.2 meters. By 2100, sea levels are expected to rise by 50 cm. (Türkeş et. al 2000; Anonymous, 2001b).

Water Quality

Both the amount and quality of water resources will be impacted by climate change and global warming. Water quality issues will worsen as temperatures rise because declining precipitation and flows will result in higher pollution concentrations (Küçükklavuz, 2009). Water quality is under pressure from drought and heavy precipitation. Higher concentrations of pollutants, particularly from factories, will result from streams and lakes having less water during dry months. As a result, the quality of the water will decline. Less oxygen is present in warmer water. One of the most significant factors influencing the quality of water, the drop in dissolved oxygen levels, causes major pollution issues. In addition to lowering dissolved oxygen concentrations, warmer water promotes the growth of algal blooms, which use oxygen as they decompose. The temperature of river water rises marginally less than that of the air. Basins that contribute significant amounts of ground water experience the smallest increases. The temperature of the water has a significant impact on chemical and biological processes. Higher temperatures, however, will cause the concentration of some chemical species to rise while that of others will fall. However, the water's chemical load is contingent upon its arrival at the riverbed. For instance, because of the soil and other contaminants it carries, the water quality entering a dam lake during floods is relatively poor. It should be remembered that issues with water quality brought on by changing climate conditions will have a significant negative impact on human health and raise the demand for water treatment, which will result in financial burdens. (Albek, 2007). As the capacity and reserves of water basins will decrease with global warming, it will cause environmental pollution to increase (Galip, 2006). Reduced water availability will cause agricultural regions to become more salinized and barren, and the overuse of pesticides and fertilizers to increase productivity will increase soil and water pollution. (Öztürk, 2002).

Productivity and Quality of Agricultural Products

Global warming may affect the living and breeding areas of many living things. In some areas, vegetation may decrease due to drought. This will have serious consequences in terms of economic losses (Albek, 2007). Agricultural inputs are the element most affected by climate change. Changing climate can change agricultural practices. The impact of global warming on agriculture will manifest itself through changes in the rain regime and decreases in the amount of rain falling. Global warming reduces the amount of water and causes soil fertility and crop types to change. This will greatly affect countries that have to survive directly dependent on the land. Global warming will gradually reach serious levels, causing soil moisture loss and drought in some parts of the world, which will cause a decrease in agricultural production and an increase in the prices of world agricultural products. Countries that are importers of such products will be more affected by this situation, and welfare declines will occur due to price increases (White and Blum, 1995). Crop productivity will decline, especially in arid and tropical regions (low latitudes); Even small increases (1-2 degrees) in local temperatures will increase the risk of starvation. Even if product productivity increases slightly in the middle and high latitudes, where an increase of 1-3 degrees may occur at first, there will be a decrease in product productivity later as temperatures increase a few more degrees. The increased frequency of droughts and floods will negatively affect local sectors in low latitudes, which can only be self-sufficient. With continuous warming, the distribution and productivity of fish species will change, which will negatively affect the economic activities of fishing and aquaculture (Kibaroglu, 2008).

The total arable agricultural land in the world is 3.2 billion hectares. In recent years, there has been a decrease in agricultural land per capita. While this decrease is 14.3% in developed countries, it is 40% in developing countries. Agricultural land per capita is 0.23 hectares, and in 2050 this rate will decrease to 0.15 hectares due to global warming. Likewise, it is stated that agricultural production will decrease by 50% in arid regions such as Africa and Central Asia (Ateş, 2008; Filinte, 2007; Marda and Şahin, 2007).

CONCLUSION

Humanity's interest grows and is threatened by the effects of climate change and global warming, which have recently emerged as one of the most significant environmental issues and the most talked-about topics in public opinion worldwide. It is imperative that the necessary steps be taken as soon as possible to preserve the continuation of nature's living life because global warming is a serious issue that upsets the natural balance and endangers the existence of all living things. Global climate change will also have other effects other than those summarized above. For example, there will be a slight increase in winter precipitation and significant decreases in summer precipitation. The decrease in precipitation will negatively affect water resources and the amount of water per capita will decrease significantly with the effect of population increase, therefore it is inevitable that global warming will affect water resources.

Given that the majority of people today experience water scarcity, it is evident how serious the threat is. Turkey is going to become a water-poor nation. There will be less snow cover, and the time it takes for snow to melt will shift to earlier hours. New irrigation systems and water storage structures will therefore be needed.. Considering that a budget of around 200 billion US dollars will be needed in the world for these investments, there is no doubt that a very significant amount for Turkey will be allocated for this purpose. If the required steps are not taken to combat climate change, water resources in arid and semi-arid regions will become one of the world's most significant issues. Water is the source of life. The need for water will rise, creating new issues. Global warming will cause precipitation to decline in Turkey, and drought and rising temperatures will alter land use, agricultural practices, water resource use, and water quality. Large agricultural areas will face salinity-sodium problems due to the poor quality irrigation water to be used. Most of the irrigation water will be used at least 2-3 times.

Agricultural production planning will be made in our country. The type of plants to be grown in areas opened to irrigation due to lack of water and increasing air temperatures will be planned by a central authority. The production of plant species that use a lot of high-quality water will be subject to permission. Water prices will rise very high and wars may break out between countriesWater-rich nations will benefit from significant strategic advantages. The efficient and well-planned use of water resources is the first step in combating climate change. To maintain the ecological balance and postpone the effects of climate change, people must be made aware of the importance of protecting the world's water balance.

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CHAPTER 7

THE RELATIONSHIP BETWEEN FOREST RESOURCES MANAGEMENT AND WATER RESOURCES: CURRENT SITUATION, CHALLENGES AND POLICY SUGGESTIONS

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1. Introduction

Forests cover about nearly one-third of the world's land area (FAO, 2020) and supply essential ecosystem services that promote human well-being and environmental sustainability. These services range from economic benefits such as wood and non-wood forest products to ecological functions such as water resource protection, biodiversity conservation, soil conservation and climate regulation (Mercer et al., 2011; Kornatowska & Sienkiewicz, 2018).

These ecosystem services that forests provides are also defined as forest functions. The concept of forest function has become an important part of forestry based on sustainable and functional planning (OGM, 2017). Today, three main forest functions (economic, ecological and sociocultural functions) and 10 general forest functions belonging to these functions have been determined in Türkiye based on the generally accepted classification in line with international progress (OGM, 2014a).

One of the essential functions of forests is the hydrological function. The hydrological function, which is expressed under the subheadings of drinking water protection, domestic water protection and water resources protection, expresses the importance of forest resources in terms of water resources. The availability and quality of clean water resources in many parts of the world are increasingly threatened by overuse, misuse and pollution, and it is increasingly recognised that both the quantity and quality of water is highly affected by forests. Furthermore, climate change is altering the role of forests in regulating water flows and influencing the availability of water resources. Therefore, the relationship between forests and water has become a critical issue that needs to be given high priority (Bergkamp et al., 2003; Calder et al., 2007).

Thus, this study examines the relationship between forest resource management and water resources. The positive and negative externalities created by forest resources on water resources are discussed in detail, the policies related to the forestry sector and water resources are addressed, what kind of forest resource management is needed to protect water resources is discussed and recommendations are presented.

2. Hydrological Function of Forests

Although water is a precious and limited resource that is indispensable for the survival of all living things, and especially humans, access to clean and sufficient fresh water resources and water resources management has become one of the most important problems at the global level. The consumption of water is increasing significantly, especially with population growth and urbanization. In addition as a consequence of the unconscious and excessive usage of environmental resources from which water resources are obtained, access to clean water has also started to be restricted. Considering the fact that climate change, which is thought to have serious effects on freshwater resources, it is obvious that the size of the problem will increase even more in the near future (Yüksel et al., 2011; Ertürk, 2012; Haddeland et al., 2014).

Water use has been increasing globally by about 1% per year over the last 40 years and is expected to increase at a similar rate by 2050, driven by a combination of population growth, socio-economic development and changing consumption patterns. As a result of climate change, seasonal water scarcity will increase in water-abundant regions such as Central Africa, East Asia and parts of South America, and worsen in already water-scarce regions in the Middle East and Africa. On average, 10% of the global population lives in countries experiencing high or critical water stress. Moreover, only 2.5% of the world's total water is available for human use (UN, 2023).

Considering the current situation of water resources in Türkiye, it is possible to say that similar problems are also valid. The consumable surface and groundwater potential in Türkiye is 112 billion m^3 per year on average, of which 44 billion m^3 is used (DSİ, 2015). In order for a country to be accepted as a rich country regarding water potential, its per capita water potential should be greater than 1,700 m^3/year. In Türkiye, the annual amount of usable water per capita is 1,294 m^3/year, and it is likely that Türkiye, which is not a rich country in terms of water potential, will be among the water-shortage countries in the coming years, considering population growth and the effects of climate change. (DSİ, 2023).

In order to leave healthy and sufficient water resources for future generations, it is necessary to protect existing watersheds and forest resources, which play an important role in protecting watersheds. Forests have a crucial place in the sustainability of water resources, as more than 75% of water supply is derived from forest and mountain ecosystems, which provide water to more than half of the world's population (MEA, 2005). Forests also contribute significantly to the management of water flows by serving as natural reservoirs that hold and slowly release water. This function helps to reduce flood risk, control the flow of rivers and maintain groundwater levels, and in this way forests provide a vital service to the all living things by preventing natural disasters and assuring a sustainable water supply. (Kramer et al., 1997; Vardon et al., 2019). Forests also improve the quality of water by regulating the water regime, by supplying water resources during periods when water is scarce and by cleaning the water (OGM, 2014a).

As stated above, the impacts of forests on the quality, quantity and regime of water are considerable and therefore the role of forests and the forestry sector in the protection and planning of water resources is becoming increasingly important. The impacts of forestry activities on water resources within the scope of sustainable forest resources management should be prioritized and planning for forest resources and water resources management should be handled together.

3. Externalities of Forest Resources on Water Resources

Forests provide many products, services and benefits, but also have some externalities. For this reason, in line with the increasing importance of forest resources today, determining the externalities of forests and forestry activities is also becoming more important. Positive externalities of forests include benefits provided by forests such as protecting and sustaining water resources, improving water quality, climate regulation, biodiversity conservation, carbon sequestration, soil conservation, avalanche and flood prevention, etc. Such benefits or positive externalities provided by forests are achieved by preventing losses that are likely to occur as a result of the absence of forests in an area or the destruction of existing forests in an area.

On the other hand, negative externalities also occur as a result of some interventions on forests. The negative externalities of forests include soil erosion, floods and avalanches as a result of inadequate or inappropriate management activities, and losses in the landscape value of the area due to excessive increase in the use of forest land. Similarly, forest fires, loss of biodiversity, landscape value and recreation value arising from plantation forestry are among the main negative externalities of forests.

3.1. Impacts of Forestry Activities on Water Resources

There is a bilateral relationship between forest resources and water resources. On the one hand, forests affect the quality and quantity of water, and on the other hand, water resources are essential for the growth and development of forests. In addition to their role in the hydrological cycle, forests have a major role in the quality and quantity of water because of their functions such as preventing erosion and sedimentation, regulating the water regime and filtering water. For this reason, all forestry activities carried out in the forest resources management process have positive and negative effects on water resources.

In this context, in this study, the direct or indirect effects of silvicultural activities, harvesting, forest road construction and other forestry activities and forest fires on water resources are discussed.

3.1.1. Silvicultural Activities

According to the communiqué titled "Technical Principles of Silvicultural Practices" prepared by "the General Directorate of Forestry Silviculture Department" and which is in force, silvicultural activities are carried out in accordance with the different functions expected from forests in order to establish new forests in our country, to maintain and rehabilitate naturally grown forests and to ensure that these forests fulfill the functions expected from them and to maintain them in a sustainable manner.

In this communiqué, "Silvicultural Principles to be Applied in Forests with Hydrological Function" are determined as follows (OGM, 2014b):

- ➢ Only in places where water yield is important and at the forefront, forests of the same age should be established, and stand closure should be broken in order to increase water yield and to prevent the formation of raw humus. For this reason, erosion control measures should also be taken where necessary.

- Where the quality and continuity of water is important, a layered and different aged structure should be preferred.
- In order to ensure hydrological and soil protection functions at the same time, mixed stands should be established and the mixture should be encouraged through maintenance interventions.
- In forests with hydrological functions where both water yield and water quality (drinking water) are important, clear cutting cannot be done within the strict protection area. In areas outside the strict protection area, shelter wood cutting should be considered first, and in case of necessity, clear cutting should be carried out up to a maximum of 3 hectares.
- However, in areas where water yield is important and at the forefront, in areas outside the medium distance protection area specified in the Water Pollution Control Regulation, shelter wood cutting should be considered first, and up to 10 hectares of clear cutting can be carried out for the purpose of rehabilitation in some intolerant trees (calabrian pine, pinaster pine, etc.) by taking erosion control measures in mandatory cases.

Since forested areas with hydrological function are the areas that keep the ground water, water in rivers, freshwater lakes, ponds and dams clean and ensure that water resources are continuous and regular, the most important thing that should be done regarding the waterside areas located in forested areas is to protect the natural vegetation, to carry out rehabilitation work in places that do not have sufficient density and closure, and to make afforestation when necessary (Avşar, 2008).

There are many academic studies examining the effects of different silvicultural techniques applied worldwide on the quality and quantity of water, and it has been determined that silvicultural activities affect water quality, including sediment transport, nutrient losses, carbon transport, changes in acidity and temperature (Shah et al., 2022).

3.1.2. Harvesting Activities

Among forestry activities, harvesting activities have the highest potential to have a negative impact on water quality compared to other activities. The main factors affecting the extent of the impact of production activities are; "the use of heavy machinery during harvest, the size of the felling area, topography, soil type and local environmental conditions, especially meteorological conditions (Shah et al., 2022). The production activities include wood production, logging, felling, ploughing, and skidding. Trees located in the river basin have a great impact on the sun's rays reaching the river, the amount of evaporation, the amount of sediment reaching the river, the surface runoff rate and the stream flow. For this reason, as a result of tree felling in such areas, evapotranspiration and interception will decrease, the soil will become moister and as a result, it will lead to soil mobilization. The moved soil reaches the rivers and causes an increase in the amount of sediment in the water. In addition, as a result of the harvesting, the streams on which the cover is removed are exposed to more sun rays and the water temperature increases. Due to the increase in sediment and increased water temperature, the quality of water changes. (Gülcü et al., 2008).

The change in the amount of sediment also influences the physical, chemical and biological characteristics of water. For example, "the physical properties of water such as colour, smell, taste, temperature, turbidity change, light permeability decreases, heat absorption from the surface of the water increases and increased sediment causes blockages along the stream bed". The elements in the sediments can also affect the chemistry and quality of water by interacting with other substances. Moreover, with the rise in water temperature, dissolved oxygen uptake and the amount of dissolved oxygen in the water decreases and aquatic metabolic activities change (Tessier, 1992; Koralay et al., 2015). The increase in temperature causes the proliferation of blue-green algae and other destructive microorganisms in the environment and as a result, toxic substances are produced in the water; the lives, migration movements and reproduction of fishes are adversely affected due to the rise in water temperature by a few degrees (Chang, 2003).

Another effect of harvesting activities on water resources is the change in nutrients in water. When harvesting removes vegetation close to water sources, it can reduce interception losses in the area, allowing more water to reach the soil, thus generally diluting nutrient concentrations. In addition, production (cutting and transport) can also reduce nutrient uptake from the soil and accelerate soil decomposition by increasing the accumulation of nutrients in mineral soil that can be utilized by plants (Görcelioğlu, 1993).

The methods used during the removal of felled trees from the forest also cause changes on water resources in various ways. For example; during the removal of the logs from the compartment by tractor, the soil is compacted and an impermeable layer is formed on the routes where the ploughing and shifting operations are carried out. As a result of soil compaction, drainage routes are disrupted and both surface runoff increases and the direction of surface runoff may change (Gülcü et al., 2008; Koralay et al., 2015).

3.1.3. Forest Road Construction Activities

One of the factors that have a substantial effect on water quality is forest road construction activities (Shah et al., 2022). In order to fulfil all kinds of forestry activities, especially production, in an organised manner, it is necessary to have an effective road network. Although forest roads constitute a small part of the total forest land, they significantly increase the total amount of erosion (Gülcü et al., 2008).

Road construction activities collect and direct the surface runoff waters, which are widely travelling down the slope, to flow together and also increase the slope of the excavation slopes. Excavation slopes interrupt both surface runoff and shallow subsurface runoff and collect them in edge ditches. Precipitation falling on the road surface causes direct surface runoff, resulting in an increase in peak flows in streams, an increase in water temperature and a significant increase in the amount of suspended sediment (Görcelioğlu, 1993; Gülcü et al., 2008).

3.1.4. Other Forestry Activities

Other forestry activities carried out in forest areas also have an impact on the quality and quantity of water at different intensities. For example, an increase in pesticide concentrations in streams may occur as a consequence of the usage of chemicals such as "insecticides, fungicides, herbicides, etc." used within the scope of maintenance and protection activities in forests in and around forest water resources (Gülcü et al., 2008). The effect of pesticide use on water quality can be in three ways: (i) pesticide concentrations in streams, (ii) the response of stream chemistry to pesticide application and (iii) the effect of pesticide application on erosion. Pesticides can enter the stream directly during application or they can reach the stream through soil movement. However, this effect is insignificant if these chemicals are not used in the buffer zone around water sources (Görcelioğlu, 1993).

Another forestry activity that affects the quality and quantity of water is grazing. Grazing in forested areas can cause erosion if it is not well planned and managed. As a result of the removal of vegetation by grazing, surface runoff may increase, the level of suspended sediment in water increases and microbial contamination increases. Intensive recreational use and accommodation facilities such as mountain chalets with inadequate wastewater systems can also increase pathogenic organisms entering the streams to harmful levels (Görcelioğlu, 1993).

3.2. Effects of Forest Fires

In Türkiye and in the world, forest fires are the most pressing factor on forests and constitute a global problem. The importance of the negative impacts caused by forest fires is increasing continuously. The destruction of forest areas, which have a vital importance as carbon sinks especially in combating climate change, increases greenhouse gas emissions and means the destruction of all ecosystem services.

Forest fires also affect all components of the hydrological cycle, causing negative consequences on interception, evapotranspiration, infiltration and surface runoff waters. When a fire occurs, the dead cover and vegetation in the forested area are destroyed, the net amount of precipitation reaching the soil surface increases, and therefore a decrease in interception occurs. As a result of the disappearance of vegetation cover after the fire, soil erosion and surface runoff amounts increase. Similarly, as a result of the fire, less precipitation turns into vapour in the evapotranspiration process and as a result, surface runoff is higher. In addition, when vegetation and dead cover in the watershed are destroyed as a result of fire, infiltration characteristics also change. With the decrease in the permeability of the soil surface as a result of fire, the infiltration capacity of the soil decreases and the water that cannot infiltrate into the soil reaches the water resources by passing to the surface flow. With the increase in surface runoff, the amount of sediment transported to stream and river beds increases significantly (Aydın et al., 2017; URL, 1).

Forest fires severely affect the hydrological cycle as well as water quality, and water quality degradation occurs after fires. For example, turbidity is often "the most visible water quality impact of fire" (FAO, IUFRO and USDA 2021). In addition, the increase in sediment levels after fires particularly affects drinking water systems; water reservoirs are filled or damaged as a result of sediment accumulation, and the resulting costs of cleaning the existing sediment increase. On the other hand, forest fires cause an increase in the amount of chemical elements on the soil surface and the concentration of elements such as nitrogen, phosphorus and potassium in stream water increases significantly (Aydın et al., 2017).

4. Managing Forests for Water

Throughout history, human beings have interacted with forest resources as well as other natural resources in various ways. The ways and understanding of utilization of forests have changed depending on the needs and expectations shaped according to the social, economic and legal developments in society. While the first people utilized forests for shelter, nutrition and hunting, later, with the transition from nomadic life to settled life, people used forests to supply firewood, to build houses and tools and to graze their animals.

In the medieval period, forest management expanded to include wildlife, as in the English Royal Forest, where access could be granted to hunt game species (rabbits, foxes and deer, etc). Production of preferred tree species was prioritized to satisfy the needs of society. Especially in the 17th and 18th centuries, with the wood shortage in Central Europe, the necessity to utilize forest resources in a regular and planned manner came to the fore. In many countries, other functions of forests other than providing wood raw materials have started to be considered important by the public (Eraslan, 1983; Jørgensen, 2004).

Especially since the 20th century, there have been significant developments in the way forests are viewed in developed countries. Regional, national and global demands for forest resources have rapidly changed and thus forest resources have begun to be seen not only as a resource that provides wood raw material production, but also as a resource with ecological and sociocultural services such as quality water supply, recreation, environmental protection and biodiversity. As a result of this situation, a modern understanding of utilization of forest resources in line with the principle of sustainability and multiple utilization has developed.

Those responsible for the management of forest resources around the world engage in a range of practices to get desired outcomes, such as "increasing forested areas, conserving biodiversity, sequestering carbon or reducing the risk of wildfire". Many of these management practices also affect water services and, if well designed and implemented, can contribute to water management objectives (FAO, IUFRO and USDA 2021). In order to minimize the negative impacts of all kinds of forestry activities, silvicultural interventions, harvesting, road construction works and other forest resource management practices carried out in forests on water resources, forest resource management should be planned and carried out taking into account the water function. In other words, forests should be managed for water.

When the developments in Türkiye are evaluated, it is seen that almost all of the forests in our country (99.9%) are under the control of the state and are managed by "the General Directorate of Forestry under the Ministry of Agriculture and Forestry". Forest resources in Türkiye are managed through forest management plans prepared on the basis of the smallest management unit, the forest enterprise chief. With the regulation made in 2008, the Ecosystem-Based Functional Planning approach has started to be adopted in planning (Resmi Gazete, 2008). Based on this approach, the functions, management objectives and protection targets of forest resources are determined at the level of the forest management unit in our country, and working sections are formed depending on each objective and target, and then, as a requirement of multi-purpose utilization, a forest area is managed for two or more objectives and targets.

In Türkiye, depending on the above-mentioned developments in forest resources management, water function is tried to be taken into consideration in all kinds of forestry activities within the principle of multi-purpose utilization, just like other functions. Under this heading, how forest resources are managed for water is discussed under the sub-headings of watershed-based forest management, drinking water management of forests and control of water-related natural disasters.

4.1. Watershed-Based Forest Management

The concept of watershed management emerged with the need for the effective use and protection of water resources, and especially after the mid-20th century, sustainable management of watersheds has become increasingly important as a result of the damages arising from global population growth and industrialization. Watershed management includes objectives such as protecting all natural resources including forest resources, improving water quality and preventing erosion for the conservation, enhancement and sustainable utilization of water resources. This management addresses the water cycle, soil health, biodiversity and the impacts of human activities as a whole. At the same time, watershed management is a planning and implementation process that encourages the cooperation and participation of stakeholders and integrates knowledge and experience with scientific research and technological innovation. This management process, called "integrated watershed management", in which all stakeholders in the watershed are included in the process, ensures that different views and needs are taken into account at every stage from the preparation of watershed management plans to implementation and monitoring (Heathcote, 2009; Yıldırımer and Demirci, 2024).

The watershed-based approach to managing forest resources is being adopted and is becoming increasingly widespread in Türkiye. The quantity and quality of water supply is intricately related to the watersheds in which water is collected and flows in. Watersheds are dependent on many biological, socio-economic and physical processes active in landscapes. Watersheds are a suitable unit for restoration and management planning because they can be identified on maps and remotely sensed data and do not change much over time. Forests' role in maintaining water values vary depending on their location within a watershed and thus require different management strategies. Forest management decisions should take into account factors such as regulation of water temperature and flow, water quality and downstream fisheries at the watershed scale. Defining watershed borders at the national level is an essential step towards efficient water management, as it allows forest management to be considered in the context of the watershed (FAO, IUFRO and USDA 2021).

4.2. Managing Forests for Drinking Water Supply

A large percentage of drinking freshwater resources are located in forested areas. While a forested watershed can yield a fresh and rich water supply, a watershed in forested areas with clear-cutting or other land use types may require treatment to make it safe for drinking. On the other hand, industrial wastewater treatment plants are often expensive, encouraging water managers to reduce deforestation and improve forest and land management in drinking water source watersheds. (Calder, 2007).

For a healthy drinking water cycle, it is necessary to protect the natural forest cover that feeds the watershed. Natural forests adapt to regional environmental factors and fulfill a key role in the water cycle. By protecting natural forests, creating buffer zones close to water sources (streams and rivers), not harvesting in these areas and carrying out rehabilitation works, the quality and quantity of drinking water can be protected. In addition, the biggest threat to water quality in fully forested watersheds is erosion caused by forest roads on steep terrain. Therefore, it is also necessary to take measures to prevent erosion (FAO, IUFRO and USDA 2021).

4.3. Control of Water-Related Natural Hazards

Forests provide environmentally based solutions to a number of problems through their capacity to mitigate soil and riverbank erosion and mitigate natural hazards such as "floods, landslides, rockfalls, avalanches and storms". To mitigate the threat of these environmental dangers, forest areas are set aside and managed according to conservation objectives. Good planning and management of forest resources in urban and rural areas can be effective not only in improving the availability and quality of urban water supplies, but also in preventing and mitigating water-related disasters. When forests are well managed, the overall water cycle is positively affected and water infiltrates more easily into the soil, which can reduce runoff and the severity of potential flooding. (FAO, IUFRO and USDA 2021).

Forests with a protective function generally can be vulnerable to large-scale effects from damages such as wildfire, storms, floods and insect damage. Climate change, on the other hand, poses an increasing threat to the conservation function of forests, given the potential impacts of temperature increase, changes in precipitation and more intense storms and drought. Therefore, forest areas managed with the objectives of drinking water protection, domestic water protection and water resources protection also fulfill the conservation objectives of nature conservation and erosion prevention functions.

4.4. Related Benefits of Managing Forests for Water

While forest resources are protected and managed for water purposes, they also fulfill other ecosystem services. These ecosystem services include:

- Carbon sequestration
- Biodiversity conservation
- Recreational utilization
- Socio-cultural utilization
- Forests play a crucial role in the climate change mitigation (OGM, 2010):
- "As being sinks, as they remove CO_2 from the atmosphere through photosynthesis",
- "As being a reservoir by storing carbon in the trunks, leaves, branches, roots, dead and living cover and forest soil",
- "As being a clean energy alternative to fossil fuels",
- "As being a source of CO_2 when they burn or are destroyed."

For these reasons, while forest areas are managed for water conservation, they also sequester carbon and better fulfill their role as carbon sinks.

Another vital function of forests is the protection of biodiversity as they are home to flora and fauna. The availability of clean water is essential for wild animals to survive. Water from forests also contributes to the maintenance of aquatic biodiversity, both in rivers and streams and in near- coastal systems. Biodiversity in aquatic ecosystems adapts to various water quality conditions, such as "temperature, mineral content, pH, oxygen content, turbidity and nutrients, and water quantity". (FAO, IUFRO and USDA 2021).

While forests are managed for water conservation, they can also provide opportunities for a variety of recreational activities. For example, recreational activities such as fishing, boating and swimming can be an important co-benefit of forest management to support water services. While recreational use can provide economic benefits for the area, it can also have negative effects on forest and water resources if not well managed. These forests can also have aesthetic and public health functions. For example, the aesthetic value provided by a clean river landscape or the festivals that local people keep alive in that area can be expressed as socio-cultural benefits of these areas.

4. Estimation of the Economic Value of the Water Function of Forests

In the past, all ecosystem services from different ecosystems around the world were considered free goods and their use was considered almost unlimited. However, the acceptance of natural resources as free goods brought with it excessive and unconscious utilization of these resources. Since the 1970s, the idea that natural resources are scarce and should have a price or value in exchange for the benefits gained from their use by consumers.

It is easier to estimate the value of goods and services that have a direct market because they are priced. The issue of how to estimate the value of environmental goods and services that do not have a market has started to gain importance at this point. For this reason, various valuation approaches and methods have been developed to determine/estimate the economic value of all ecosystem services mentioned above. Value determination methods are classified as follows. (Merlo and Croitoru, 2005):

When there is a market price:

"Effective Price and Shadow Price"

When there is no market price:

A. Demand curve approaches: "Contingent Valuation Method, Choice Modeling Method, Travel Cost Method, Hedonic Pricing Method, Hedonic Travel Cost Method and Production Function Method"

B. Approaches other than the demand curve: cost-based methods: "Damage Avoided Cost Method, Replacement Cost Method, Preventive Expenditure Method and Opportunity Cost Method"

Water function, one of these ecosystem services that forests can provide, is a fundamental function for all organisms and the importance of this function can be emphasized by estimating the economic value of the water function of forests. However, it does not seem possible to talk about an economic value determination method that gives a clear and complete result in economic value estimation. Although it is difficult, estimating the value of forest water resources will provide useful information for effective and efficient forest resources-water resources management, planning and policy decisions.

In other words, a better understanding of the effect of forests on water quantity, quality and regime is possible by estimating the economic value of water production and watershed protection benefits of forest resources. The watershed protection benefit of forest resources is one of the components of value whose economic value is one of the most difficult to estimate, and the following methods can generally be used to estimate the economic value of this benefit (Willis et al. 2003; Merlo and Croitoru, 2005; DG AGRI, 2008; UN, 2018): "Opportunity Cost Method, Damage Avoided Cost Method, Replacement Cost Method, Preventive Expenditure Method and Willing-to-pay methods."

In estimating the economic value of watershed protection in foreign countries, contingent valuation and choice modeling methods, and the avoided loss cost method are often used. In studies that aim to determine the willingness to pay, value is assigned to water quality improvement (Tervonen et al., 1994; Stenger and Willinger, 1998; Colombo et al, 2006), clean water provision (Thorsen, 2008) and watershed protection (Pattanayak and Kramer, 2001). In addition, the economic value of watershed protection as a whole has been determined using the damage avoided cost method (Croitoru et al., 2005; Kazana and Kazaklis, 2005; Mendes, 2005).

In a literature review study, 665 studies were reviewed and classified according to the valuation methods (de Groot et al. 2012). Among these studies, those on the economic value estimation of water are given in Table 1. While the economic value estimation of water supply in the scope of supply services is generally based on market price, cost-based methods are more preferred for the value components in the scope of regulation services.

Table 1. Valuation methods used in water-related ecosystem services

Ecosystem service	**No. of estimates**	**Methods**									
		DMP	**PF**	**AC**	**MC**	**RC**	**HP**	**TC**	**CV**	**GV**	**Other**
Provisioning services	**287**	**219**	**23**	**8**	**2**	**14**	**0**	**0**	**1**	**8**	**12**
Water	38	5	10	7	1	9				3	3
Regulating services	**152**	**20**	**7**	**51**	**9**	**40**	**0**	**0**	**7**	**0**	**18**
Water flow regulation	5		2	1		1					1
Waste treatment	31	1	1	5	2	19			1		2
Erosion prevention	17	4		7	1	1			1		3

Source: de Groot et al. (2012). The acronyms are: DMP: Direct market pricing; PF: Production Function; AC: Avoided Cost; MC: Mitigation Cost; RC: Replacement cost; HP: Hedonic Pricing; TC: Travel Cost; CV: Contingent Valuation; GV: Group Valuation;

In Türkiye, studies on this subject are limited in number. In the study carried out by Bann and Clemens (1999), only the economic value of soil conservation was tried to be determined under the title of watershed protection. In the studies of Yolasığmaz (2004) and Karahalil et al. (2009), for calculation of the water production value, soil samples were taken from the sampling areas and water production values were derived by using water balance tables for each soil series. Then, the relationship between water production value and breast surface for each sample area was tested by regression analysis. Finally, in order to create economic matrices for water production, calculation was made based on the monetary value of one m^3 of water.

In another study, the economic value of the water production and water resources protection function of forests was estimated based on the management, research, development, expropriation and afforestation expenses incurred by the relevant institutions for the area with the help of the cost method based on a watershed example (Eker, 2005). In the study conducted by the World Bank Group (2015), the economic value of watershed protection benefits was estimated by the unit value transfer method. In the study aiming to reveal the ecosystem values of the area within the scope of Yıldız Mountains Biosphere Project, while estimating the economic value of water use by households, the payment tendency value in the study conducted by Bilgiç et al. (2008) was adapted for the area by utilizing the benefit transfer method.

5. Payments for Forest Ecosystem Services

New financial resources are needed for the sustainable management of forests, especially in the less developed and developing countries. For this reason, new financing mechanisms for the sustainable management of ecosystem services are becoming the most important agenda item in international forestry processes and new financial instruments and mechanisms are being developed for this purpose. Payments for ecosystem services (PES), one of these financial instruments, has become increasingly widespread in recent years.

Payments for ecosystem services are defined as "payment for an environmental service, a voluntary transaction in which a well-defined environmental service (or land use) is purchased by at least one buyer from at least one provider who guarantees its supply." (Wunder, 2005). PES is an incentive-based approach aiming to protect and restore environmental resources and ecosystems through linkages between beneficiaries and providers of ecosystem services (Lurie et al., 2013). PES programs deal with the issue of negative externalities by generating a market environment where externalities are internalized. Without the need for regulatory agencies to implement restrictive policies, PES programs improve environmental facilities through voluntary agreements between individuals (Yıldırımer and Demirci, 2017).

PES programs are used in many countries for various purposes to conserve forest resources and benefits. In the forestry sector, PES programs are implemented in the following areas (Wunder, 2005; Mercer et al., 2011):

- **Watershed protection:** "With more than three-quarters of the world's freshwater coming from forested watersheds, forests play a critical role in protecting water quality by absorbing excess nutrients, reducing soil erosion and controlling water flows. For these reasons, forest landowners can generate significant revenues for the watershed services their land provides."

- **Carbon sequestration and storage:** "Carbon sequestration and storage is one of the vital ecosystem services provided by forests. Carbon sequestration occupies a privileged position among other ecosystem services, as it provides global benefits. Forestry-related carbon offset projects, such as afforestation or reforestation and improved forest management, offer businesses and individuals the opportunity to invest in projects to offset their own greenhouse gas emissions."
- **Biodiversity conservation:** "Payments for biodiversity services come in three categories: public payments to landowners, voluntary payments and payments in compliance markets. There is also a private market for biodiversity services through the purchase of hunting leases and payment of entrance fees for hunting and wildlife watching on private land."
- **Bundled services:** "Most payment for conservation programs are designed to produce a bundle of ecosystem services. There are several traditional government conservation programs in different countries that pay for bundled services. There are also significant voluntary payments to landowners by non-governmental land trusts and other organizations to protect these services."

PES for watershed services play a crucial role in watershed protection. Many PES programs related to watershed protection have been implemented worldwide. These programs are built through three processes (Mercer et al., 2011):

- **Public payments:** "Public payments for watershed services are often aimed at protecting drinking water sources to reduce the costs of water treatment. Also in some countries, state and local governments have many programs to protect water quality resources."
- **Voluntary transactions:** "There are several examples of private companies voluntarily paying for watershed services. These companies do not invest directly in land management practices, but instead pay landowners not to exercise their water rights and instead keep water in rivers."
- **Compliance-driven transactions:** "These include markets and payment mechanisms developed in response to government regulation, such as water quality trading. Water quality trading has its own rules and shows promise as a way to control source pollution without the need for additional regulation."

When implementing PES programs, analysis and design should take into account local and regional structural elements such as ecosystem structure, processes and services, type of actors, institutional interaction, capacity and scale (UN, 2018). While most market-based and incentive-based programs for watershed protection focus on a single watershed-related service, there is an increasing interest in programs that conserve or restore several ecosystem services alongside the goal of watershed protection. About one-third of active programs combine ecosystem services such as biodiversity conservation, carbon storage and landscape beauty (Bennett et al., 2013).

In addition, these watershed protection programs have some socio-economic objectives. Since most programs are developed and implemented in less developed and developing countries, these programs provide benefits to the poor. These socio-economic objectives include poverty alleviation, promotion of economic development, more efficient management of resources and management of indigenous peoples' rights (Bennett et al., 2013).

Although there is an increased awareness on sustainable water resources management in Türkiye and studies are ongoing in this field, no incentive-based program such as PES has been established or implemented in Türkiye so far. In order to support sustainable watershed management activities, PES programs should be carefully evaluated and new initiatives should be introduced. All PES implementation areas (watershed protection, improving water quality and quantity, regulating water flow and reducing pollution) are suitable areas for investment and financing (Yıldırımer and Demirci, 2017).

6. Conclusions and Suggestions

In most regions of the world, the existence and quality of clean water resources are under threat because of climate change, excessive and unconscious use and pollution. The role of forest resources in protecting water resources, regulating the water regime and ensuring the quality and quantity of water is of vital importance. For this reason, it would be beneficial to carry out studies by considering the water function of forests in forest resources management and all forestry activities. Within the scope of this study, which aims to reveal the relationship between forest resources management and water resources, the following conclusions and suggestions were tried to be put forward.

- Although there are studies investigating the impact of different forestry activities on the quality and quantity of water resources worldwide, it is seen that there is a limited number of studies in this field in Türkiye. Especially considering the importance of water resources both today and in the future, it is important to popularize studies examining the impact of forestry activities on water resources in order to determine and implement forest-water resources management policies in a better way.

- The primary objective should be to prevent damage to water resources in all kinds of forestry activities. These activities negatively affect the quality of water and cause an increase in water temperature and sediment and a decrease in the amount of dissolved oxygen in water. Therefore, forestry activities should be implemented in a way that does not harm water resources within and adjacent to forests. Measures should also be taken to reduce soil erosion.

- In Türkiye, there has been a growing awareness among resource managers and decision makers on the determination of the value of forest ecosystem services. In addition, as a requirement of the multi-purpose planning approach, significant changes have occurred in the understanding of the preparation and implementation of forest management plans. However, the current management regulations do not include detailed information on the determination of the value of benefits other than wood raw material.
- At this point, forest ecosystem services need to be more realistically included in the forest resources planning process in order to ensure more effective water resources management. As a prerequisite for conducting economic valuation studies in these areas, it should be explained how forest ecosystem services, including the water function, should be defined and how their values should be estimated.
- One of the important issues regarding the protection of water resources is integrated watershed management. In the current situation, it is possible to state that Türkiye's watershed management policies and strategies are shaped in line with the international agreements to which it is a party and sustainable development goals, and studies on this issue are given importance. Thus, protection and sustainable use of water resources are ensured and climate change can be combated more effectively.
- However, integrated and comprehensive policies and strategies need to be implemented and disseminated in order to take measures and develop solutions against today's biggest challenges such as global climate change, biodiversity loss and sustainable use of water resources. In this context, it is essential to compare Türkiye's approaches to watershed management, water resources management and combating climate change with international examples, learn best practices and adapt these practices to local conditions.
- In order to ensure integrated watershed management in our country, coordination between relevant ministries should be provided. Protection of forest assets, especially in water production watersheds, should be the main priority in all kinds of projects and studies planned to be realized.
- On the other hand, studies on PES mechanism, which is an alternative financial incentive mechanism for forest resources, should also

be given importance. In this context; first of all, PES programs implemented worldwide should be investigated and a strategy should be developed for their applicability in our country. The necessary institutional and legal infrastructure should be established to implement PES programs, pilot implementations should be carried out and PES implementations should be made widespread with the experience to be gained from this experience.

- Municipalities or water filling facilities should be responsible for the protection and conservation costs of the watersheds where they meet their water needs. For example, mechanisms should be put in place to provide financial support to forest villagers living in or adjacent to the watershed where water is produced. Even the forestry organization should be able to generate income from alternative financial mechanisms such as PES as a compensation for the ecosystem services it provides.

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CHAPTER 8

DOES *Schizodactylus inexspectatus* PROVIDE AN ECOLOGICAL BALANCE IN SEA TURTLE CONSERVATION?

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Brief Information about *Schizodactylus inexspectatus*

Schizodactylus inexspectatus [Werner, 1901] (Orthoptera: Schizodactylidae) is one of the endemic species of Türkiye and occur only Adana and Mersin provinces (Aydın, 2005; Aydın & Khomutov, 2008; Aydın & Karaca, 2011). Some possible regions where this species could live were examined for its distribution. The most important of these localities was Cyprus (once connected to the provinces of Mersin and Adana), which is separated from the Anatolian peninsula. As a result of the field studies, no evidence was found that *S. inexspectatus* lived in Cyprus. However, doubts about its possibility of survival still persist. Although the coastal dunes on the Mediterranean hotspot in Turkey have been studied in detail for the distribution of the insect, the possibility of the species living in some small dune areas is still under debate.

The behavior and lifestyle, as well as its biological characteristics, of the endemic sand dune cricket are quite different from its other relatives. Both adult and nymph *S. inexspectatus* show burrowing and excavating behaviors (Aydın & Khomutov, 2008). This species lives alone in a gallery it has built in the sand during the day. The reason it lives alone is because the species shows a cannibalistic property. When individuals of the species come together, the stronger eats the weaker one. Since they exhibit hermaphroditism, they do not need another individual for mating. They lay their eggs in groups a few centimeters below the sand dune. The hatched nymphs immediately disperse and begin digging burrow. This species has a lifespan of 2 years and lives alone until the end of its life. The individuals rest in the moist chamber inside their burrows all day long, and as soon as the sun sets, they immediately leave their burrows and begin hunting. Aydın (2005) stated that the adults and nymphs were active from after sunset until early in the morning. They feed on almost all invertebrates living in desert ecosystems. It was observed that individuals who were tested under laboratory conditions also ate products such as uncooked fish and raw meat. In field studies, observed individuals have also been shown to feed on some butterflies that rest on plants. Aydın & Khomutov (2008) reported that both in fieldwork and under laboratory conditions, *S. inexspectatus* was observed after it had attacked its prey, holding it between its strong legs and squeezing it by the abdomen.

Besides, food preferences of cannibalistic species of *S. inexspectatus* were also investigated under field conditions in previous studies. It is a carnivorous insect and prefers to feed on *Gryllotalpa gryllotalpa* (L., 1758) (Orthoptera: Gryllotalpidae), Scarabaeus sacer (L., 1758), *Pentodon bidens* (Pallas, 1771) (Coleoptera: Scarabaeidae), *Scaurus puncticollis dlabolai* (Kaszab, 1959), *Zophosis dilatata* (Deyrolle, 1867), *Erodius orientalis oblongus* (Solier, 1834) (Coleoptera: Tenebrionidae), *Blattella germanica* (L., 1767) (Orthoptera: Blattellidae), and *Myrmeleon* spp. (Neuroptera: Myrmeleontidae), much like many species of the family Acrididae (Orthoptera) (Uvarov, 1952; Aydın &

Khomutov 2008). The endemic sand dune cricket prefers tenebrionid species as its food. Because tenebrionids are spread over almost the entire delta (both Çukurova and Göksu) and have the ability to live in almost all sand dune habitats. Individuals immediately start digging a new burrow with the sunrise. The depth of the burrows is related to humidity. In a humid area, the burrow excavation is stopped and a chamber is built there and they rest for the whole day. Hazra & Tandon (1991) stated that burrows of the other similar species *S. monstrosus* end when the crickets arrive at moist areas. They have nine pre-adult nymph stages and individuals dig burrows at different depths depending on their size. Aydın & Khomutov (2008) remarked that the depths of burrows are dependent upon soil properties and the burrows are generally made with one small chamber until the specimen finds humid places.

The burrows of both adult and immature stages of S. inexspectatus are closed after they are completed. Besides, this small chamber enables the cricket to rest during the day and to consume its food during the night and during the daytime, burrows are mostly closed due to the high temperatures (Aydın & Khomutov, 2008).

Unfortunately, the habitats in the Çukurova (Adana) and Göksu (Mersin) Deltas, where the distribution of the species has been proven, are increasingly being destroyed. The population of this species have been decreasing as many of their unique habitats are being destroyed by cattle grazing, the extension of agriculture, sand excavation, etc for more than 40 years and finally tourism and turning the sand dunes to the agriculture land for more than 15 years, although this geographical region is under protected by the law of national park statue. Therefore, the species should be included in the International Union for Conservation of Nature's (IUCN) Red List of Endangered Species as a critically endangered species (CR) (Arndt, et al. 2005; Aydın 2011a, 2011b, 2011c, 2018; Aydın et al. 2005; Aydın and Karaca 2009, 2018; Aydın and Kazak 2007, 2010; Lillig and Aydın 2006; Şekeroğlu and Aydın 2002).

The Çukurova Delta and Göksu Delta are in the distribution range of this endemic sand dune cricket in Mersin and Adana province and are also sea turtle nesting areas (Aydın, 2005; Aydın & Khomutov, 2008; Aydın & Karaca, 2011; Türkozan & Kaska, 2010). No scientific paper has been found showing that the insect's burrow intersects with sea turtle nests. Thus, it is though that neither adults nor nymphs of this cricket made burrows in sea turtle nests during the nesting seasons on these beaches.

Brief Information about Sea Turtles

Sea turtles are known typically long-lived animals and adults produce considerable amounts of offspring during its lifetime (Ikaran, et al., 2020). However, 356 species of turtles worldwide, approximately 61% are threatened or already extinct (Lovich, et al., 2018). During the last centuries sea turtle populations worldwide have been declining or driven nearly to extinction due to human activities (Alfaro, et al., 2008). Besides Ikaran et al., (2020) declared that the most common invertebrates interacting with the eggs were insects that affected 82% of the nests (Ikaran, et al., 2020). Our understanding of biology, behaviors, ecology and pathology of sea turtle is obtained almost entirely through the short phase in their lives when they come to ashore to lay their eggs (Alfaro, et al., 2008).

The Mediterranean populations of loggerhead and green turtles are categorized as Least Concern (LC) and Endangered (EN), respectively, on the IUCN Red List of Threatened Species (Seminoff 2004; Casale 2015). Alata (Ergene et al., 2006, 2009) and Kazanlı (Ergene et al., 2013) beaches are among the most important sites for green turtles (*Chelonia mydas* (L., 1758)), and a small number of loggerhead turtle (*Caretta caretta* (L., 1758)) nest these two beaches regularly as well.

Invertebrates that infested sea turtle nests have also been described as *Pimelia* sp (Coleoptera: Tenebrionidae), *Elater* sp (Coleoptera: Elateridae), antlion, *Myrmeleon* sp (Neuroptera: Myrmeleontidae), Scarabaeidae larvae (Coleoptera), Muscidae (Diptera), Enchytraeidae (Oligochaeta), Cyrptostigmata (Acari), Oniscidae (Isopoda), and Formicidae (Hymenoptera) found on Mediterranean beach. (Aymak et al. 2017, 2020; Baran et al., 2001; Katılmış et al., 2006; Özdemir et al., 2006; Türkozan, 2000; Türkozan & Baran, 1996; Uçar et al. 2023; Urhan et al., 2010).

Its though that after completing the larval stage in the infested sea turtle nests, individual *Pimelia* sp. larvae (Tenebrionidae; Coleoptera), *Elater* sp. larvae (Elateridae; Coleoptera), Scarabaeidae larvae (Coleoptera), and antlion larvae (Myrmeleontidae; Neuroptera) might be a potential choice of prey for this carnivorous sand dune cricket outside the sea turtle nests on the sand surfaces.

Distribution of Sea Turtles, Endemic Sand Dune Cricket, and Tenebrionidae species with high potential to infested sea turtle nests

The most preferred egg-laying areas of sea turtles are Yumurtalık Lagoon, Akyatan Lagoon, Ağyatan Lagoon and Tuzla Lagoon in the transects of beach and fore dune. The habitat of the endemic sand cricket, *Schizodactylus inex*spectatus, has been described shifting dune, fixed dune, fixed grey dune, and some part of the dune slack in the delta (Aydın, 2005; Aydın and Karaca, 2011; Aydın and Khomutov, 2008). Neither the sea turtle nesting areas nor the endemic sand dune cricket habitats overlap, and these species live in their own unique habitats. The carnivorous endemic sand dune cricket has no relationship with sea turtle nests. This shows that the coastal successions are shared with species belonging to the Reptilia (sea turtles) and Insecta (endemic sand dune crickets) classes (Aydın, 2005; Aydın & Khomutov, 2008; Aydın &

Karaca, 2011) and each prefer their own habitats. Sea turtles mostly prefer foredunes and sometimes embryonic shifting dunes for laying their eggs, while the endemic sand dune cricket occupies nearly all dune successions except foredunes (Figure 1).

In his PhD study, Aydın (2006) revealed the distribution of Tenebrionidae species living in the Çukurova Delta. Based on the data obtained from this thesis, it is known that tenebrionid species are distributed both in the beach and fore dune transects where sea turtle nests are located and in the shifting dune, fixed dune, fixed grey dune, and some part of the dune slack transect where *S. inexspectatus* lives (Figure 1).

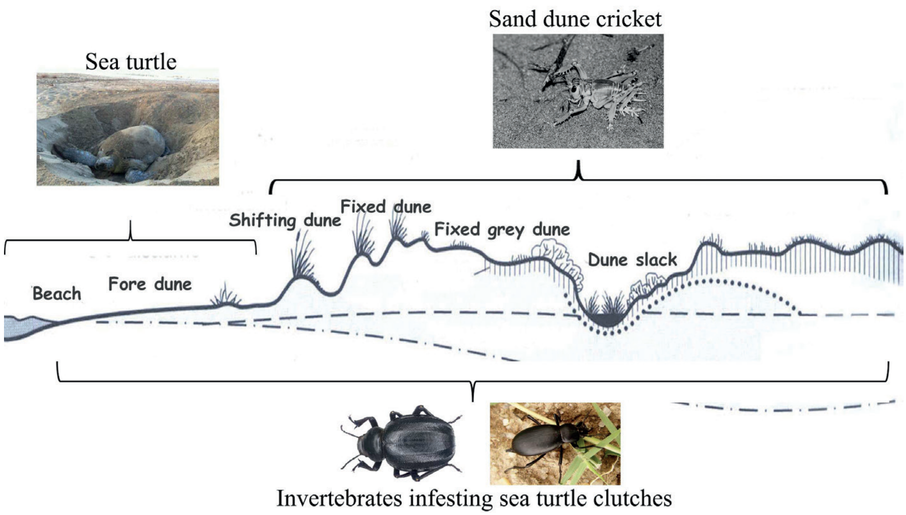

Figure 1. *Illustration showing the sharing of habitats of the sea turtle, endemic sand dune cricket and some of the tenebrionid species distributed in Çukurova Delta (The image was created by G. Aydın).*

Although all species belonging to the Tenebrionidae family seem to be distributed throughout all dune habitats of the delta, it is observed that some species belonging to the family prefer some specific dune habitats. Eighteen tenebrionid species have been identified in the delta so far. Among these species identified by Aydın (2006), only thirteen species were determined to have spread to sea turtle nesting areas (Aydın, 2006). The tenebrionid species that can reach sea turtle nesting areas were identified as *Zophosis dilatata* (Deyrolle, 1867), *Erodius orientalis oblongus* (Solier, 1834), *Scaurus puncticollis dlabolai* (Kaszab, 1959), *Zophosis punctata punctata* (Brullé, 1832), *Ammobius cyprius* Grimm, 1991, *Gonocephalum rusticum* (Olivier, 1811), *Blaps cribrosa* (Solier, 1848), *Dailognatha crenata* Reiche & Saulcy, 1857, *Leichenum pulchellum pumilum* (Baudi di Selve, 1876), *Opatroides punctulatus* *subcylindricus* (Ménétriés, 1849), *Stenosis punctiventris* (Eschscholtz, 1831), *Sclerum humerosum* (Miller, 1861) and *Phaleria acuminata nigriceps* (Mulsant & Wachanru, 1853) according to their abundance in the mentioned areas (Figure 1).

Results and Discussions

The Çukurova Delta was selected as the study area. Three main animal groups were examined in the Çukurova Delta. These animal groups were determined as "sea turtles" that prefer to lay their eggs in the coastal area, "endemic sand dune cricket" living in nearly whole dune habitats except foredune and beach intersections, and "some tenebrionid species" that are thought to damage turtle nests and live in the whole dune habitats. The studies conducted for these three animal groups were examined and the hypothesis that *S. inexspectatus* protects sea turtles by feeding on tenebrionid species that damage sea turtle nests was studied. The aim of the study is to found out the answer of the question; would the endemic sand cricket, which feeds on the invertebrates mentioned above that damage turtle nests, be a key species for protecting sea turtles?

When the list of food preferences of *S. inexspectatus* in the study of Aydın & Khomutov (2008) were evaluated, some individuals of the invertebrate groups on their list were seen only in the larval stages in infested sea turtle nests. Its though that because adult and even immature stage individuals of these invertebrates are probably among the food preferences of dune crickets, the sea turtle nests infested by the larvae of these invertebrates on the beach are also potential food producers for this species. This carnivorous endemic sand dune cricket is a predator that generally feeds on invertebrates in its habitat; moreover, an adult individual can consume at least as much food daily as its own size, and some tenebrionid species adult complete their larval stages in sea turtle nests are prey. When we consider this issue in terms of ecological relationships, a predator/prey relationship emerges.

Tenebrionid adult individuals are also among the food preferences in the habitat of the endemic predatory dune cricket. Large amounts of prey mean greater numbers of predators, so it is believed that the population density of these invertebrates will affect, to some extent, the populations of this predatory species. Besides, there is an important relationship between the plant diversity and insect biodiversity on dune successions (Aydın, 2011a).

The cricket is known as a predator of the tenebrionid and the other invertebrates living in sand dune, and the presence of crickets will prevent increases in the number of pest individuals that will join the reproductive cycle, and the population of the mentioned pest will not increase in sea turtle nests. Endemic sand dune cricket can contribute to the protection of loggerhead and green turtle nests from especially tenebrionid species infestation. Thus, *S. inexspectatus* may be a keystone species to prevent infestation or maintain steady levels of infestation of sea turtle nests on sea turtle nesting beaches within the distribution range of this cricket species.

Channa et. al., (2013) mentioned that *Schizodactylus minor* played a very important role in the local food chain that prevents certain insect population from increasing and becoming dominant in field. Besides Channa et. al., (2013) mentioned that *S. minor* is important food source for reptiles (snakes, wall lizards) and birds in Pakistan. Similarly, it is thought that *S. inexspectatus* might also be a food source for such as reptiles and birds on the delta. These characteristics of *S. inexspectatus* and its importance in the food chain are an indication that this endemic species is a keystone species in dune ecosystems.

Our aims to confirm the hypothesis that the endemic sand dune cricket protects sea turtles by consuming Tenebrionid species that infest sea turtle nests as food. As is known, the endemic sand cricket feeds on many tenebrionid species in the delta and is a polyphagous predator. Some tenebrionid species, which are consumed as food by the endemic sand dune cricket, are known to infest sea turtle nests. Decreasing populations of these pest species may cause sea turtles nests to be less infested. This ecological relationship between the three main animal groups mentioned is an issue that needs to be emphasized for the protection of sea turtles. Preserving the population density of the predatory endemic sand dune cricket could stabilize the populations of invertebrates to some extent.

Another important issue is the protection of the endemic sand cricket, as well as the protection of its habitat. The elimination of *S. inexspectatus* will reduce the pressure on tenebrionids and other species that infest sea turtle nests, and will lead to an increase in the population density of such pests. This will increase the egg infestation rates in sea turtle nests. The protection of these habitats will ensure the protection of *S. inexspectatus* and therefore the sea turtle populations that biologically interact with them. For this reason, in the protection of sea turtles, which are of great importance for the ecosystem, it would be beneficial to protect keystone species with such characteristics in desert ecosystems. Moreover, this study can provide a basis for further studies to identify which invertebrate groups complete their larval stages in infested sea turtle nests and which groups are among the food preferences of endemic sand dune crickets on sea turtle nesting beaches that are in the distribution range of this cricket species.

The protection of the endemic sand dune cricket, which plays an indirect role in protecting sea turtles, also It will be possible with its protection. For this reason, we defend that agricultural areas and construction should not be allowed in regions that need to be protected, especially in Çukurova and Göksu Deltas throughout our country. We believe that protecting our protected areas as required and in accordance with the rules will also protect keystone species in that ecosystem, such as sea turtles and endemic sand crickets, as well as many valuable species that have not yet been discovered.

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CHAPTER 9

APPLICATIONS RELATED TO THE USE OF SALICYLIC ACID IN FRUITS

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ENTRANCE

Abiotic stress factors are important factors that negatively affect the development and deterioration. Abiotic stress factors are stress factors such as drought (water), temperature, freezing, cold, salt, light and heavy metal stresses. Normal deteriorations of these parameters that occur during the development process, growth distribution, flower and pollen development, fruit formation and their results may decrease, and even the emergence of these stress conditions at a severe level may lead to the initial formation at the beginning (Jaleel et al. 2009).

One of the important effects on the development process of the plant is the types of drought and the effects that occur accordingly. Drought is exhibited more in the period from initial pollination to grain filling time. Terminal drought, which occurs in these periods, negatively affects plant metabolism and initial results. It causes morphological, characteristic and biochemical changes in plants (Yavaş et al. 2016). The most important factor that eliminates the threat of production in the world is drought. Drought stress reduces the central neck, root length, leaf spacing, fresh and dry biomass . It accelerates the formation, development and aging of the grain, and as a result of the decrease in assimilate change, thousand grain weight, grain number, yield and quality do not decrease.

Studies are being carried out on processes to be increased to meet the stress conditions of recent years. This ability, such as salicylic acid, has been discovered to have positive effects on plants. SA reduces water losses by regulating the number and spacing of stomata , and accelerates photosynthesis. Increasing the resistance of the plant to drought and maintaining its development (Yavaş et al ., 2016).

Researcher Johann Buchner was able to isolate a very small amount of salicin from the bark of the willow tree in a study he conducted in Munich in 1828. Salicylic acid (SA) was first discovered by scientist Raffaele It was developed by Piria in 1838 in a laboratory environment from the willow plant (*Salix Alba* L.) could be obtained (Lee et al. 1995; Popova et al. 1997) .

Centuries ago, the Romans came to the willow tree when everyone was cured of fevers and pains (Raskin 1992). Today, most scientists believe that it contains salicylic acid and has been an important part of the plant's development (Lynn and Chang 1990, Arteca 1996).

It has been reported that SA provides resistance to plants against adverse environmental conditions such as drought, salinity, high/low temperatures and has economic benefits. Adaptation to the intensity of stress changes varies. These mechanisms are activated by the reorganization of metabolism and the action of defense structures. Molecules such as calcium, jasmonic acid, abscisic acid, as well as salicylic acid, known to be the growth promoters of plants, play an important role in the transmission of stress dissipation and activation of the initiation of initial tolerance (Klessing and Malamy 1994, Hayat et al. 2010). The development of such defense development in plants is important in terms of increasing the sustainability of food production and protecting the management. SA applications increase the water level in the tissues, allowing antioxidant enzymes to work more effectively and thus helping to ensure survival even in drought conditions.

SA is a natural plant that exhibits various characteristics on plants. It is especially effective in formation development and growth efficiency. In the dry period when plants are under stress, their growth rate slows down, fruit production and yield decrease (Baranyiova et al ., 2014). SA plants made in this way can accelerate plant metabolism and encourage plants to increase and pollen production, thus allowing them to bear fruit. However, it is important that SA applications are made in controlled doses. Because high doses can cause stress in plants and negatively affect growth.

Salicylic acid has gained an important place among plant hormones today. After being synthesized in drugs, SA can be rapidly transported from the place where it is produced to other tissues without being metabolized and actively transported. Plants grown in agriculturally important plant species contain SA in their plants at all times and everywhere (Özeker , 2005).

As a result of the studies, it is revealed that the degradation of SA is effective in modeling the responses to water deficiency. Pre-application options with SA applications in plants; Increased water content in plant tissue, increased activity of statistical enzymes, these changes play an important role in survival under drought and counteracting the negative effects of stress on growth and yield. SA, a phenolic natural, is widely used as an endogenous hormone-like function. It plays an important role in defense mechanisms against both biotic (living source) and abiotic (environmental) stress workers (Zhang et al. 2011; Loutfy et al. 2012).

Drought, especially the transition period of growth (pollination and grain filling stages), creates more serious effects and is called "terminal drought". During this period, drought causes various morphological, characteristic and biochemical changes in the plant, negatively affecting yield and quality. Terminal drought prevents the center from being wiped out by systems such as water loss, stomatal closure, and slowing down of photosynthesis. In addition, as a result of the addition of assimilates (products such as carbohydrates), grain number, thousand grain weight and general yield decrease (Yavaş et al. 2016).

High temperature is also an important stress condition in agricultural enterprises. High resistance levels among cultivated plants vary. SA, which increases the tolerance of plants to different stress conditions and acts as a molecule in the plant temperature range, attracts attention. Therefore, SA, which is an external effect on the plant before heat stress, can increase the original temperature values (Altinci et al. 2020)

Among abiotic stress factors, reproduction, cold stress or freezing stress are important factors that limit plant production (Reyes and Jennings , 1994). Plants can develop resistance to freezing stress. Salicylic acid (SA) is a natural internal growth extension and signal molecule that provides change in plants (Fariduddin et al ., 2003; Gunes et al., 2007). It is studied that external salicylic acid applications are effective in reducing freezing stress and improving tolerance to cold by regulating plant biology (Tasgin et al ., 2003). Today, discussions on the changes in temperature degrees of freezing stress are still ongoing.

USE OF SALICYLIC ACID IN FRUIT PRODUCTION

Studies are being carried out on processes to be increased to meet the stress conditions of recent years. This ability, positive effects on plants such as salicylic acid have been discovered. SA can accelerate water losses and photosynthesis by regulating its stocks . At the same time, it increases resistance to initial drought and provides sustainability. SA provides resistance to plants against adverse environmental conditions such as drought, salinity, high/low temperatures and provides economic benefits.

Stress resistance enables growth rates to adapt. These mechanisms operate through metabolism reorganization and defense disruption. In particular, molecules such as calcium, jasmonic acid, abscisic acid, as well as SA, play a role in transmitting stress lysis and activating the initial gap initiation (Klessing and Malamy 1994, Hayat et al. 2010).

The obtained data and literature information details show that external SA applications can be easily used against freezing stress due to the reasons such as protecting the natural balance without harming living things such as pollinator states, increasing adaptation, yield and quality, being economical and being able to apply simple methods (Ünal et al ., 2015).

As a result of salicylic acid applications after harvest in apples, which are climacteric fruits, salicylic acids can inhibit ethylene synthesis, reduce central systemic resistance and thus reduce fungal rot in systems. In the decomposition of fruits, SA positively changes rooting and accelerates photosynthesis (Sabir et al. 2013; Hayat et al. 2007).

One of the most important problems in cultivation is drought, which is an event that the plant goes through at every stage and the return in the last stage is serious. The daily physical appearance and chemical change of the stress experienced by the plant during the development process change significantly. Water stress causes the moisture content to be preserved, the stomata to close and the physical activities to be performed successfully. When the environment cannot be fulfilled, the chlorophyll rate decreases. In order to minimize the effect of drought on the plant, nutrient applications should be made. The fact that this production takes place during or before the development process, the results are positive. Salicylic acid applications are important applications that affect plant pests from outside. Plant developments have positive effects (Yavaş et al. 2016).

Yıldız et al. (2014) stated that SA and PA applications have positive effects on plant development in plants such as SA and polyamine (PA) against different abiotic stresses, negative degradation and this stress and are an effective method in protecting plants under different stress conditions. It was emphasized that it is necessary to determine the appropriate SA and PA amounts for different plant species and commercial applications should be made based on these comparisons.

During storage of pear fruits, salicylic acid applications are also used as edible surface coating after harvest. It has been observed that the softening of the fruit flesh hardness is significantly delayed. The diagram of the effects of salicylic acid (SA), methyl salicylate (MeSA) and Semperfresh (SMF) applications in order to delay the life of the Deveci pear variety during the storage period and to preserve its quality ; It has been determined that the ripening period of the fruits is extended and the shelf life of the fruits is increased, the fruit flesh hardness is not negatively affected, even there are no bursts, and the biochemical compounds are also preserved (Sakaldaş and Gündoğdu, 2016).

After the harvest of the Kütahya sour cherry variety, the processes carried out to store the fruit in cold conditions and to preserve the quality change throughout the shelf life; It has been observed that the application life of the fruit with salicylic acid in different regions is extended, the durability and shelf life of the fruit are extended, and the flesh firmness of the fruit is preserved for a longer time (Ufitinema et al.2023).

In the research conducted by Çoban (2023) in Şanlıurfa, characters that are separated from the seedling breakage of walnut variety, germination and development of seedlings. SA and stratification applications provide positive contributions to germination and seedling rates.

salicylic acid (SA) and gibberellic acid (GA3) applications on tree and cold storability in satsuma tangerines, it was determined that it prevented the shedding of the fruit in use, delayed the peeling and increased the duration of the fruit on the tree (until January). In addition, it was observed that the storage of the fruit, deterioration in the fruit and quality loss were limited. In pre-harvest applications to satsuma tangerine fruits, it prevented fruit decay due to ripening by inhibiting ethylene synthesis and increased fruit firmness and water yield. (Kutlar and Şen ., 2021)

Salicylic acid (SA) is a natural fruit product that has been proven to increase the privacy. The effect of SA on the MD2 pineapple section was observed in the cold storage of MD2 pineapple after SA applications for up to 40 days (Cano Reinoso and Wibowo , 2023).

The shelf life characteristics of peach fruit directly affect quality. As determined by Erogul and Özsoydan (2020), SA-applied fruits show better characteristics such as fruit weight, fruit flesh variety, total antioxidant content, total phenol content and titratable acidity, and their storage, fruit flesh hardness and loss are reduced. It was determined that cold infection, which is one of the most important handicaps in the storage of apricot fruits, was reduced with SA application, decay was prevented and storage increased (Ezzat et al ., 2017).

CONCLUSION AND RECOMMENDATIONS

Salicylic acid has been found to play an important role in plant biology since it was first isolated from the willow tree. In recent years, SA significant progress has been made in the biosynthesis and metabolism. The increasing effect of SA in the chambers against resistance may be linked to the thermogenic (heat-producing) parts in the temperature. SA It is important to determine the genes and pathways involved in the biosynthesis of plants and to conduct research in terms of plant protection and biotechnology .

SA is beginning to be accepted as a growth extension that is compatible with the disruptions for plant hormones and is used in management practices. In SA diseases in plants, it contributes to a high rate of contribution together with transgenic plant studies. Especially SA applications have an important role in increasing the response to stress conditions.

The development of such defenses in plants is important in terms of increasing the sustainability of food production and protecting the management. Salicylic acid has been shown to have protective properties against salt stress. With the selection and variety of plants resistant to salt stress, the use of widespread SA, such as arid and saline soil structures; It has been concluded that higher plant yields will be obtained from unit area. Researchers have revealed the relationships between drought and salinity stress and plants. Many studies have been conducted to determine how salicylic acid affects plants against salt stress for this purpose. The growth made, the characteristic features of SA in plants produced in saline agricultural areas are seen to be important.

Plant structure naturally synthesized SA will be beneficial in adverse field conditions, will reduce drought and salt damage, will have a positive effect on crop yield, and others will have reduced crop loss. In addition, even partial success in soils with different salinity characteristics may lead to new expansion in agriculture.

The most important problem that shortens the storage life of soft-stone and hard-stone fruits is the hardness of the fruit flesh that merges in a short time during storage. Salicylic acid applications have been made mostly to find a solution to this problem. The data in the research results have been shown successfully, even if it is data.

Salicylic acid (SA) applications are considered as a promising tool in agriculture. SA can be recommended from the perspective of yield values , which are environmentally friendly and at the same time affordable . However, new cases need to be carried out in field conditions in order to ensure the continued potential benefits of SA , to better understand the existing ones and to identify different areas of effect .

Resources

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CHAPTER 10

THE EFFECT OF DIFFERENT NITROGEN FORMS AND DOSES ON SOME YIELD CHARACTERISTICS OF ANNUAL RYEGRASS[1]

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1. INTRODUCTION

Our country is one of the most important countries in Europe with a population of more than 82 million. In the past, the majority of the country's population lived in rural areas and earned their livelihood from agriculture. In recent years, the rural population has been decreasing due to migration to cities. Along with urbanisation, changes in people's dietary patterns increase the interest in animal foods (Özdemir, 2019). The need for proper and balanced nutrition of humans and animals is one of the important problems not only in our country but also in many countries. It is necessary to ensure proper and balanced nutrition for the rapidly increasing population by maximising the use of limited natural resources (Kesiktaş, 2010). The demand for food increasing with the population triggers animal and plant production. Eggs, meat, milk and other derivative foods that play an important role for humans in nutrition are animal protein. Amino acids, which play an important role for the growth and development of an ordinary person, are abundant in animal proteins. For this reason, the main material required for the development of animal husbandry is feed and its main sources are meadow and pasture forage plants (Sezgin, 2014).

Companies and large institutions that want to realise animal husbandry activities in material terms have to grow a significant part of the high quality roughage obtained from pasture and fodder plant production themselves. Dairy cattle breeding is not possible without high quality feed. Dairy cows need to consume an appropriate amount of feed to provide the desired milk fat for a regular digestive system and milk yield. Legume forage crops represent the highest quality, protein-rich roughage in forage crops. In addition, meadow and pasture forages and dry grasses are also considered as high quality roughages (Çelik and Şahin Demirbağ, 2013).

Annual ryegrass (*Lolium multiflorum* Lam.) is one of the most valuable forage crops today as a cheap, efficient and high quality feed. Italian ryegrass, which is widely used in animal husbandry in developed countries, is a palatable forage crop rich in protein, dry matter, soluble carbohydrates and minerals. It is also an excellent supplement to solve the feed problem of Turkish livestock. It is widely cultivated throughout our country, especially in the Mediterranean, Marmara and Aegean regions. Forage crop cultivation is one of the strategies to meet the high quality roughage needs of the country's livestock. It is known that legume forage crops are protein sources and wheat forage crops are carbohydrate sources in animal nutrition. It is stated that Italian ryegrass is one of the wheatgrass forage crops with the highest roughage production potential and fertiliser use efficiency (Açıkgöz, 2001).

While the cultivation area of Italian ryegrass in our country was 4832 decares and 17023 tonnes of green grass yield in 2014, this situation reached 373275 decares of cultivation area and 1380195 tonnes of green grass yield in 2021 (TÜİK, 2022).

In order to address the yield and quality investigated in forage crops, the plants must be fertilised in appropriate combinations and ratios at the required times. In addition to yield, feed quality has the greatest value for animal health. Nitrogen, the most important nutrient for plants, constitutes the majority of dry matter. In addition, nitrogen is incorporated into proteins, chlorophyll, enzymes and vitamins in plants. Nitrogen is the most widely used nutrient.

Nitrogen fertilisers in appropriate amounts increase protein content, but excess nitrogen use in plants also leads to the accumulation of nitrates and alkaloids.(Bellitürk et al., 2007) A positive response has been reported in Italian Grass in nitrogen fertiliser application (Çolak, 2015; Özdemir et al., 2019). Nitrogen fertilisation is the most widely used method in agricultural practices and plants can only utilise 30-35% of the nitrogen used. On the one hand, significant amounts of nitrogen enter the atmosphere through evaporation every year, but on the other hand, it is washed out of the soil and can no longer be used by plants. The aim of this study was to determine the effect of appropriate nitrogen forms and doses on yield and some other yield characteristics of Italian ryegrass (*Lolium multiflorum* Lam.) in order to close the yield and quality feed deficit in our country. Çolak (2015), in a study conducted with Italian ryegrass under Central Anatolian conditions in 2008 and 2009 using 4, 8, 12, 16, 20 and 24 kg da^{-1} pure nitrogen, reported that plant height ranged between 50.1-68.3 cm, crude protein yield ranged between 54.84-58.04 kg da^{-1}, green grass yield ranged between 1931.8-845.5 kg da^{-1} in 8 kg da^{-1} nitrogen application for the best quality grass yield. Çetin (2017), in the study investigating the effects of nitrogen application (0, 5, 10, 15, 20, 25 and 30 kg da^{-1}) on the yield and quality of winter sown annual ryegrass in Tokat-Kazova conditions; it was observed that the average plant height of Italian ryegrass was obtained from 20 kg da^{-1} nitrogen application with 109.7 cm. It was also reported that dry matter yield (1222.6 kg da^{-1}) and the highest green grass yield (4544.2 kg da^{-1}) were obtained at 25 kg da^{-1} nitrogen application.Bıçakçı and Türk (2018) investigated the effect of seven different nitrogen applications (0, 5, 10, 15, 20, 25 and 30 kg N da^{-1}) on the herbage yield and quality of Italian ryegrass and reported that the increase in nitrogen application increased hay yield, crude protein content and yield. They stated that the highest herbage yield and forage quality were obtained at 25 kg da^{-1} nitrogen application.

Assouma and Çelen (2022) investigated the effect of different nitrogen doses (0, 7.5, 15, 22.5 and 30 kg da^{-1}) on grass yield and silage quality in four Italian ryegrass cultivars (Elif, Big Boss, Baquend and Medoacus) under Izmir conditions. As a result of the study, 15 kg nitrogen dose application per decare was recommended.

2. MATERIAL AND METHOD

The research site, where the effects of different nitrogen norms and different nitrogen doses on yield and some other yield components of Italian ryegrass (*Lolium multiflorum* Lam.) were investigated in the experiment fields of Ege University Faculty of Agriculture, Department of Field Crops, during the 2021-2022 growing period, is located at the coordinates intersecting between the beginning of 38°27'05.95" north latitude and 27°13'29.37" east longitude, and its height from the sea is approximately 27 metres.

The data on monthly total precipitation and monthly average temperature values of the experimental site are shown in Table 1 (Anonymous, 2022). The data on monthly total precipitation and monthly average temperature values of the experimental site are shown in Table 1 (Anonymous, 2022).

Table 1. Some climatic data of the research area (Anonymous, 2022)

MONTHS	Monthly Total Precipitation (mm)		Monthly Average Temperature (°C)	
	Long Years	2021-2022	Long Years	2021-2022
November 2021	95	51.9	14.1	12.4
December 2021	144	178.3	10.5	11.2
January 2022	121	34.1	8.8	7.9
February 2022	101.9	132.2	9.5	10.0
March 2022	74.3	24.8	11.7	8.6
April 2022	47	18.4	15.8	17.7
May 2022	29.3	6.1	20.7	22.3
Total/Average	613.5	445.8	13.01	12.8

When the values in Table 1 are analysed, it is understood that a typical Mediterranean climate prevails in the experimental area. When the temperature values in the region where the trial area is located are examined throughout the planting season, it is observed that the average temperature reached the highest value in May (2022). The average rainfall in the same month is the lowest with 6.1 mm. In addition to the drought conditions caused by low rainfall, the large amount of water released into the atmosphere by plants through transpiration during this period plays an important role in the decrease in nutrient yield. In order to ensure optimum yield in this period, the irrigation system must meet the water needs of the plants.

In order to determine the soil properties of the trial area, soil samples (0-30 cm) taken from the field in the trial area in accordance with the procedure were physically and chemically analyzed at Ege University Faculty of Agriculture, Department of Soil Science and Plant Nutrition and the results obtained showed that the soil of the trial area is loamy at a depth of 0 to 30 cm, and this alluvial structure, which is the Bornova Plain, shows a very heavy soil quality. The pH value determined at 0-30 cm depth was 7.88, indicating that the soil in the parcel was slightly alkaline. For annual ryegrass a pH range of 5.0 to 7.8 is reported as the most suitable range (Assouma, and Çelen, 2022). As a result of the examination of climate and soil characteristics, it was determined that there were no factors preventing the growth and development of the plant material used in the experiment.

In the research, the material used as seed was obtained from the private sector. Italian ryegrass (*Lolium multiflorum* Lam.) "Baqueano" variety was used.

2.1 Method

In this research conducted during the 2021-2022 growing period, the effects of two different nitrogen forms and different doses on yield, yield components and quality of Italian ryegrass (*Lolium multiflorum* Lam) as top dressing were investigated. The experiment was organised with 2 factors and the factors considered are given below.

a) Nitrogen forms: Urea and Urea+NBPT ((N-(n-butyl) thiophosphoric triamide)) inhibitor were used as 2 different nitrogen fertiliser forms.

b) Nitrogen doses: In the study, 5 different nitrogen doses (0, 5, 15, 20 and 25 kg da^{-1}) were applied.

The research was organised according to the randomised blocks experimental design with 3 replications and the plots were established as 2x2=4 m^2. A gap of 2 m was left between the blocks.

Preparation of the research area and soil tillage was started 15 days before sowing, the field was firstly ploughed with a plough at a depth of 20-25 cm and the field was made ready for sowing by sowing. After all the operations, the parcellation process was started and the operations were carried out according to the experimental plan.

2.2 Sowing and maintenance

Germination tests were carried out before sowing. The amount of seeds to be sown per decare of Annual ryegrass was determined as 4 kg da^{-1}. The sowing process was carried out manually on 19 November 2021, when the temperature and soil conditions were suitable for the rows opened with 20 cm row spacing with the help of a marker, with 10 rows in each plot. Immediately after sowing, the seeds were covered with soil and irrigation was applied. Along with sowing, 25 kg da^{-1} of 12.12.12.12 organomineral fertiliser was applied with the calculation of pure 3 kg nitrogen per decare. In the nitrogen fertiliser application, half of the nitrogen was applied with sowing and the other half was applied during the emergence period. The first irrigation was applied on the same day after sowing in order to help seed germination. In the experimental field, irrigation was carried out after sowing when necessary. After sowing, weeds were controlled by hand and with the help of a weed whacker until the plant harvest was completed and no herbicide was applied.

During the harvesting period; harvesting operations were carried out in the area remaining after the edge effect was removed in each plot. The plants were harvested by mowing at a height of 5 cm on 15 May 2022 during the spike emergence of Italian grass.

In the study, Herbage yield (kg da^{-1}): The middle 2 rows of each plot were harvested and mowed.weighed and the values found were converted to decare. Dry matter yield (kg da^{-1}): Dry matter yield was calculated by multiplying dry matter rate with herbage yield. Crude protein content (%): After the samples taken from each plot were dried and ground with a blender, nitrogen analysis was performed on the ground samples, and the obtained ratios were multiplied by a coefficient of 6.25 and crude protein ratios were determined as %. Crude Protein Yield (kg da^{-1}): Crude protein yields were obtained by multiplying the crude protein ratios obtained for each plot by the dry grass yields.

The results obtained from the experiment were statistically analysed using "TOTEMSTAT" statistical evaluation programme. In the analyses, the least significant difference (LSD 5%) value was calculated and shown in the lower part of the tables (Açıkgöz et al., 2004).

3. RESULTS AND DISCUSSION

Herbage yield (kg da^{-1}) and Dry Matter Yield (kg da^{-1})

The values of different nitrogen forms and doses for green grass yield of Italian ryegrass are shown in Table 2.

According to the results of the statistical analysis of the data related to green grass yield, it was observed that nitrogen doses had a significant effect, while fertiliser forms and fertiliser x nitrogen doses interactions were not statistically significant. In terms of nitrogen doses, the highest green grass yield was determined at 20 kg da^{-1} nitrogen dose with 2631 kg da^{-1}. The lowest green grass yield value was obtained from the control (0 dose) application with 1175 kg da^{-1}.

High yield is the most important target in crop production in order to provide feed for animal production. Yield is one of the first traits checked to compare crop performance.

Since it is a quantitative trait, it is affected by all factors such as the number of plants per unit area, plant type and maturation period, utilisation method, sowing time, harvesting time and the amount of nitrogen applied.

As can be seen in Table 2, it is observed that green herb yield increases with increasing nitrogen doses and decreases in yield after 20 kg da^{-1} nitrogen dose application. Our green herb yield values obtained are similar to the green herb yield values of İnce (2000) 1388.7-2509.2 kg da^{-1}; Kavut and Geren (2018) 2305 kg da^{-1}; Özdemir (2019) 2071.0 kg da^{-1} and Aktar et al. (2021) 1798.1-2764.8 kg da^{-1}.

It was observed that our findings were lower than the 5193 kg da^{-1} obtained by Göktepe (2015) and 3377.33-4457.67 kg da^{-1} obtained by Vural and Kökten (2020) in studies conducted in different locations. These differences are thought to be due to ecological conditions, nitrogen forms applied and genetic structure.

Table 2: Effect of different nitrogen forms and doses on Herbage Yield (kg da^{-1}), Dry Matter Yield (kg da^{-1}) Annual ryegrass

NITROGEN DOSES (kg da^{-1})	HERBAGE YIELD (kg da^{-1})			NITROGEN DOSES (kg da^{-1})	DRY MATTER YIELD (kg da^{-1})		
	UREA	U+NBPT	Mean		UREA	U+NBPT	Mean
0	1142	1208	1175	0	301	320	311
5	1896	2082	1989	5	483	527	505
15	2145	2167	2156	15	535	533	534
20	2637	2625	2631	20	665	656	660
25	2318	2467	2393	25	590	624	607
Mean	2028	2110	2069	Mean	515	532	523
LSD (%5): F: ns ND:140 FxND:ns				LSD (%5): F:1 ND:2 FxND:3			

In the statistical evaluation, it is understood that the factors of nitrogen doses and fertiliser forms and the interaction of fertiliser x nitrogen doses do not contain statistically significant differences in dry matter yield. Dry matter percentage depends on the amount of water in the plant and this is possible with the presence of structural and non-structural compounds or organelles in the plant. In general, although the percentage of water is high in young cells and tissues where physiological activities take place strongly in plants, physiological activity and water content decreases as cells and tissues age.

The values of different nitrogen forms and doses for dry matter yield of Italian ryegrass (*Lolium multiflorum* Lam.) are given in Table 2.

When the results of the statistical analysis were evaluated, it was observed that the nitrogen doses factor had a significant effect, while the fertiliser forms factor and fertiliser forms x nitrogen doses interactions were not statistically significant. When evaluated in terms of nitrogen doses; the highest dry matter yield value was obtained from 20 kg da^{-1} nitrogen application with 660 kg da^{-1} and the lowest dry matter yield value was obtained from the control nitrogen dose in 311 kg da^{-1} nitrogen application. When the dry matter yield data obtained according to the research results are evaluated; Kuşvuran and Tansı (2005), 620.20-677.00 kg da^{-1} in Çukurova; Gültekin (2008), 657.06-1103.83 kg da^{-1} in Çukurova, Şimşek (2015), 205. 30 kg da^{-1}, Fessehazion et al. (2011), 1561.00 kg da^{-1} in South Africa, Peker (2013), 462.66-663.66 kg da^{-1} in Ankara, Çetin (2017), 781.9 kg da^{-1} in Tokat, Özdemir (2017), 550.10-1697.10 kg da^{-1} in Bursa, Aktar et al. (2021) reported that they obtained 435-671 kg da^{-1}.

In our research, it is observed that we obtained higher results than some of the results and lower results than others. It can be thought that these differences may be due to different ecological conditions and different factors such as applied fertiliser forms, sowing time, harvest time.

Crude Protein Ratio (%) and Crude Protein Yield (kg da^{-1})

When the results of the statistical analysis were evaluated, it was observed that the nitrogen doses factor had a significant effect, while the fertiliser forms factor and fertiliser forms x nitrogen doses interactions were not statistically significant (Table 3). When analysed in terms of nitrogen doses; the highest crude protein ratio values were obtained in 25 kg da^{-1} and 20 kg da^{-1} nitrogen applications with 12.95% and 12.90%, respectively, and the lowest crude protein ratio was obtained from the control application with 11.35%. The values obtained for crude protein ratio were higher than the values obtained by Kesiktaş (2010) as 9.7%, Barchiesi-Ferrari et al. (2011) as 12%, Çolak (2015) as 11.17%, Türk et al. (2019) as 7.13% and Aktar et al. (2021) as 10.3-12.3%. Our findings were lower than the values of 13.20% by Özdemir et al. (2019). It was similar to the values of Şimşek (2015) 11.58%, Kavut and Geren (2018) 11.40%, Çetin (2017) 12.9% and Türk et al. (2019) 7.13-14.07%.

In our research, increases in crude protein ratios were also observed with the increase in nitrogen doses applied. Kesiktaş (2010); Bıçakçı and Türk

(2018); Özdemir et al. (2019); Türk et al. (2019); Çolak and Sancak (2016) stated that the crude protein ratio increased in Italian grass as the nitrogen dose increased. Kuşvuran and Tansı (2005) reported that the crude protein ratio increased in parallel with the increase in nitrogen dose and the highest crude protein ratio was obtained from 25 kg da^{-1} N dose. These results support the results obtained from our study.

When the results of the statistical analysis of crude protein yield were examined, it was observed that the factors of fertiliser forms and nitrogen doses had significant effects, and the fertiliser x nitrogen doses interaction was also found to be statistically significant. As can be seen in Table 3, the highest crude protein yield values were obtained from urea+NBPT with 103 kg da^{-1} and urea application with 101 kg da^{-1} and 20 kg da^{-1} nitrogen application. The lowest crude protein yield values were obtained from the control application of Urea+NBPT and Urea treatments with 40 kg da^{-1} and 41 kg da^{-1}, respectively. The average crude protein yield values were determined as Urea (74 kg da^{-1}) and Urea+NBPT (77 kg da^{-1}) in the applied fertiliser forms.

When the obtained data were analysed in terms of nitrogen doses, the highest crude protein yield was obtained from 20 kg da^{-1} nitrogen application with 102 kg da^{-1} and the lowest value was obtained from the control application with 41 kg da^{-1}.

Table 3 . Effect of different nitrogen forms and doses on Crude Protein Ratio (%) and Crude Protein Yield (kg da^{-1}) and in Annual ryegrass

NITROGEN DOSES (kg da^{-1})	CRUDE PROTEIN RATIO (%)			NITROGEN DOSES (kg da^{-1})	CRUDE PROTEIN YIELD (kg da^{-1})		
	UREA	U+NBPT	Mean		UREA	U+NBPT	Mean
0	11.50	11.20	11.35	0	41	40	41
5	11.50	11.57	11.53	5	63	64	63
15	12.25	12.50	12.38	15	81	86	84
20	12.85	12.95	12.90	20	101	103	102
25	12.90	12.99	12.95	25	85	91	88
Mean	12.20	12.24	12.22	Mean	74	77	76
LSD (%5): F:ns ND:0,391 FxND:ns					LSD (%5): F: 1 ND:2 FxND:3		

As a result of the research, it is seen that the crude protein yield values are in harmony with the crude protein yield values of Akgül (2001) 79.8 kg da^{-1}, Kesiktaş (2010) 52.6 kg da^{-1}; Pavinato et al. (2014) 75.9-87.4 kg da^{-1}; Çetin (2017) 91.6 kg da^{-1}; Kavut and Geren (2018) 48 kg da^{-1}, Özdemir et al. (2019) 55.43 kg da^{-1}.

4.CONCLUSION

In order to make sustainable agriculture valuable in Turkey and to increase the yields in limited areas, important findings were found in the results of the study. According to the results of the study conducted in Bornova/Izmir conditions; it is observed that the highest herbage yield and other yield and quality characteristics of Italian ryegrass were obtained at nitrogen doses of 20 and 25 kg da^{-1}. Based on the general results of this study, 20 kg da^{-1} Urea+NBPT nitrogen application can be recommended as top fertiliser for Annual ryegrass plant under the climate and weather conditions of our region in terms of both environmental pollution and being more economical. According to these results, it is thought that it would be more appropriate to repeat the study for one more year in order to make healthier recommendations.

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CHAPTER 11

TURKEY'S GLOBALLY THREATENED AND PROTECTED FISH SPECIES AND STRATEGIES FOR THEIR CONSERVATION

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Turkey's coastline, totaling 8 210 km, stretches along the Mediterranean Sea in the south, the Aegean Sea in the west and the Black Sea in the north. In the northwest of the country, between the Istanbul Strait and the Çanakkale Strait, lies the Sea of Marmara, an important inland sea that connects the Black Sea to the rest of the world by sea. The country is roughly rectangular in shape, 1 600 km from west to east and 650 km from north to south, and is located between 25°40'-44°49' East longitude and 35°51'-42°06' North latitude. With its geographically important location, being one of the 40 largest countries in the world, in other words, its large surface area and growing population, Turkey has a critical role for the stability of the region.

Biodiversity refers to the differentiation among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which these ecosystems are a part, including diversity within and between species and ecosystem diversity. Biodiversity includes diversity within and between species and ecosystems, but also includes not only living beings but also their environment. In today's world, many fish species in marine and freshwater ecosystems are facing extinction due to many factors such as environmental changes, overfishing, habitat loss and pollution. This situation threatens the balance of ecosystems and creates a serious concern for the conservation of biodiversity. Conservation of endangered fish species is critical not only for their future, but also for the health of marine and freshwater ecosystems. Worldwide, assessments of fish species conservation show that the most threatened species internationally are those that are overfished and have narrow ecosystems. In addition to their ecological role, many endangered fish species are of economic and cultural importance to human life.

These species contribute to the healthy functioning of seas and ponds, but also have an impact on people's lives in areas such as food, trade and tourism. The International Union for Conservation of Nature (IUCN) divides endangered fish species into several categories. These categories include different levels such as "critically endangered", "endangered" and "vulnerable". Species that are not well protected are rapidly being classified in these categories, and the number of protected species is increasing (IUCN, 2024).

For nearly three decades, endangered species have been published on the Red List created by the World Union for Conservation of Nature and Natural Resources (IUCN). Following the first studies on this subject, the new system was established in 1994. One of the most important aims of this system is to identify the factors affecting the threat of extinction of living things in the natural environment and to explain this to people. This system includes a wide range of taxa. The Red List was created with the arrangements made by Mace and Lande, Mace et al., IUCN, Mace and Stuart, IUCN /SSC Criteria Review Working Group and Gardenfors et al. In the most recent revision made by

IUCN, in addition to the list of threatened species, the new version was revised in line with the changes affecting the criteria, the definition of some key names, the finalization of imprecise criteria and the suggestions of the working groups.

SOME THREATENED AND PROTECTED FISH SPECIES

While many fish species are endangered, some are particularly endangered. Here are some of these species:

1) **Sturgeons (Acipenseridae)**

Sturgeons are found only in the northern hemisphere. The Caspian Sea, which until recent years accounted for 90% of the world's sturgeon catch and has sturgeon stocks where the highest quality caviar is produced, is still the focal point of sturgeon fishing and caviar production (Williamson, 2003). Between 1950 and 1960, artificial production of sturgeon was accelerated in order to compensate for the spawning areas lost due to the dams built on the rivers flowing into the Caspian Sea and the Sea of Azov, which constitute the spawning grounds of sturgeon. In this way, it is aimed both to protect natural populations and to increase stocks.

Thus, in the 1970s and 80s, sturgeon catches in the Caspian Sea and the Sea of Azov increased dramatically (Barannikova et al., 1995). However, after the collapse of the Soviet Union, increased illegal and poaching caused serious reductions in the number of broodstock required for hatcheries (Burtsev et al., 2002). Due to the high value of sturgeon caviar, despite all the measures taken, illegal and unregulated fishing could not be completely prevented, which caused stock replenishment alone to be insufficient. On the other hand, it should be taken into consideration that unconscious stock replenishment may cause negative effects on genetic diversity (Secor et al., 2002).

Sturgeon is a large and ancient fish species belonging to the family Acipenseridae and usually living in rivers, lakes and seas. Sturgeons have a lineage dating back thousands of years and are also known as "living fossils". There are 29 different species of sturgeon in the world, but some species are in danger of extinction. Sturgeon is an economically important fish, especially for its meat and eggs (caviar), depending on its sex. In the Black Sea, A. sturio, A. gueldenstaedti, A. stellatus, A. nudiventris and H. huso, which are naturally found in Turkish waters, are covered by Annex I, while A. sturio is covered by Annex II. After Turkey became a party to the convention in 1996, the fishing of sturgeon in Turkish waters was completely banned within the scope of the circular prepared by the General Directorate of Protection and Control of the Ministry of Agriculture and Rural Affairs regulating the fishing of aquaculture products for commercial purposes in the seas and inland waters (Ustaoğlu et al., 2004).

2) **Bluefish (Pomatomus saltatrix):** Bluefish is especially protected by fishing bans and catch limits.

3) **Turbot (Scophthalmus maximus**): The turbot is strictly protected due to its declining population.

4) **Coral (Pterophyllum sp.):** Coral species play an important role in protecting the marine ecosystem and some of them are among the vulnerable species.

5) **Vimba vimba, Alburnus spp**. are important species in freshwater ecosystems and some are threatened.

6) **Sea fish such as sea bream and sea bass:** Sea bream is a marine fish native to the Mediterranean and Aegean Sea. Due to overfishing and habitat degradation, regulations are in place to protect the species. Fishing of these species is also restricted in certain periods.

7) **Mountain trout (Salmo trutta macrostigma**): This species is endemic to the Mediterranean Sea and lives mainly in Turkey and neighboring countries. This fish is under serious threat due to overfishing and habitat loss. Pollution of natural habitats and changing water levels have made this species even more vulnerable.

8) **Bluefin Tuna (Thunnus thynnus):** Bluefin tuna is one of the largest fish in the sea and is of great commercial value worldwide. However, its population has declined rapidly due to overfishing. Bluefin tuna is endangered and various conservation measures are being taken to regulate its international trade.

9) **Bluefish (Pomatomus saltatrix**): Bluefish is a fish species found especially in the Black Sea and the Aegean Sea. However, the number of this species is decreasing every year due to overfishing. Although bluefish is an economically important species, it is one of the species whose populations should be protected and fishing regulations should be made.

10) **Freshwater Mullet (Arabibarbus grypus):** Freshwater mullet is an endangered fish species found in some freshwater lakes in Turkey. It is threatened by water pollution and changes in water levels in its habitat. In addition, settlements and agricultural activities in ponds also make it difficult for this species to survive.

11) **Trout (Salmo trutta):** Trout is an important species in Turkey's freshwater ecosystems, especially in mountainous regions. Various conservation programs are in place to protect endangered trout species.

12) **Mediterranean Monk Seal (Monachus monachus**): Some species among the fish, which constitute the main food source of the Mediterranean monk seal, are under protection, especially due to pollution and overfishing in the seas.

13) **Sea Leopard (Hydrurga leptonyx):** This species is also a critical part of the marine ecosystem and is under protection due to pollution and fishing.

14) **Turbot (Scophthalmus maximus):** The turbot, which is found in the Mediterranean and Black Sea, is among the marine fish under protection in Turkey, especially due to overfishing.

15) **Carp (Cyprinus carpio):** Common in Turkey, carp is an important freshwater fish species. It is one of the species under protection due to overfishing and habitat loss.

16)**Abramis brama** Salmonids are endangered freshwater fish that live mainly in wetlands and ponds.

17) **Redwing (Scardinius erythrophthalmus):** The redwing is a threatened fish species found in many freshwater ecosystems in Turkey.

18) **Silefish (Scorpaenidae family):** The sile fish is a threatened species of overfishing, especially in some parts of the Black Sea.

ROTECTION WORKS AND STRATEGIES

One of the biggest threats facing endangered and protected fish species is overfishing. Commercial fishing, especially in the oceans, leads to the rapid depletion of fish species, causing irreversible changes in the marine ecosystem. Overfishing prevents fish populations from reproducing and disrupts the natural balance. Another threat factor is habitat loss. The natural structure of water bodies is deteriorating, especially due to water pollution, increased construction in coastal areas and agricultural activities. As ecosystems lose their breeding and feeding grounds, the survival of fish species becomes more difficult. In addition, climate change also changes the temperature levels of the seas, causing some fish species to move away from their habitats (Ergüden et al., 2015). In Turkey, there are various laws and regulations for the conservation of these species. In particular, the "Draft Law on Fisheries" and the "Draft Law on Marine and Inland Water" aim to regulate fishing activities and promote sustainable fishing.

In addition, fishing bans, size limits and fishing seasons have been set for some species. These local and national regulations for the protection of fish are aimed at ensuring the sustainability of ecosystems and protecting endangered fish species. Sensitive species mentioned in the Communiqué on Fisheries are fish species and other aquatic organisms that are of critical importance for ecosystems and need to be protected. These species are usually species that are in danger of extinction and therefore under special protection. Protected Species: These are fish and other aquatic products that are under special protection according to Turkish legislation and whose commercial catch or production is restricted.

Various national and international efforts are being made to conserve endangered fish species. These efforts include sustainable fishing practices and the establishment of marine protected areas, along with direct interventions. For example, setting catch quotas and promoting sustainable methods in the fishing industry can help to increase the populations of fish species. In addition, environmentally friendly practices such as cleaning the seas and lakes and removing chemicals from the water can improve fish habitats. International cooperation is also very important. The United Nations and other global organizations have developed protocols and agreements for marine conservation, regulating international fisheries and proposing solutions to protect species.

On March 3, 1973, 21 countries signed the "Convention on International Trade in Endangered Species of Wild Fauna and Flora" (CITES or Washington Convention). The Convention entered into force on July 1, 1975. Today, the CITES Convention is a truly global convention covering 168 contracting countries. The international trade of more than 30 thousand animal and plant species included in the annex lists is regulated according to the provisions of this convention. As its name suggests, the Convention covers not only endangered species, but also species that are not yet endangered but could be endangered by international trade.

Appendices I, II and III of the CITES convention list the species affected by trade and threatened with extinction and impose restrictions and prohibitions on trade in these species. Annex I covers all species that are or may be affected by trade and are in danger of extinction. These species are in serious danger of extinction and trade is only possible in exceptional circumstances and with special authorization. Annex II includes species that are not currently in absolute danger of extinction but could become extinct if trade is not subject to strict regulations. Turkey has made commitments to protect the rich biological diversity of our country, to ensure its sustainable use and to prevent its negative impact from international trade through the international agreements and conventions to which it has become a party and signed until today. Global and regional environmental conventions to which Turkey is a party impose various responsibilities on Turkey. In accordance with the CITES convention to which Turkey is a party, Turkey is also obliged to take measures to protect sturgeon and ensure the continuation of their generations.

Especially in recent years, in developed countries, rehabilitation works in breeding areas are given importance in order to ensure the continuation of sturgeon generations. The most effective way to prevent species extinction is to protect natural environments and prevent habitat destruction. Otherwise, it is a fact that hunting bans or stock replenishment alone will be insufficient. As a country with natural habitats and breeding grounds of sturgeon, it is necessary to take effective measures and increase scientific studies on this subject in order to protect the biological diversity in our natural waters and to ensure the continuity of the generations of these valuable fish, which are of great importance for the economy of our country. In particular, determination of the current status of sturgeon species in our country's waters and rehabilitation of our rivers, which constitute their breeding grounds, in such a way that reproduction can take place again are practices that should be done before it is too late (Ustaoğlu, 2006).

In conclusion, the conservation of endangered fish species is of great importance not only for the future of the species, but also for ecosystem health and human life. In order to protect these species, public awareness should be raised, fishing activities should be regulated and habitats should be protected. Conservation efforts at both local and global levels can help preserve biodiversity and help endangered species survive.

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CHAPTER 12

TURKEY ENDEMIC FISH SPECIES AND CHARACTERISTICS BELONGING TO THE NEMACHEILIDAE FAMILY

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INTRODUCTION

Species known as scavenger or stone cutter belonging to the Nemacheilidae family are small fish distributed in the fresh waters of Asia and its islands, Europe and Northeast Africa. Nemacheilidae has approximately 48 genera and more than 661 species (Nelson et al., 2016). Individuals belonging to this family live in shallow areas of streams, and their scales are small and usually embedded in the skin. They have a total of three pairs of whiskers around their mouth, one pair on the lower jaw and two pairs on the upper jaw. They are distributed in almost all rivers of Turkey (Turan et al., 2019).

1. ***Barbatula bergamensis*** (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in the Kozak stream in Bergama (NE). *Barbatula bergamensis* is one of our local loaches from the Nemacheilidae family. It is an endemic species due to the location where I found this species (Kozak Stream). The habitat of this species is medium and slow-flowing streams, lakes and temporary ponds. If the current in the stream is not strong, they spend their time buried at a depth of 40-50 cm, on or under the fine sandy/sedimentary ground. If the current is current, they usually live in coastal areas, intertwined with pebbles. They are in areas where rocks and gravel are abundant. *Filamentous algae* and *Fontinalis antipyretica* can also be found along with the rocks. When summer begins, breaks occur in the end branches of the streams, and there is a slight chance that they can be trapped in these temporary ponds. There is a dense population of plane trees in the region. This leads to the presence of plane tree roots, branches and leaves, although not many, in the region. It is a group of greenback carp that travels in groups (URL-1) (Figure 1).

Figure 1. *Barbatula bergamensis (URL-1)*

2. ***Oxynoemacheilus anatolicus*** (Erk'akan, Özeren & Nalbant 2008):

It is benthopelagic and lives in the Karamanlı Dam Lake in Burdur (EN). It has only been recorded in southwestern Anatolia, from three spring-fed streams flowing into Lake Burdur. Its habitat consists of slow-moving streams with sandy, muddy, or gravelly beds, surrounded by dense aquatic vegetation. It is currently found in three streams and is reported to be abundant in one of them, but remains under threat from water extraction, pollution, and dam construction. Additionally, water bodies in its area are drying up due to climate change and unsustainable water extraction for human use. *Oxynoemacheilus anatolicus* differs from its counterparts by having a dorsal fin <28>5 spines and 7 branched rays, pectoral fin with 8 branched rays, pectoral fin length and caudal fin with 18 branched rays, body and head shape, head depth and body and caudal peduncle are different. The body color is distinct, with tiny irregular spots visible on the rings during its lifetime (URL-2) (Figure 2).

Figure 2. *Oxynoemacheilus anatolicus (URL-2)*

3. ***Oxynoemacheilus araxensis*** (Bănărescu & Nalbant 1978):

It is demersal and lives in the Aras River (DD). *Oxynoemacheilus araxensis* is a species of ray-finned fish. It is from the genus Oxynoemacheilus. It was discovered from specimens collected at a single location near Kandili, the type locality in the upper reaches of the Euphrates River in eastern Turkey. While numerous superficially similar fish populations exist within the Euphrates drainage and remain undescribed, they have not been documented elsewhere; these populations might either belong to this species or to *Oxynoemacheilus kaynaki*. Its habitat can be described as streams with gravelly bottoms and moderately fast currents (Freyhof, 2014a) (URL-3). There is no photograph in fishbase.

4. ***Oxynoemacheilus atili (***Erk' akan, 2012):

It is demersal and lives in Beyşehir Lake and Eflatun spring (NT). Turkish Name: Scavenger fish English Name: Loach Distribution in our country: Lake Beyşehir Endemism Status: It is endemic to our country (URL-4) (Figure 3).

Figure 3. *Oxynoemacheilus atili (URL-4)*

5. *Oxynoemacheilus banarescui* (Delmastro, 1892):

It is demersal and lives in the streams flowing into the Black Sea (NT). Turkish Name: Scavenger fish English Name: Loach Distribution in our country: Some rivers flowing into the Sea of Marmara Endemism Status: It is endemic to our country (URL-4) (Figure 4).

Figure 4. *Oxynoemacheilus banarescui (URL-4)*

6. *Oxynoemacheilus ceyhanensis* (Erk'akan, Nalbant & Özeren, 2007):

It is demersal and lives in the Yalak village of Kahramanmaraş, Elbistan, in the Ceyhan river basin (DD). Turkish Name: Elbistan scavenger fish English Name: Elbistan loach Distribution in our country: Ceyhan River Endemism Status: It is endemic to our country (URL-4) (Figure 5).

Figure 5. *Oxynoemacheilus ceyhanensis (URL-4)*

7. ***Oxynoemacheilus ciceki*** (Sungur, Jalili & Eagderi 2017):

It is demersal and lives in the Sultan reeds in Kayseri (NE). *Oxynoemacheilus ciceki* sp. n. It is different from other Oxynoemacheilus species. Characters in the Kızılırmak basin, none of them are unique. *Oxynoemacheilus ciceki* sp. from *O. angorae* irregular spots with yellowish brown or pale gray on the side (versus yellowish spots with mid-lateral row of horizontally elongated fused spots), cheeks with numerous small spots (without pigmentation), without scales (restrained), with shorter pelvic fin are distinguished (Sungur et al., 2017) (Figure 6).

Figure 6. *Oxynoemacheilus ciceki* (Sungur et al., 2017)

8. ***Oxynoemacheilus cinicus*** (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in the Cin stream (DD) (Figure 7).

Figure 7. *Oxynoemacheilus cinicus (URL-5)*

9. *Oxynoemacheilus cyri* (Berg 1910):

It is demersal and lives in the Kura river drainage (LC). Turkish Name: Göle scavenger fish English Name: Göle loach Distribution in our country: Kura-Aras river system Endemism Status: Not endemic (URL-4) (Figure 8).

Figure 8. *Oxynoemacheilus cyri (URL-4)*

10. *Oxynoemacheilus ercisianus* (Erk'akan & Kuru, 1986):

It is demersal and lives in fresh waters between Erciş and Patnos (EN). Turkish Name: Van scavenger fish English Name: Van loach Distribution in our country: Van Lake basin Endemism Status: It is endemic to our country (URL-4) (Figure 9).

Figure 9. *Oxynoemacheilus ercisianus (URL-4)*

11. *Oxynoemacheilus erdali* (Erk'akan, Nalbant & Özeren, 2007):

It is demersal and lives in the Murat River in Ağrı (NE). Turkish Name: Scavenger fish English Name: Loach Distribution in our country: Euphrates River Endemism Status: It is endemic to our country (URL-4) (Figure 10).

Figure 10. *Oxynoemacheilus erdali (URL-4)*

12. *Oxynoemacheilus eregliensis* (Bănărescu & Nalbant 1978):

It is demersal and lives in the streams flowing into the lakes of Central Anatolia (VU). *Oxynoemacheilus eregliensis* is a species of stone loach found in streams and springs with gravel, sandy, or muddy substrates and slow-moving waters within the Tuz Gölü basin of Central Anatolia, Turkey (Freyhof, 2014b) (Figure 11).

Figure 11. *Oxynoemacheilus eregliensis (URL-6)*

13. *Oxynoemacheilus evreni* (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in the Tekir stream in the Göksu basin (LC). *Oxynoemacheilus cosmos* is a species of fish in the order Cypriniformes, classified under the genus Oxynoemacheilus. It is widespread and locally plentiful in the Ceyhan drainage, inhabiting streams and rivers with gravel substrates and flowing in moderately fast to very fast currents. It may have experienced a mild decrease in population due to the construction of dams, but it can tolerate some habitats altered by humans (URL-7).

14. *Oxynoemacheilus germencicus* (Erk'Akan, Nalbant & Özeren, 2007):

It is demersal and lives in freshwater in Aydın Germencik (VU). The Carian loach, *Oxynoemacheilus germencicus,* is a species of fish in the order Cypriniformes and a member of the genus Oxynoemacheilus. In Western Anatolia, it is found exclusively in the Büyük Menderes River and the lower Gediz River. It likely also inhabited the Küçük Menderes River, situated between the Büyük Menderes and Gediz, but has vanished from this river due to pollution and isolation. It is widely distributed and locally common in two additional rivers, but its populations have decreased and face threats from climate change, human activities like dam construction and water extraction, as well as pollution, all of which contribute to reduced rainfall in the area (URL-8) (Figure 12).

Figure 12. *Oxynoemacheilus germencicus (Güçlü et al., 2013)*

15. *Oxynoemacheilus hazarensis* (Freyhof & Özuluğ, 2017):

It is demersal and lives in the Caspian Lake (NE). Turkish Name: Caspian scavenger fish English Name: Hazar Loach Distribution in our country: Hazar Lake Endemism Status: Endemic to the Caspian River and our country (URL-4) (Figure 13).

Figure 13. *Oxynoemacheilus hazarensis (URL-4)*

16. *Oxynoemacheilus kaynaki* (Erk'akan, Özeren & Nalbant 2008):

It is demersal and lives in the Göksu River (LC). It is a species of black cumin found in Göksu, the right tributary of the Euphrates in Southeastern Anatolia (URL-9). There is no photograph in fishbase.

17. *Oxynoemacheilus kosswigi* (Erk'akan & Kuru, 1986):

It is demersal and lives in the Kızılırmak river basin (Yıldızeli-Sivas) (LC). Turkish Name: Scavenger fish English Name: Paphlagonian loach Distribution in our country: Kızılırmak River Endemism Status: Endemic to our country (URL-4) (Figure 14).

Figure 14. *Oxynoemacheilus kosswigi (URL-4)*

18. *Oxynoemacheilus mediterraneus* (Erk'akan, Nalbant & Özeren, 2007):

It is demersal and lives in the Madenli-Aksu stream in Eğirdir (LC). Turkish Name: Scavenger fish English Name: Pamphylian loach Distribution in our country: Eğirdir Lake Endemism Status: Endemic to our country (URL-4) (Figure 15).

Figure 15. *Oxynoemacheilus mediterraneus (URL-4)*

19. *Oxynoemacheilus mesudae* (Erk'akan, 2012):

It is demersal and lives in Büyük Menders, Küçük Menderes and Gediz rivers and in Işıklı lake (EN). Turkish Name: Scavenger fish English Name: Işıklı loach Distribution in our country: Büyük Menderes, Küçük Menderes, Gediz rivers Endemism Status: Endemic to our country (URL-4) (Figure 16).

Figure 16. *Oxynoemacheilus mesudae (URL-4)*

20. *Oxynoemacheilus paucilepis* (Erk'akan, Nalbant & Özeren, 2007):

It is demersal and lives in the Mancilik stream in Sivas (EN). Turkish Name: Scavenger fish English Name: Mancilik dwarf loach Distribution in our country: Euphrates River Endemism Status: Endemic to our country (URL-4) (Figure 17).

Figure 17. *Oxynoemacheilus paucilepis (URL-4)*

21. *Oxynoemacheilus phoxinoides* (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in Lake Iznik (CR). The İznik loach, scientifically known as *Oxynoemacheilus phoxinoides*, is a ray-finned fish species belonging to the genus Oxynoemacheilus. The type is native to a single small stream, less than 5 kilometers in length, located within the Lake İznik drainage in northwestern Anatolia. The species is plentiful within its limited habitat, but its population seems to be in decline. The primary threat is believed to be water extraction from streams for irrigation, and with climate change, the risk of drought is increasing as regional rainfall continues to decrease. (URL-10) (Figure 18).

Figure 18. *Oxynoemacheilus phoxinoides (Çiçek et al., 2019)*

22. *Oxynoemacheilus samanticus* (Bănărescu & Nalbant 1978) :

It is demersal and lives in Sabun water (Kilis), Afrin stream (Kilis), Deliçay and Kınacık stream, Kilis (LC). *Oxynoemacheilus samanticus*, the Red River sportfish, is a type of ray-finned fish in genus Oxynoemacheilus. It inhabits rapidly flowing streams and rivers on gravel grounds and is native to Turkey, Eastern Anatolia, where it is found in the Kızılırmak system flowing into the Black Sea and at the source of the Euphrates River (URL-11) (Figure 19).

Figure 19. *Oxynoemacheilus samanticus (URL-12)*

23. *Oxynoemacheilus seyhanensis* (Bănărescu 1968):

It is benthopelagic and lives in the Zamantı stream of the Seyhan River (CR) (Figure 20).

Figure 20. *Oxynoemacheilus seyhanensis (Seçer et al., 2020)*

24. *Oxynoemacheilus seyhanicola* (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in the Seyhan river basin (EN). *Oxynoemacheilus seyhanicola* is a species of ray-finned fish belonging to the genus Oxynoemacheilus. It is native to gravel substrates in moderately fast-flowing currents within approximately 60 km of the lower Seyhan River near Adana, Turkey. Dams are under threat from water extraction and climate change (URL-13). There is no photograph in fishbase.

25. *Oxynoemacheilus simavicus* (Balik & Bănărescu 1978):

It is demersal and lives in the Simav stream (CR). *Oxynoemacheilus simavicus*, also known as the Simav loach, is a species of stone loach in the genus Oxynoemacheilus. Simav, a tributary of Gediz in Western Anatolia, is endemic to a single river. Populations have declined and this is due to threats like water contamination and extraction, which has led to the conservation status of this type being assessed as Critically Endangered by the IUCN (URL-14) (Figure 21).

Figure 21. *Oxynoemacheilus simavicus (URL-15)*

26. *Paraschistura chrysicristinae* (Nalbant 1998):

It is demersal and lives in the Batman River (CR). *Paraschistura chrysicristinae* is a ray-finned fish species belonging to the genus Paraschistura. In the 1970s, it was observed at two locations in the Batman River, a tributary of the Upper Tigris in Turkey, but it has not been seen there since. The reasons for its disappearance are unknown, as the habitat in the regions where it was documented appears to be of good quality (URL-16). There is no photograph in fishbase.

27. *Seminemacheilus ispartensis* (Erk'Akan, Nalbant & Özeren 2007):

It is demersal and lives in the Isparta stream in Eğirdir-Isparta (VU).

28. *Seminemacheilus lendlii* (Hankó 1925):

It is demersal and lives in Akşehir, Eber, Eymir, Mogan, Eğirdir, Burdur, Çavuşcu, Salda and Tuz lakes, Dalaman stream and Sakarya river system (VU). *Seminemacheilus lendlii,* also known as the Anatolian loach or Northern pond loach, is a stone loach species endemic to Turkey. This species grows up to 9 centimeters (3.5 inches) in length. While it was once widespread across Central Anatolia, it is right now confined to the outflows and tributaries of the Tuz Gölü and Beyşehir Lake basins. It can be found in stagnant water and swamps, lakes, springs and streams with dense vegetation (URL-17).

29. *Turcinoemacheilus minimus* (Esmaeili, Sayyadzadeh, Özulug, Geiger & Freyhof 2014):

It is demersal and lives in the Upper Euphrates drainage (NE).

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CHAPTER 13

DETERMINATION OF CAPITALIZATION INTEREST RATE IN DIYARBAKIR PROVINCE

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1. INTRODUCTION

In legal terms, land is defined as a portion of the earth's surface with legally and geometrically delineated boundaries. Land is immovable, cannot be replicated or diminished, and is indestructible. Besides serving as a foundation for businesses, providing the primary setting for human activities, and possessing financial value, land is also a source of wealth due to the raw materials and ores it contains (Öztürk, 2013; Bayramoğlu and Özdemir, 2021). Agricultural land, meanwhile, is not only the main source of food production but also a means of livelihood for the rural population.

Agricultural land is appraised for various reasons, and the results of these valuations are significant for the landowner, the appraiser, and relevant institutions. Therefore, it is necessary to objectively determine the value of agricultural land, considering and mathematically expressing the factors that affect this value in valuation calculations (Karakayacı, 2011; Sklenicka et al., 2013).

The valuation of agricultural land is a current issue that is in the center of attention day by day. Agricultural valuation is carried out for different purposes and the value obtained is important for the land owner and related institutions. Agricultural land is heterogeneous and each agricultural land has different qualities that affect its value. For an objective agricultural valuation application, the factors affecting the value must be expressed mathematically and included in the calculations. In addition, determining the factors that increase or decrease the value of agricultural land can be effective in both land demand and investment policies (Çınar et al., 2018). The factors affecting the value may vary from region to region and from person to person. The most important stage of the valuation process is to determine these factors correctly, express them mathematically and determine to what extent they affect the value (Alkan and Duran, 2024).

With Turkey's rapidly growing population, food demands have been on the rise. However, despite the increase in demand, agricultural lands have not expanded; in fact, they are shrinking daily due to factors such as construction, dam building, road construction, soil degradation, and erosion (Sayılı, 1996).

Within the scope of development strategies, infrastructure investments are made to improve the living standards of rural and urban populations, healthy and quality life, clean water, accessible clean energy and economic growth. Due to these investments made in the public interest, it is necessary to expropriate immovable properties belonging to private and legal persons. In addition to the fact that expropriations are carried out in accordance with the laws in force, especially the Constitution, it is of great importance to make realistic estimates in today's conditions in calculating the expropriation price (Kılıç, 2011a).

Valuation is of great importance in expropriation transactions. Valuation, as the name suggests, is the determination of the monetary value of a good (Doğramacı 1997).

Two methods are used as synthetic method and analytical method when expropriating or appraising any property. In recent years, models using advanced statistical methods have been developed to reveal the effect of land characteristics on land price. With the help of these models, it is aimed to determine the land price based on objective criteria. (Başer and Kılıç, 2016).

In order to apply the synthetic method, in other words, the market method, two main issues must be determined. It is the principle of free competition and price invariance with the existence of real market prices under the same conditions and very new (Doğramacı 1997). Within the framework of these issues, it is very unlikely that two issues can occur at the same time. Because the buyers and sellers of a land may not have commercial purposes for most of the time. People living in rural areas are very attached to their land, and the sale of a land is a big deal with its own measure of value.

The analytical method, on the other hand, can be used in the expropriation of immovables that provide continuous income. The value of the immovable property is the accumulation of the appreciation of all the income that is supposed to be derived from it in the future. This process is also called the capitalization of income or the income method.

In the valuation of agricultural land in Turkey, the income method is used within the scope of the Expropriation Law No. 2942 (Kılıç 2011b). In expropriation transactions, within the framework of the principles specified in the Expropriation Law, real estate valuation procedures are carried out by the appraisal commissions established by public institutions and the experts appointed by the court (Akbay, 2020). In addition, the Soil Conservation and Land Use Law No. 5403 was published in the Official Gazette No. 25880 dated 19/07/2005 and entered into force in order to protect, develop, classify, determine the minimum size of agricultural lands, prevent divisions and use them in a planned manner in accordance with the principle of environmental priority development (Official Gazette, 2005). Within the scope of this law, agricultural lands; According to their natural qualities and importance in the country's agriculture, they are classified as absolute agricultural lands, special crop lands, planted agricultural lands, marginal agricultural lands and greenhouse agricultural lands. In addition, different classifications can be made regarding the protection, development and use of agricultural lands. These classifications are an important factor affecting agricultural valuation. In the income method, it is necessary to know the average annual net income of the agricultural land and the capitalization rate prevailing in the region. Methods that exploit the income-generating potential of land are based on the assumption that the value of agricultural land is determined by its use value; however, since non-use values such as asset value and inheritance value are not taken into account, the partial value of the land is actually determined (Awasti, 2014). Another method frequently used in determining the value of agricultural land is the market value method. In the income method, it is difficult to calculate the capitalization rate and determine the average annual net income. Due to these difficulties, in some countries, the income method is used as a complement to the market value method or to control the results obtained from the market value method (Tanrıverdi et al., 2002; Karakayaci and Oğuz, 2006; Gündoğmuş and Taşaşçı, 2017; Ünal and Dönmez, 2019). In countries such as America and Canada, the market value method is used, and in countries such as England, Switzerland and Turkey, the income method is used (Karakayacı and Oğuz, 2006).

The most important issue in the valuation studies carried out according to the analytical method in agricultural lands is the determination of the capitalization interest rate. Very small changes in the capitalization interest rate cause an increase or decrease in the value of land. The capitalization interest rate is obtained by dividing the price at the time of sale by the net income of the alternation. There are several factors that affect the capitalization interest rate. These factors may differ according to regions, provinces and districts. Capitalization interest rate; It can vary from region to region, provinces and districts, and even according to two parcels located very close. For this reason, the capitalization rate should be determined according to regions, provinces and districts.

There are studies on calculating the capitalization rate in rural areas in general and determining the value of agricultural land according to income and market value methods (Engindeniz, 2001; Aslan, 2002; Oğuz and Ünal, 2004; Karakayaci and Oğuz, 2006b; Avcı, 2010, Baştürk, 2011), The value of agricultural land varies over time depending on the development of the region, and the land value and capitalization rate needed for many purposes must be up-to-date. In this context, the capitalization rates and land values calculated for wheat agricultural lands in the Lice district of Diyarbakır province, which is one of the most important potentials of Turkish agriculture, will contribute to the valuation activities.

The purpose of this study is to determine the capitalization rate in agricultural lands in the Kulp district of Diyarbakır province.

MATERIALS AND METHODS

Material

The main material of this research consists of the primary quality data obtained as a result of the face-to-face survey conducted with corn and wheat producers in Argün, Konuklu and İnkaya villages of Lice district of Diyarbakır province in 2023.

In addition, secondary data obtained from various domestic and foreign researches, DSI, TurkStat and related institutions and organizations were used in the study.

Method

Data Collection Method

The number of producers to be surveyed was determined according to the proportional sample volume formula and was based on a 95% confidence interval and a 10% margin of error. The proportional sampling volume formula used to determine the sample volume is as follows (Newbold 1995, Miran 2003).

$$n = \frac{Np(1-p)}{(N-1)\sigma_p^2 + p(1-p)}$$

Formula;

n = Sample size

N = Total number of producers

p = Proportion of producers to be included in the sample

σ^{2p} = Ratio variance.

As a result of the calculations made using the above formula, the sample size was calculated as 67.

Data Analysis Method

In determining the yield levels obtained from the corn and wheat products grown in the region, the average yields obtained from the survey results were compared with the records of the District Directorate. The sales prices of the products were determined based on the averages obtained from the survey results. The gross production value obtained by the products is calculated by multiplying the average product yields by the average product prices. The production costs of plant products in agriculture consist of variable and fixed costs. In the research, the variable cost elements of the products; labor and tow costs and material (seed, fertilizer, pesticide, water, etc.) costs, fixed cost elements; interest on the sum of expenses and management provision. In calculating the interest provision of the total costs, half of the interest rate (17%) applied by the Ziraat Bank for subsidized agricultural enterprise loans in

2023 (for a six-month period) was taken into account (Kıral et al., 1999; Bland, 2008). In calculating the management provision, 3% of the total expenses were taken. In order to calculate the net income from the products, the total production costs were subtracted from the gross production value (Aras, 1988; Kıral et al., 1999). The gross production value is determined by multiplying the amount of production obtained by the price received by the producer. In the calculation of labor costs, the wages paid for temporary workers in enterprises are added to the provision of family labor. The calculation of material costs is based on the amount of inputs used by the producers and the current prices paid for these inputs. In order to ensure homogeneity in the calculation of machine traction costs, unit land processing fees (tool-machine rent) in the region are taken as basis for manufacturers using their own tools-machines. As a matter of fact, this method has been applied in many studies (Çiçek et al., 1999; Cinemre and Kılıç, 1999; Tanrıvermiş, 2000; Engindeniz, 2008; Engindeniz, 2010; Örük ve Engindeniz, 2019).

If the commodity whose value is to be determined has a continuous income and market conditions vary, the study was carried out on the basis of the income method, since it is more appropriate to use the income method.

The method of capitalization of incomes; It is expressed as the reduction of future income to the moment of valuation and is based on the net income from the land. However, in order to apply this method, it is necessary to know the capitalization rates calculated according to the region, land quality and management type, based on market values.

Although capitalization rates may change over time depending on the change in market conditions, it can be used for many years because it is not possible for this change to occur in a short time. Especially in regions where land markets are stagnant and real purchases and sales are very low, it is always possible to value according to the net income method if the capitalization rates are known. This method is seen as the most suitable method in cases where there is not much buying and selling, heterogeneous immovables such as land, and free market conditions.

As a result, when determining the value according to the income method, they should also examine the values formed in the market in order to update or determine the capitalization rate.

While determining the capitalization rate in the research region, the "Capitalization of Income" method was used. For this reason, it is the calculation of the rents of the products grown by the enterprises examined in the research region and the ratio of the rotation system, which is common in the same region, to the land sales price by determining it. The following equation is used in the calculation of capitalization interest rate (Mülayim, 2008):

$f=\Sigma Rni/\Sigma Dni$

f : Capitalization Rate

R: Net income generated on agricultural land

D: Sale price of Agricultural Land

By determining the region where the capitalization rate will be calculated, the immovables that have been the subject of purchase and sale in that region in the last 1 year are determined as a precedent and their sales prices are determined. In appraisal studies, Article 11 of the Expropriation Law No. 2942. In accordance with the article, the valuation of agricultural lands is determined by capitalizing the net income according to the Capitalization of Revenues method and determining the m2 unit price for the land.

In the determination of the capitalization interest rate, the sales of relatives cannot be accepted as precedent sales of land as precedent sales. Comparable immovables to be used in the calculation of capitalization interest rate must have similar characteristics with other immovables in the region. In addition, attention should be paid to the use of real prices in the free market in sales to be used as a precedent. In order to make the calculation more transparent, the lands that were sold close to the period when the study was carried out were tried to be taken as a precedent.

RESEARCH FINDINGS

Social Economic Characteristics of the Producers in the Examined Enterprises

It was determined that approximately 39% of the producers in the enterprises examined within the scope of the research were high school graduates and 20.90% were primary school graduates (Table 1).

Table 1 Producers' level of education

Education	Frequency (N)	Percentage (%)
Illiterate	6	9.0
Literate	9	13.40
Primary school	14	20.90
Secondary school	5	7.50
High school	26	38.80
Associate	7	10.40
Total	**67**	**100.00**

It was determined that 50.70% of the producers interviewed within the scope of the study were between the ages of 46 and 60, 31.30% were between the ages of 26-45, and 17.90% were 61 years and above (Table 2).

Table 2. Age distribution of manufacturers

Age groups	Frequency (N)	Percentage (%)
<25	-	-
26-45	21	31.30
46-60	34	50.70
61+	12	17.90
Total	**67**	**100.00**

The average land size of the producers interviewed within the scope of the research is 15.86 decares, the average number of parcels is 1.52 and the average parcel width is 10.43 decares (Table 3).

Table 3. Producers Land Availability

	Average	Minimum	Maximum
Land Size	15.86	1.00	55.00
Number of parcels	1.52	1.00	4.00
Average parcel size	10.43	1.00	13.75

The average wheat yield was 648.58 kg/da, the average straw yield was 761.02 kg/da and the average corn yield was 1512.19 kg/da (Table 4).

Table 4. Yields Obtained in the Examined Enterprises

Crops grown (Wheat and Corn)	Yield (kg/da)
Wheat (Grain)	648.58
Straw	761.02
Corn (Grain)	1521.19

The average income per kg of the producers interviewed within the scope of the research is 7 TL for wheat, 0.91 TL for straw and 6.52 TL for corn (Table 5).

Table 5. Prices Received by the Manufacturer in the Examined Enterprises

Prices received by the producer (Wheat and Corn)	Sale price (TL/kg)
Wheat (Grain)	7.03
Strew	0.91
Corn (Dane)	6.52

The average income per decare of the producers interviewed within the scope of the research is 5252.05 TL for wheat and 9918.16 TL for corn (Table 6).

Table 6. Gross Production Values Obtained by Products in the Examined Enterprises

Products	**Gross production value (TL/da)**
Wheat	5252.05
Corn (Dane)	9918.16

The total expenses per decare of the producers interviewed within the scope of the research were determined as 2423.53 TL for wheat and 4907.78 TL for corn. The net profits per decare of the enterprises were calculated as 2828 TL for wheat and 5010 TL for corn (Table 7).

Table 7. Production Costs and Net Profit of Products Grown in the Examined Enterprises

Cost Elements		**Wheat**	**Corn (Grain)**
Labour and Machinery	Tillage	176.56	241.07
	October	215.21	1088.28
	Maintenance operations	196.00	237.12
	Harvest	397.91	510.70
Total		**985.68**	**2077.17**
Material costs	Seed	276.00	850.00
	Fertilizer	415.22	623.00
	Pesticide	54.92	65.78
	Water (diesel)	436.79	775.60
Total		**1182.93**	**2314.38**
Total of variable costs		**2168,61**	**4391.55**
Interest on costs (8.5%)		184.33	373.28
Management fee (3%)		70.59	142.95
Total of production costs		**2423.53**	**4907.78**
Selling Price		**2.44**	**0.72**
Gross production value		**5252.05**	**9918.16**
Net profit		**2828.52**	**5010.38**

The average annual net profit of the producers interviewed within the scope of the research according to the rotation patterns per decare is 3919 TL (Table 8).

Table 8: Annual Average Net Revenues Obtained by Alternation Schemes in the Examined Enterprises (TL/da)

Products	Gross production value	Total Costs	Net Income
Wheat-Corn	7585.11	3665.65	3919.46

Approximately 86% of the producers interviewed within the scope of the research have not sold their land in the last 1 year (Table 9).

Table 9. Status of producers selling land in the last 1 year

Responses	Frequency (N)	Percentage (%)
Yes	9	13.43
No	58	86.57
Total	67	100.00

The sales prices of the producers interviewed within the scope of the research and who have sold land in the last 1 year are given in Table 10.

Table 10. Land Information Sold in the Settlements Covered by the Research

Village	Land size (da)	Crop Rotation	Net Income (TL)	Retail Price (TL)
Inkaya	19	Wheat-Corn	74469,74	550000
Inkaya	4	Wheat-Corn	15677,84	117000
Inkaya	9	Wheat-Corn	35275,14	190000
Knox	2	Wheat-Corn	7838,92	550000
Knox	12	Wheat-Corn	47033,52	320000
Knox	1,5	Wheat-Corn	5879,19	37000
Inkaya	18	Wheat-Corn	70550,28	503000
Inkaya	15	Wheat-Corn	58791,90	455000
Argun	15	Wheat-Corn	58791,90	336000
Total	95,50	-	374308,43	3058000,00

In the study, the total net income obtained from these recently sold lands was proportional to the Total of the sales prices of the lands and the capitalization rate was calculated as 12.20% as follows:

$$\frac{374308.43}{3058000.00} = 0.122$$

In Turkey, capitalization rates vary between 1.5% and 12% by province. Generally, the capitalization rate, especially in regions like the Black Sea, Aegean, and Mediterranean where agricultural land is scarce, ranges from 3% to 5%. Conversely, in the Eastern and Southeastern regions, where there are various issues regarding the reliability of land ownership and consequently lower demand for land compared to other provinces, this rate is found to be quite high (Table 11).

Indeed, in the study conducted by Birinci (1997), the capitalization rate for farmland in Erzurum was determined to be 10.94% for dryland and 11.96% for irrigated land; in the research by Öztürk, Çoşar, and Engindeniz (2013) conducted in İzmir, it was found to be 5.63%; in the study by Caner et al. (2022) conducted in Aydın, it was 5.23%; and in the research by Serez et al. (2022) in İzmir, it was determined to be 4.13%.

Table 11. Expropriation Values

	Average	Minimum	Maximum
Land Size	15.66	1.00	55.00
Expropriation value	399268,66	19000.00	1020000.00
Expropriation value per decare	25496.08	19000.00	18545.45

In Turkey, a capitalization interest rate of 5% is used for irrigated lands and 6% for dry lands in determining expropriation prices.

4. CONCLUSION AND RECOMMENDATIONS

In our country, expropriation studies are conducted due to the construction of railways, highways, dams, etc. In valuation studies, the majority of expropriation costs are paid as land prices. When expropriation works are carried out on irrigable agricultural lands that have high demand and good productivity, and are close to populated areas, the unit prices per square meter of land increase, leading to a rise in expropriation costs. Existing shortcomings in the practice increase expropriation costs and cause delays in investments. Therefore, it is important to transparently calculate the capitalization rate to prevent injustices and ensure accurate transactions in the regions where expropriation activities are conducted. Because small changes in the capitalization rate can lead to significant differences in value. It is essential to analyze whether the determined capitalization interest rate is appropriate for that region based on net income.

Determining the capitalization interest rate is very important in the valuation of agricultural lands. In this study, an average capitalization rate was calculated according to land types in the Lice district of Diyarbakır province using the income capitalization method. As a result of the research, it was determined that approximately 39% of the interviewed producers are high school graduates and about 50% are in the age range of 46 to 60. The average land size of the producers surveyed is 15 decares, the average number of parcels is 1.5 decares, and the average parcel width is 10 decares. The average wheat yield of the producers is 648 kg/da, the average straw yield is 761 kg/da, and the average corn yield is 1512 kg/da. The average income per kilogram for producers is 7 TL for wheat, 0.91 TL for straw, and 6.52 TL for corn. The average income per decare for producers is 5252 TL for wheat and 9918 TL for corn. The average total expenses per decare for producers are 2423 TL for wheat and 4907 TL for corn. The average net profit per decare for producers is 2828 TL for wheat and 5010 TL for corn. The average annual net profit per decare obtained according to the rotation patterns of the producers is 3919 TL. Approximately 86% of the producers surveyed have not sold their lands in the last year. In the research, the total net income obtained from recently sold lands was compared to the total sale prices, resulting in a capitalization rate of 12.20%.

It is incorrect to apply the determined capitalization rate to every land parcel in the region. In this case, all positive and negative factors that may affect land value must also be considered during implementation. The obtained capitalization rate must be adapted to the land intended for valuation. Researches to be conducted in different periods and in different enterprises in the region should support these studies. Different capitalization rates can be determined according to different land types and operating methods even within the same region or district. Those who will perform the valuation work must evaluate the lands by considering all their positive and negative aspects. Increasing the number of such studies nationwide is necessary for more accurate determination of land values.

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CHAPTER 14

DAMAGE TO SOIL AND ENVIRONMENT CAUSED BY EXCESSIVE FERTILIZER USE

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INTRODUCTION

Fertilizers used to increase yields in agricultural production can be beneficial when applied at the right doses. However, excessive fertilizer use can lead to various environmental and ecological problems. The damages caused by excessive fertilizer use to the soil and the environment can be evaluated in a wide range. These include degradation of soil structure, pollution of water resources, reduction of biodiversity and decrease in air quality.

Excessive fertilizer application can severely impact soil health and water quality. High levels of fertilizers, particularly those rich in ammonium, may cause salt buildup, which hampers plants' ability to absorb water and nutrients. Additionally, such practices can lead to soil acidification, disrupting microbial communities essential for soil fertility. The structural integrity of soil may also deteriorate, resulting in compaction and loss of aggregate stability (Rahman & Zhang, 2018). Furthermore, runoff from fertilized areas can introduce nitrates into groundwater and surface waters, posing risks to human health. This runoff often stimulates excessive growth of aquatic vegetation and algae, which can deplete oxygen levels in water bodies, harming aquatic life (Craswell, 2021).

Excessive use of fertilizers has significant consequences for air quality, primarily through ammonia emissions. This ammonia can contribute to the formation of acid rain and fine particulate matter, which are harmful pollutants. Additionally, nitrogen-based fertilizers can emit potent greenhouse gases like nitrous oxide, exacerbating climate change (Savci, 2012). In terms of biodiversity, over-fertilization can diminish the variety and functions of soil microorganisms, adversely impacting soil health and plant development. Furthermore, it can lead to the degradation of natural habitats, thereby reducing overall biodiversity (Jwaideh et al., 2022).

Excessive fertilizer use poses serious risks to human health, particularly through the contamination of drinking water with nitrates, which can cause conditions like methemoglobinemia, especially in infants. Additionally, the buildup of heavy metals and chemical residues in the soil can compromise the safety of food crops. Given these potential hazards, it is crucial to adopt balanced and mindful fertilizer practices to protect soil and environmental health. Implementing sustainable agricultural methods, such as using organic fertilizers and integrated nutrient management, can help mitigate these adverse effects.

IMPACT ON SOIL FERTILITY

Excessive fertilizer application has complex effects on soil fertility. In the first instance, it can increase yields by stimulating plant growth. Over time, however, soil structure is degraded due to excessive nitrate and phosphorus accumulation. This can alter soil pH, creating an unsuitable environment for plants (Smith et al., 2019).

Fertilizers are important inputs used to increase soil fertility in agricultural production. However, excessive fertilizer use can cause various negative effects. Excessive fertilizer application can alter soil pH, creating an unsuitable environment for plants. It has also been reported that over-fertilization can cause an imbalance in some nutrients (e.g. potassium) (McBride, 1994; Cakmak, 2005). Excess nitrogen fertilizer use can negatively affect soil structure, reducing the amount of organic matter and causing soil clogging (Lal, 2004; Lal, 2015).

Over-application of fertilizers can diminish the availability of essential nutrients for plants and may even cause harm to them (Marschner, 2012; Ryan et al., 2001). This practice adversely affects soil microbiology, resulting in reduced microbial diversity and activity (Hartmann et al., 2015). Additionally, excessive fertilizer can create issues with soil salinity, which hampers plant growth (Munns, 2002). It is important to note that over-fertilization can also contribute to increased soil erosion and physical degradation (Montgomery, 2007; Lal, 2000). Moreover, this practice disrupts the natural cycling of carbon and nitrogen in the soil, ultimately impacting long-term soil fertility (Vitousek et al., 1997).

Research has shown that excessive use of fertilizers may have genotoxic and mutagenic effects (Sakai et al., 2011). Furthermore, fertilizers can leach into groundwater, contributing to nitrate pollution and negatively impacting water quality (Cui et al., 2011). The influence of fertilizer overuse on plant physiology and stress resilience has produced varied findings (Khan et al., 2010; Marschner, 2012). It is crucial to apply fertilizers appropriately to enhance energy efficiency and promote sustainable agricultural practices (Drinkwater et al., 1995).

The impact of nitrogen fertilizers on greenhouse gas emissions has been documented, suggesting that their use can exacerbate global warming (IPCC, 2007; Smith, 2017). Research into the effects of fertilizers on the plant microbiome is an emerging field (Bulgarelli et al., 2013). Maintaining soil quality is vital for ensuring the sustainability of fertilizer practices (Brady and Weil, 2008; Lal, 2009). Investigating the relationship between nutrient bioavailability and optimal fertilization strategies presents new avenues for application (Chaparro et al., 2012).

The relationship between fertilizer application and water quality is a significant area of research, particularly regarding eutrophication (Carpenter et al., 1998; Smith et al., 1999). Comparative studies have highlighted the benefits of organic farming for sustainable fertilizer use (Lotter et al., 2003). Additionally, the effects of fertilizer practices on local economies have been explored, focusing on agricultural productivity and associated costs (Harris, 2002).

Research on the effects of fertilization strategies on plant nutrient content and plant quality is important to increase productivity in agricultural production (Marschner, 2011). In the context of climate change, studies on the effects of fertilizer use on the carbon cycle and greenhouse gas emissions are critical for the sustainability of global agriculture (Reay et al., 2012). Research on the effects of fertilization strategies on seed quality and plant diseases is important for quality management in agricultural production (Steiner et al., 2007).

Studies on the effects of over-fertilization on plant diseases provide critical information for preventing harmful effects in agricultural production. The effects of fertilizer use on environmental sustainability are evaluated in terms of conserving natural resources and optimizing agricultural productivity (Foley et al., 2011; Rockström et al., 2009). The effects of fertilization strategies on plant physiology provide critical information for plant growth regulation and nutrient utilization (Marschner, 1995).

The effects of fertilizer use on agricultural production techniques are critical for increasing productivity and conserving natural resources (Godfray et al., 2010). Research on the effects of fertilization strategies on plant metabolism is important for understanding plant growth and development processes (Marschner, 2011; Buchanan et al., 2021). The impacts of fertilizer use on economic sustainability are assessed in terms of agricultural costs and incomes (Pretty and Bharucha, 2014; Tilman et al., 2001).

Fig.1. Excessive fertilizer use

The impacts of fertilization strategies on agricultural biodiversity are critical for ecosystem services and habitat conservation (Foley et al., 2005). The impacts of fertilizer use on food security and nutrition play an important role in ensuring sustainability in agricultural production and combating hunger (Godfray et al., 2010). The impacts of fertilization strategies on climate change adaptation are important to increase the adaptive capacity of agricultural production systems (Foley et al., 2011; Thornton et al., 2014).

WATER QUALITY AND ITS IMPACTS ON WATER RESOURCES

Overapplication of fertilizers results in higher levels of nutrients like nitrate and phosphorus, which can be washed into surface waters and groundwater through rainfall. This nutrient runoff can initiate eutrophication, causing rapid algal blooms and oxygen depletion in aquatic environments (EMA, 2020).

The use of fertilizers in agriculture significantly affects water quality and resources. Specifically, excessive applications can lead to a range of issues in both aquatic ecosystems and groundwater supplies.

Excessive fertilizer use can lead to the transport of nutrients, especially nitrate and phosphorus, to surface waters and trigger the eutrophication process (Smith et al., 1999; Carpenter et al., 1998). Phosphorus-derived fertilizers are reported to negatively affect water quality by increasing algal growth in aquatic ecosystems (Paerl and Otten, 2013; Schindler, 2006). The effects of eutrophication on aquatic animal populations, especially fish and other aquatic organisms, have been studied. Algal blooms caused by excessive fertilizer use can reduce dissolved oxygen levels in aquatic ecosystems, which can be detrimental to aquatic life (Diaz and Rosenberg, 2008).

Research on the impacts of excessive fertilizer use in coastal areas on marine biodiversity suggests that ecosystem services may be reduced (Breitburg et al., 2018). The leaching of fertilizers from agricultural fields into surface waters and pollution of these water bodies is a serious concern for water quality management. Leaching of fertilizer compounds such as nitrate into groundwater tables can lead to contamination of drinking water supplies and potential risks to human health (Spalding and Exner, 1993).

Excessive fertilizer use in agricultural river basins has been observed to cause pollution and imbalances in aquatic ecosystems (Sharpley et al., 2003; Withers et al., 2001). The effects of fertilizer-induced eutrophication processes in freshwater lakes can lead to degradation of aquatic ecosystems and threaten the availability of drinking water supplies (Schindler, 2012). Research on the effects of excess nutrient salts in coastal waters on ecosystem health and fisheries shows that fertilizer use can have an impact even in remote coastal areas (Nixon, 1988).

In addition to the use of fertilizers, the spread of pesticides into water bodies can increase negative impacts on water quality. It has been reported that phosphorus-based fertilizers can impair water quality by increasing the growth of seaweeds (algae) (Anderson et al., 2002). Research on the effects of excessive fertilizer use in coastal ecosystems on biodiversity and ecosystem health is important for the conservation of natural resources (Carpenter, 2005).

Studies on the effects of fertilizer use on local and regional water management strategies provide important clues for sustainable water resources management (Whitehead et al., 2015). The potential pollution effects of fertilizer use on drinking water sources can be of serious concern for water health (Nolan et al., 2002). The effects of fertilizer use on groundwater dynamics have been investigated in terms of water resource protection and pollution prevention (McMahon et al., 2008). It is emphasized that protecting water quality can increase the capacity to provide ecosystem services Assessment, M.E. 2001). Studies on how the global water crisis is linked to excessive fertilizer use and agricultural water consumption provide critical information for sustainable water resources management (Rockström et al., 2009; Falkenmark, 1989).

Environmental risk assessment methods have become essential for evaluating the effects of fertilizer application on water resources (EPA, 2011). Studies indicate that over-fertilization can heighten soil erosion, leading to increased sedimentation and pollution in surface waters (Montgomery, 2007; Lal, 2004). Research examining how fertilizer-related water quality issues in ponds affect recreational activities and economic value offers valuable insights for local communities (Dodds and Welch, 2000). Additionally, the impact of fertilizer use on biogeochemical cycles, as well as nutrient movement and storage, remains a critical area of investigation (Galloway et al., 2008; Howarth et al., 2002).

Research on how aquatic plant biomass changes with fertilization strategies provides important clues to understanding the biological and chemical balance of aquatic ecosystems (Søndergaard et al., 2015). Studies on the sustainability of fertilizer use in coastal ecosystems provide guidelines for conserving natural resources and managing human interactions (Nixon, 2009). For the sustainable management of surface waters, the impacts of fertilizer use are important for protecting water resources and optimizing ecosystem health (Carpenter and Bennett, 2011; Carpenter and Brock, 2006).

Research into the social and economic consequences of water quality degradation provides crucial insights into both environmental and human aspects of fertilizer use. Effective policy and management strategies are vital for safeguarding water resources and mitigating the negative effects of fertilizers on water quality (UNEP, 2011). Additionally, understanding the impact of global change on water quality related to fertilizer use is essential for modeling future scenarios and ensuring the protection of water resources (Meybeck et al., 2003).

The effects of fertilizer use on water supply are evaluated with a focus on agricultural water consumption and sustainable management practices. Establishing robust legal and regulatory frameworks is critical for protecting water resources and reducing the adverse impacts of fertilizers on water quality (UN-Water, 2015).

IMPACTS ON BIODIVERSITY

Excess fertilizers accumulated in soil can negatively affect local plant and microbial populations. In particular, nitrogen compounds can be toxic to some soil microorganisms, which can upset the balance of the soil ecosystem (Giller et al., 2011).

Excessive use of fertilizers can reduce the diversity of native plant and animal species in agricultural areas. The use of pesticides and fertilizers can create unsuitable environments for organisms living in agricultural monocultures (Bengtsson et al., 2015; Batáry et al., 2011). The overuse of fertilizers can disrupt natural interactions between plant and animal species in agricultural areas. For example, the use of pesticides and associated changes in the food chain can lead to an increase in pest species and a decline in native species (Tscharntke et al., 2021).

Excessive fertilizer use can also have significant impacts on soil biodiversity. Changes in microbial activities can have negative impacts on the species diversity of natural soil microorganisms (Geisseler and Scow, 2014; Griffiths and Philippot, 2013). The transport of fertilizers from agricultural fields to water systems can also affect biodiversity in aquatic ecosystems. In particular, excessive accumulation of nutrients such as phosphorus and nitrate can put pressure on aquatic plant and animal species (Carpenter et al., 1998).

Reduced biodiversity can also lead to reduced ecosystem services. For example, ecosystem services, such as pollination and natural pest control, can suffer with reduced biodiversity (Hooper et al., 2005). The impacts of excessive fertilizer use on biodiversity can also complicate conservation and restoration efforts. The decline of native species and loss of genetic diversity can hinder the restoration of natural ecosystems (Suding et al., 2015).

The interactions of excessive fertilizer use with climate change can further negatively affect biodiversity. In particular, increased greenhouse gas emissions and disturbances in biological balances can affect the distribution of species and their natural habitats (Sala et al., 2000). It is important to develop the necessary policies and management strategies to conserve biodiversity.

Effective policy decisions are required for sustainable agricultural practices and the protection of natural habitats (United Nations, 2010).

IMPACTS ON CLIMATE CHANGE

The use of nitrogen fertilizers can lead to the greenhouse effect by increasing emissions of nitrous oxide (N_2O) gas. These gases are long-lived in the atmosphere and have a high potential for global warming (Davidson, 2009).

Fertilizers are chemicals widely used in agricultural production to increase yields. However, excessive fertilizer use can contribute to climate change in various ways. Fertilizers containing excess nitrogen can increase emissions of greenhouse gases such as methane (CH4) and nitrous oxide (N2O) on agricultural land. Methane is formed as a result of microbial activity, especially in wetlands and rice fields, while nitrous oxide is often released during soil treatments and fertilization (Smith, 2017; Butterbach-Bahl et al., 2013).

Fertilizer use can also affect soil carbon storage capacity. Fertilizers such as phosphorus and potassium can accelerate or slow down the breakdown of organic carbon by altering microbial activities in the soil. This can lead to a decrease or increase in soil carbon stocks (Leifeld and Fuhrer, 2010).

The effects of fertilizer use on the water cycle can have indirect impacts on climate change. In particular, excess nitrogen and phosphorus can be transported into aquatic systems, leading to eutrophication and reducing the ability of aquatic ecosystems to adapt to climatic changes (Vitousek et al., 2009; Schindler, 2012).

Fertilizer use can also alter the effects of agricultural practices on local climate. For example, irrigation and fertilization practices can influence regional climate systems by altering microclimate characteristics and precipitation patterns (Rosenzweig et al., 2001; Lobell et al., 2009).

Sustainable agricultural solutions are needed to mitigate the impacts of climate change. Policy and management strategies such as using less nitrogen fertilizers, promoting organic farming practices and adopting agricultural methods that reduce carbon emissions play an important role in combating climate change (FAO, 2013; IPCC, 2019). The effects of fertilizers on biogeochemical cycles can have indirect impacts on global warming. In particular, nitrification and denitrification of nitrogen can affect atmospheric compositions and greenhouse gas concentrations, which can increase global warming trends (Galloway et al., 2008; Howarth et al., 2002).

ECONOMIC IMPACTS

Unsustainable levels of fertilizer use can increase the costs of agriculture in the long run and reduce crop yields with reduced soil fertility (Cassman et al., 2002). Fertilizers are chemicals commonly used to increase yields in agricultural production. However, excessive fertilizer use can harm human health and the economy in various ways.

The transport of fertilizers from agricultural lands to waters can lead to the contamination of groundwater and surface waters with compounds such as nitrate and phosphate. Nitrate, in particular, can pose serious risks to human health when consumed in excess, causing health problems such as methemoglobinemia (blue baby syndrome) (Ward et al., 2005). Some fertilizers used in agricultural applications can release volatile organic compounds (VOCs) or dusts into the air. These substances can have adverse effects on human health through inhalation, in particular increasing the risk of respiratory diseases (Schwartz et al., 2019).

Overuse of fertilizers can accumulate on plants and enter the food chain, leaving residues in products consumed by humans. These residues can contain chemicals that can harm human health in the long term and raise concerns about food safety (Carpenter et al., 1998). Water and air pollution from fertilizers can exacerbate health problems and thus increase health expenditures. In particular, nitrate-induced health problems can place additional burdens on health systems and increase treatment costs (Weyer et al., 2001; Ribaudo et al., 2001). Excessive fertilizer use can increase soil erosion and reduce the productivity of natural resources. This can lead to a reduction in agricultural productivity and hence economic losses. Environmental restoration and cleanup costs are also a significant economic burden (Bateman et al., 2011; Xepapadeas and Passa, 2005). Policy and management strategies to mitigate potential impacts on health and the economy are important. For example, environmental regulations that regulate and limit fertilizer use can be effective in reducing these impacts and promote sustainable agricultural practices (UNEP, 2013).

MANAGEMENT AND POLICY RECOMMENDATIONS

Various management strategies and policy recommendations should be developed to reduce the harms of excessive fertilizer use. These may include determining the correct fertilizer dosages, improving fertilizer application techniques and providing training to farmers (FAO, 2020). Management and policy recommendations for excessive fertilizer use include various strategies to manage and solve problems in this regard. Here are some management and policy recommendations in this context:

- It is important to establish and enforce local, national and international regulations that regulate and control fertilizer use. These regulations should aim to monitor, limit and manage fertilizer use (OECD, 2017).

- Promoting sustainable agricultural practices can reduce the impacts of fertilizer use. These practices can include organic farming methods, conservation of natural resources and improving soil fertility (FAO, 2019).

- Education and awareness-raising campaigns about the impacts of fertilizer use should be organized among farmers, agricultural professionals and the general public. These campaigns should aim to raise awareness on the correct use of fertilizers and their environmental impacts (van der Weijden et al., 2019).

- It is important to develop and implement appropriate management plans in agricultural areas. These plans should cover issues such as protecting water resources, reducing soil erosion and supporting biodiversity (Giller et al., 2015; Verma et al., 2018).

- Promoting innovative agricultural technologies and best practices can reduce the impacts of fertilizer use. For example, precision agriculture techniques and smart fertilization systems can minimize environmental impacts by optimizing fertilizer use (Zhao et al., 2016; Singh et al., 2015).

- Environmental sensitivity and risk assessments should be conducted to continuously evaluate and minimize the environmental impacts of fertilizer use. These processes can provide the scientific basis for policy formulation and implementation (Bhattacharyya et al., 2015).

- Multi-stakeholder collaboration and coordination is important for managing fertilizer use. Collaboration between farmers, governments, academic institutions, non-governmental organizations, and industry representatives can develop common solutions (Wheeler et al., 2018; Srinivasan et al., 2018).

CONCLUSIONS

The environmental and soil damage caused by excessive fertilizer use has far-reaching and enduring consequences. It is essential to adopt sustainable practices in fertilizer management within agriculture. Scientific research and policy initiatives can help mitigate these environmental impacts.

Over-application of fertilizers leads to numerous harmful effects on both soil and the environment. It disrupts the natural structure of soil and its nutrient cycles, particularly through chemical fertilizers, which can alter soil texture, diminish its loamy characteristics, and increase erosion. Certain fertilizers may also shift soil pH towards acidity, complicating nutrient absorption for plant roots and harming microbial activity. Additionally, the decline in organic matter due to excessive fertilizer use reduces soil fertility, lowers water retention capacity, and may degrade soil structure.

Fertilizers can runoff from agricultural fields into water bodies, contaminating both groundwater and surface waters with harmful nutrients like nitrate and phosphorus. This contamination poses risks to drinking water safety and human health. Elevated levels of these nutrients can trigger eutrophication in aquatic ecosystems, leading to excessive plant growth and oxygen depletion, which disrupts the ecological balance.

Furthermore, the application and processing of fertilizers release gases such as ammonia, methane, and nitrous oxide, which negatively impact air quality. These gases can contribute to ozone layer depletion and other air pollution issues, leading to health complications.

Excessive fertilizer use can also harm biodiversity by threatening native plant and animal species. The destruction of natural habitats and practices like monoculture farming further diminish ecosystem diversity. Some chemical components, including certain pesticides, may have toxic effects on wildlife, directly threatening both terrestrial and aquatic organisms.

Pollution of water and air from fertilizers can lead to health problems in humans, potentially increasing healthcare costs. Conditions linked to nitrate exposure can place significant strains on healthcare systems.

In addition, the degradation of soil fertility resulting from excessive fertilizer use can lead to reduced agricultural yields, negatively impacting farmers' economic stability and raising concerns about food security. These adverse effects highlight the broader implications of fertilizer overuse across soil, water, air, biodiversity, and the economy. Thus, adopting sustainable agricultural practices and optimizing fertilizer usage are crucial steps in minimizing these negative consequences.

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CHAPTER 15

CHEMICAL COMPOSITION AND FIBER PROPERTIES OF WOOD OF FIR SPECIES NATURALLY GROWING IN TÜRKİYE: A LITERATURE REVIEW

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INTRODUCTION

Fir trees are evergreen coniferous trees belonging to the genus *Abies*, which is part of the Pinaceae family. They are closely related to pines and spruces. The *Abies* genus consists of around 50 species, including numerous subspecies, varieties, and nearly 150 cultivars. Firs are evergreen trees commonly found in forests, characterized by a pyramidal shape when young and a conical crown as they mature. Young trees have light grey, thin bark, which becomes thick and cracked with age (Yener, 2012). Mediterranean firs have fragmented and restricted distributions, consisting mainly of relict populations of predominantly endemic species. The majority of fir species are concentrated in the Black Sea region and the eastern Mediterranean (Alizoti et al. 2011).

Fir wood is typically regarded as having lower technical value than pine wood, but it is still commonly used in carpentry for its softness and ease of working. It is also utilized in general construction, paper production, composite wood and glued products, plywood, veneer, panels, and poles, as well as for fuel wood. Additionally, the cones, buds, bark and of fir trees may have considerable amounts of fine, resin-rich turpentine (Alizoti et al. 2011). The *Abies* genus plays a crucial role both economically and ecologically. Economically, firs offer valuable resources such as timber, resins, Christmas trees, and ornamental plants. Ecologically, they enhance biodiversity, support wildlife, prevent soil erosion, and assist in water regulation and carbon sequestration. These trees are essential for maintaining forest health, providing ecosystem services, and supporting climate regulation, making them a key component of both natural environments and human-managed landscapes.

A thorough understanding of the chemical composition and fiber properties of wood is essential to fully exploit its potential in various applications. This paper offers a detailed review of the chemical composition and morphological properties of naturally occurring fir species in Türkiye.

TURKISH FIR (*Abies bornmuelleriana* Mattf.)

Turkish fir (*Abies bornmuelleriana*), also known as Bornmüller's fir, is a rare coniferous tree native to northern Türkiye, primarily along the Black Sea coast (Hrivnák et al. 2017). It grows at high altitudes, from sea level to 2 000 meters, often in mixed stands with other species. This tree is a hybrid, likely between the Grecian fir (*Abies cephalonica*) and Caucasian fir (*Abies nordmanniana*). Turkish fir prefers acidic, well-drained soils and tolerates a wide range of temperatures and harsher climatic conditions compared to other conifers (EUFORGEN, 2024a).

The tree is known for its silvery foliage, which is visible due to its upward-growing needles, and its pleasant fragrance, making it a popular ornamental species. It has economic, ecological, and recreational value and is a first-class forest tree, reaching heights of 30-40 meters in suitable conditions. Endemic to Türkiye, it is primarily found in the Western Black Sea and Marmara regions (Figure 1), where it forms beautiful stands with species like *Fagus orientalis* and *Pinus sylvestris* (Yaltırık and Efe, 2000).

Figure 1. The distribution area of Turkish fir (EUFORGEN, 2024a).

The chemical composition of Turkish fir wood is detailed in Table 1.

Table 1. Chemical composition of Turkish fir wood from various regions.

Geographical Region	**H (%)**	**α-C (%)**	**L (%)**	**HWS (%)**	**CWS (%)**	**1% NaOH (%)**	**E (%)**	**A (%)**	**Reference**
-	70.67	-	28.64	2.24	1.47	-	2.88[1]	0.46	Tank (1964)
-	83.30	57.06	28.51	1.65	-	10.57	1.89[1]	0.25	Uçar and Yılgör (1995)
Düzce	78.80	-	27.92	2.20	-	11.64	0.15[2]	0.30	Özdemir (2004)
Bursa	78.28	-	27.68	2.35	-	11.71	0.36[2]	0.39	Özdemir (2004)
Bartın	76.03	51.46*	28.27	2.72	4.21	11.02	-		Alkan (2004)
Bartın	72.8	56.0	26.7	2.3	0.6	7.3	-	-	Istek et al. (2005)
-	70.18	41.96	27.68	2.89	1.37	9.94	4.86[1]	0.36	Temiz (2006)

Bartın	75.35	49.21	27.89	-	-	-	1.84[2]	-	Tumen et al. (2010)
Bolu	71.84	-	28.38	3.64	-	-	-	-	Akgül and Korkut (2012)
Bartın (HW)	70.02	46.37	26.64	2.32	1.50	7.57	1.78[2]		Ataç and Eroğlu (2013)
Bartın (SW)	70.78	45.42	27.79	2.43	1.35	8.60	1.82[2]		Ataç and Eroğlu (2013)
Karabük	73.70	43.53	30.33	-	-	-	2.69	0.36	Özbay (2015)
West Black Sea	79.86	55.61	29.50	3.60	2.33	-	2.68[2]	-	Sivrikaya et al. (2016)

H: Holocellulose, **α-C:** α-cellulose, **L:** Lignin, **HWS:** Hot water solubility, **CWS:** Cold water solubility, **1% NaOH:** 1% NaOH solubility, **E:** Extractives, **A:** Ash, SW: Sapwood, HW: Heartwood, *Kürschner-Hoffer, [1]Alcohol/benzene, [2]Ethanol.

The fiber properties of Turkish fir wood are detailed in Table 2.

Table 2. Fiber properties of Turkish fir wood from various regions.

Geographical Region	FL (mm)	FW (µm)	LW (µm)	CWT (µm)	SR	FR	RR	Reference
Bolu	3.35	38.90	-	7.64	-	-	-	Aytuğ (1959)
- (Normal stem diameter)	3.74	37.87	-	5.74	-	-	-	Tank (1964)
- (Large stem diameter)	3.82	41.56	-	6.26	-	-	-	Tank (1964)
Bartın	4.09	49.02	33.65	7.68	83.54	68.63	0.45	Alkan (2004)
Bartın	2.90	39.70	19.60	10.10	-	-	-	Istek et al. (2005)
Bartın (HW)	2.75	41.33	31.72	5.26				Ataç and Eroğlu (2013)
Bartın (SW)	3.58	49.58	39.50	5.04				Ataç and Eroğlu (2013)

FL: Fiber length, **FW:** Fiber width, **LW:** Lumen Width, **CWT:** Cell wall thickness, **SR:** Slenderness ratio (FL/FW), **FR:** Flexibility ratio [(LW/FW)*100], **RR:** Runkel ratio [(2xCWT)/LW], EW: Earlywood, LW: Latewood, SW: Sapwood, HW: Heartwood.

CAUCASIAN FIR (*Abies nordmanniana* (Steven) Spach)

Caucasian fir (*Abies nordmanniana*) is a coniferous evergreen tree native to the coastal mountains of the Black Sea in Türkiye and southern Georgia (Figure 2) (Nielsen et al. 2020). Its pure stands are rare in Türkiye. It often grows alongside other species like *Fagus orientalis*, but is not found in large (Yaltırık and Efe, 2000).

It thrives in moist, mountainous regions at elevations between 900 and 2 200 meters, though it can also be found at sea level. This species is well-adapted to cold climates and heavy snowfalls, growing up to 60 meters tall with thick, grey bark for protection against the elements (EUFORGEN, 2024b).

Figure 2. The distribution area of Caucasian fir (EUFORGEN, 2024b).

Caucasian fir is economically important in Türkiye, with its white, softwood used in general construction, veneer, plywood, and the paper industry. The tree's long needle retention makes it a popular choice for Christmas trees in Europe. It has a pyramidal shape with horizontal branches and dense foliage (Nielsen et al. 2020). The needles are dark green with distinct stomata bands, and the cones are reddish-brown, averaging 15-16 cm in length (Yaltırık and Efe, 2000). The chemical composition of Caucasian fir wood is detailed in Table 3.

Table 3. Chemical composition of Caucasian fir wood from various regions.

Geographical Region	H (%)	α-C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
-	69.85	-	30.02	1.71	1.04	8.85	3.91[1]	0.56	Tank (1964)
Artvin	76.52	-	28.95	1.87	-	12.12	0.66[2]	0.37	Özdemir (2004)
Trabzon	77.97		27.54	2.16	-	12.36	0.18[2]	0.33	Özdemir (2004)
Trabzon	84.63	51.11	27.25	1.71	4.39	11.35	-	-	Alkan (2004)

- (SW)	-	45.10	28.10	3.80	2.20	12.20	2.30[1]	0.50	Hafızoğlu and Usta (2005)
- (HW)	-	44.30	29.50	6.30	4.40	15.70	5.40[1]	0.80	Hafızoğlu and Usta (2005)
Artvin	73.88	44.82	27.34	2.50	2.78	9.12	0.24[1]	0.31	Odabaş Serin and Güleç (2014)
Giresun (1.30 m stem height)	75.38	-	28.15	-	-	-	-	-	Topaloglu and Erisir (2018)
Giresun (6.30 m stem height)	76.73	-	28.49	-	-	-	-	-	Topaloglu and Erisir (2018)
Giresun (12.30 m stem height)	77.04	-	29.53	-	-	-	-	-	Topaloglu and Erisir (2018)
Artvin (RW)	60.81	35.77	30.28	4.02	2.37	14.96	7.65[3]	0.72	Peşman et al. (2021)
Kastamonu (OW)	83.00	42.07	26.76	1.56	1.40	9.37	2.30[2]	0.37	Kaz (2022)
Kastamonu (CW)	79.07	30.69	30.14	3.00	2.27	13.15	3.06[2]	0.50	Kaz (2022)
Kastamonu	-	-	28.65	-	-	-	-	-	Beram and Yasar (2022)

H: Holocellulose, **α-C:** α-cellulose, **L:** Lignin, **HWS:** Hot water solubility, **CWS:** Cold water solubility, **1% NaOH:** 1% NaOH solubility, **E:** Extractives, **A:** Ash, SW: Sapwood, HW: Heartwood, OW: Opposite wood, CW: Compression wood, RW: Root wood.[1]Alcohol/benzene, [2]Ethanol, [3]Acetone.

The fiber properties of Caucasian fir wood are detailed in Table 4.

Table 4. Fiber properties of Caucasian fir wood from various regions.

Geographical Region	**FL (mm)**	**FW (µm)**	**LW (µm)**	**CWT (µm)**	**SR**	**FR**	**RR**	**Reference**
Trabzon	2.88	43.0	-	5.57	-	-	-	Aytuğ (1959)
- (Normal stem diameter)	3.85	39.82	-	5.54	-	-	-	Tank (1964)
- (Large stem diameter)	3.93	40.43	-	6.18	-	-	-	Tank (1964)
Trabzon	3.09	42.52	34.72	3.90	72.63	81.65	0.22	Alkan (2004)
- (MADw 10536)	3.06	36.70	16.40	-	-	-	-	Esteban et al. (2009)
- (BFH 14031)	3.03	36.80	18.00	-	-	-	-	Esteban et al. (2009)
Giresun (1.30 m stem height)	2.67	33.88	20.47	6.71	-	-	-	Topaloglu and Erisir (2018)
Giresun (6.30 m stem height)	2.31	36.95	24.90	6.03	-	-	-	Topaloglu and Erisir (2018)
Giresun (12.30 m stem height)	2.47	35.92	27.17	4.37	-	-	-	Topaloglu and Erisir (2018)

Artvin (RW)	4.67	60.30	48.22	6.04	-	-	-	Peşman et al. (2021)
Kastamonu (OW)	2.54	39.42	18.77	10.13	-	-	-	Kaz (2022)
Kastamonu (CW)	2.16	34.55	14.28	10.32	-	-	-	Kaz (2022)

FL: Fiber length, **FW:** Fiber width, **LW:** Lumen Width, **CWT:** Cell wall thickness, **SR:** Slenderness ratio (FL/FW), **FR:** Flexibility ratio [(LW/FW)*100], **RR:** Runkel ratio [(2xCWT)/LW], OW: Opposite wood, CW: Compression wood, RW: Root wood.

CILICIAN FIR (*Abies cilicica* Carr.)

Cilician fir (*Abies cilicica*) is a conifer endemic to the eastern Mediterranean, found in Lebanon, Syria, and southern Türkiye (Figure 3) (Awad et al. 2014). It thrives in mountainous areas, typically at elevations between 900 and 2 100 meters, preferring well-drained, rocky, and moist calcareous soils. The species is often found in mixed forests with other conifers and broadleaf trees. Its wood is used locally for construction and furniture, and the tree is occasionally used in landscaping and as a Christmas tree due to its attractive appearance (EUFORGEN, 2024c).

Cilician fir grows up to 25-30 meters in height. The species is found in steep, high, and karstic terrains in the Taurus Mountains and the Amanos Mountains, with a distribution that covers a wide area of southern Türkiye's high forest levels. Its bark is ash grey and smooth, becoming cracked and scaly with age. The tree has distinctive light green needle leaves, and its cones are the largest among Turkish fir species, measuring 15-25 cm in length. The species is divided into two subspecies: subsp. *cilicica* and subsp. *isaurica*. In Türkiye, Cilician fir is primarily found in the Mediterranean region, where it mixes with other species like cedar, black pine, junipers, and oaks. It is the only functional shade tree in this region, creating harmonious mixtures with light trees (Yaltırık and Efe, 2000).

Figure 3. The distribution area of Cilician fir (EUFORGEN, 2024c).

The chemical composition and fiber properties of Cilician fir wood are detailed in Table 5 and Table 6, respectively.

Table 5. Chemical composition of Cilician fir wood from various regions.

Geographical Region	H (%)	α-C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
-	71.60	-	29.12	1.09	0.41	9.81	3.32[1]	0.43	Tank (1964)
Andırın	78.52	-	27.87	1.78		9.76	0.47[2]	0.30	Özdemir (2004)
Göksun	78.20	-	27.52	1.77	-	9.67	0.39[2]	0.30	Özdemir (2004)
Akseki	79.74	-	27.78	2.78	-	11.07	0.29[2]	0.37	Özdemir (2004)
- (SW)	-	41.70	28.60	4.00	2.00	7.50	4.00[1]	0.40	Hafızoğlu and Usta (2005)
- (HW)	-	44.90	27.00	4.40	2.60	11.10	5.50[1]	0.30	Hafızoğlu and Usta (2005)
Andırın	70.29	50.98	29.42	1.80	0.31	9.37	1.36[1]	0.53	Güleç (2011)

H: Holocellulose, **α-C:** α-cellulose, **L:** Lignin, **HWS:** Hot water solubility, **CWS:** Cold water solubility, **1% NaOH:** 1% NaOH solubility, **E:** Extractives, **A:** Ash, SW: Sapwood, HW: Heartwood, [1]Alcohol/benzene, [2]Ethanol.

Table 6. Fiber properties of Cilician fir wood from various regions.

Geographical Region	FL (mm)	FW (µm)	LW (µm)	CWT (µm)	SR	FR	RR	Reference
Adana	2.65	34.1	-	5.88	-	-	-	Aytuğ (1959)
- (Normal stem diameter)	3.83	37.53	-	5.39	-	-	-	Tank (1964)
- (Large stem diameter)	4.02	38.25	-	5.77	-	-	-	Tank (1964)
- (INIA 0008)	3.38	38.10	15.50	-	-	-	-	Esteban et al. (2009)
- (BFH 14036)	2.91	39.30	15.70	-	-	-	-	Esteban et al. (2009)

FL: Fiber length, **FW:** Fiber width, **LW:** Lumen Width, **CWT:** Cell wall thickness, **SR:** Slenderness ratio (FL/FW), **FR:** Flexibility ratio [(LW/FW)*100], **RR:** Runkel ratio [(2xCWT)/LW].

TROJAN FIR (*Abies equi-trojani* Aschers. et Sint.)

Trojan fir (*Abies equi-trojani*) is a coniferous, monoecious, wind-pollinated tree species native to a few small areas in the Mount Ida region of northwestern Türkiye, near the ruins of Troy. It grows in montane forests, typically at elevations between 700 and 2 000 meters, often in mixed stands with deciduous and coniferous trees. Trojan fir is more tolerant of lower and warmer regions than other fir species, making it more dominant than species like Turkish fir (*Abies bornmuelleriana*) at lower latitudes (EUFORGEN, 2024d).

Trojan fir shares morphological characteristics with both Turkish fir and Greek fir (*Abies cephalonica*), particularly in the shape of its needle leaves. The species produces cylindrical cones, 15-20 cm long, with curved tips. It typically forms pure or mixed forests with Black Pine and Beech at altitudes between 1,300 and 1,800 meters in the Kazdağı region. Compared to other local fir species, Trojan fir grows more quickly, making it an important species in forest systems. Its natural distribution is limited to the forests of Bayramiç Forest Management and surrounding areas in Western Anatolia (Yaltırık and Efe, 2000).

This species is valuable not only ecologically, providing habitat and food for wildlife, but also economically. Its light, non-resinous wood is prized in the woodworking industry for construction, furniture, and other uses. Trojan fir is typically found on north-facing slopes in humid bioclimates (EUFORGEN, 2024d).

Figure 4. The distribution area of Trojan fir (EUFORGEN, 2024d).

The chemical composition of Trojan fir wood is detailed in Table 7.

Table 7. Chemical composition of Trojan fir wood from various regions.

Geographical Region	**H (%)**	**α-C (%)**	**L (%)**	**HWS (%)**	**CWS (%)**	**1% NaOH (%)**	**E (%)**	**A (%)**	**Reference**
-	71.30	-	28.62	1.99	1.53	10.18	3.77[1]	0.41	Tank (1964)
Kalkım	78.24	-	27.54	1.67	-	10.24	0.35[2]	0.38	Özdemir (2004)
Bayramiç	78.15		29.64	2.51		12.06	0.18[2]	0.29	Özdemir (2004)

H: Holocellulose, **α-C:** α-cellulose, **L:** Lignin, **HWS:** Hot water solubility, **CWS:** Cold water solubility, **1% NaOH:** 1% NaOH solubility, **E:** Extractives, **A:** Ash, [1]Alcohol/benzene, [2]Ethanol.

The fiber properties of Trojan fir wood are detailed in Table 8.

Table 8. Fiber properties of Trojan fir wood from various regions.

Geographical Region	**FL (mm)**	**FW (µm)**	**LW (µm)**	**CWT (µm)**	**SR**	**FR**	**RR**	**Reference**
Balıkesir	3.34	40.5	-	5.31	-	-	-	Aytuğ (1959)
- (Normal stem diameter)	3.79	36.22	-	5.36	-	-	-	Tank (1964)
- (Large stem diameter)	3.82	36.57	-	5.51	-	-	-	Tank (1964)
-	3.47	38.00	17.50	-	-	-	-	Esteban et al. (2009)

Kastamonu (795 m altitude, 3 years old)	1.26	31.10	-	-	-	-	-	Özden Keleş (2020)
Kastamonu (1350 m altitude, 3 years old)	1.25	26.30	-	-	-	-	-	Özden Keleş (2020)

FL: Fiber length, **FW:** Fiber width, **LW:** Lumen Width, **CWT:** Cell wall thickness, **SR:** Slenderness ratio (FL/FW), **FR:** Flexibility ratio [(LW/FW)*100], **RR:** Runkel ratio [(2xCWT)/LW].

CONCLUSIONS

The chemical composition of *Abies* wood is complex, involving several key constituents that determine its properties, utility, and ecological role. These constituents include polysaccharides like cellulose and hemicellulose, phenolic compounds like lignin, and various extractives, with each contributing distinct features to the wood's physical characteristics. The wood fibers of *Abies* species have distinct properties that make them suitable for various applications, particularly in the paper and pulp industry. The tree's anatomical features, chemical content, and the morphological characteristics of the fibers themselves affect these attributes. In conclusion, the chemical composition and fiber morphology of wood of tree species growing naturally in Turkey vary depending on the tree species, the region where it grows and its location on the tree.

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CHAPTER 16

USE OF ROOTSTOCK IN ALMOND CULTIVATION

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1. INTRODUCTION

Almond (*Prunus dulcis* Mill.) is a plant with a wide distribution area and originated from Central and Western Asia (Özbek, 1978). It has spread from Asia and West Asia to China and India in the east and to Northern Iran, Syria and Mediterranean countries in the west. Cultivated almonds were developed from *Amygdalus communis* L. species as a result of selections made over the years. When selecting the seeds, breeders especially preferred high quality fruits and thus obtained productive trees producing high quality fruits (Özbek, 1978).

The spread of almonds has expanded throughout history as a result of geographical and cultural interactions. First of all, almonds originated in the Middle East and the Mediterranean region. Since ancient times, the almond tree has been cultivated especially in regions such as Anatolia, Mesopotamia, Egypt and the Levant (Gradziel, 2017). Almonds were considered a popular fruit in Ancient Greek and Roman times. Greek and Roman cultures considered almonds as an important food with nutritional and medicinal properties. During this period, almond trees were generally cultivated in the Mediterranean basin. During the medieval period, the trade and cultivation of almonds spread to various parts of Europe. In medieval Europe, the almond tree was cultivated especially in countries with a Mediterranean climate, such as Spain, Italy and France. In addition, during the medieval period, almond trees spread to Central Asia and Eastern Europe under the influence of Arab traders and Mongol invasions (Toussaint-Samat, 2009). Today, almond trade and production is widespread throughout the world. Especially in California, United States of America, almond production has a significant share worldwide. Almonds are also cultivated in Spain, Australia, Italy, Turkey and many other countries.

In recent years, significant changes have occurred in almond cultivation in the Mediterranean region. In some countries, almond production has declined drastically, while in others there have been a number of innovations in almond cultivation. In this situation, not only new varieties but also new rootstocks are of critical importance. In terms of cultivars, in the Mediterranean region 'Nonpareil' is planted as the main cultivar and remains popular. However, the overall picture has changed dramatically in the Mediterranean region. In terms of rootstocks, there have been more limited changes in California. However, these changes represent a small percentage of orchard establishment with these new rootstocks (Socias i Company et al., 2009). Peach rootstocks, notably 'Lovell' and 'Nemaguard', remain the most widely used rootstocks. However, the Mediterranean region is experiencing sharp changes, with a shift from the use of different almond rootstocks to peach x almond hybrids.

Since most of the Mediterranean orchards are not irrigated, almond seedling rootstocks are widely used because of their deep root structure and consequently their nutrient and water efficiency. However, their susceptibility to nematodes is a disadvantage. Seedling rootstocks are usually produced from unselected rootstocks with unknown characteristics. Some later studies favored bitter almond seedling rootstocks because of their homogeneity and resistance to nematodes (Kochba and Spiegel-Roy, 1976).

The 'GF-' series, a peach x almond hybrid, has been the most widely used rootstock worldwide for many years and is still the clonal rootstock of choice in both irrigated and non-irrigated conditions. Later, Spanish rootstocks, especially from the CITA program, are increasingly used, especially 'Garnem' from the 'Garfi' x 'Nemared' series, together with Italian rootstocks, probably due to their better management, adaptability and resistance to nematodes (Socias i Company et al., 2009).

Root-knot nematode resistance, which has been the focus of *Prunus* rootstock breeding for many years, has been a fundamental goal for almond breeding. Partial root-knot nematode resistance derived from the open-pollinated 'GF-' rootstock, resistant to *M. arenaria* and *M. incognita*, is a product of these efforts (Esmenjaud et al., 1997). This resistance has been further enhanced by interspecific hybrids such as 'Barrier' (Roselli, 1998) and 'Cadaman' (Edin and Garcin, 1996), derived from *P. davidiana* and resistant to the four main Meloidogyne species, together with 'Sirio' (Loreti and Massai, 1998) from the IS series, which performs effectively on calcareous soils. The peach cultivar 'Guardian' was introduced to the market as tolerant to *Meloidogyne* spp., *Mesocrinema* spp. and 'Peach Tree Short Life' (PTSL) syndrome (Reighard and Loreti, 2008).

There are also a few interspecific hybrids showing cold hardiness and dwarfing traits (Eremin and Eremin, 2002). In the last 20 years, the interspecific almond x peach hybrids 'Garfi' x 'Nemared' have become increasingly in demand. The reason for this demand is to take advantage of the resistance of 'Nemared' to root-knot nematode (Ramming and Tanner, 1983) and the ability of 'Garfi' to adapt to Mediterranean conditions. Three of the selected rootstocks, 'Garnem', 'Felinem' and 'Monegro', show strong vigor and performance under replanting conditions (Gómez-Aparisi et al., 2000; Felipe, 2009). Other almond rootstocks currently in intensive use include Replant-PAC, Root-PAC-40 and Root-PAC-20 (Gasic and Preece, 2014). These rootstocks show a 40% and 20% reduction in tree vigor compared to 'Garnem', respectively.

Selection Criteria for Almond Rootstocks

In general, the characteristics desired in almond rootstocks are as follows: (1) easy reproduction, (2) good compatibility with the cultivar to be grafted on, (3) early yielding, (4) allowing more cultivation per unit area, (5) tolerance to adverse soil conditions and (6) resistance to diseases and pests.

Easy propagation is the first requirement for every rootstock. The inputs that arise in the propagation of the rootstock may cause loss of time as well as an increase in the cost of saplings. One of the criteria for seed propagation is high germination rate. However, heterogeneous seeds make it difficult to control in the garden. For this reason, seeds with a good level of homogeneity are preferred for obtaining seedlings. As for clonal rootstocks, propagation by cuttings is the most preferred method due to its low cost. However, micropropagation method is also frequently used today. This method is mostly used for clones that are difficult to propagate by cuttings. In general, it is desired that rooting is easy and the root system is strong in propagation methods.

In a commercial orchard, it may be desired to change the species or cultivar for different reasons. If a change of cultivar is desired, it is usually done by grafting the desired cultivar onto the existing rootstock with a conversion graft. In such cases, the rootstock should be compatible with all or most cultivars of the species. Successful graft fusion in almonds increases success with almond and peach (*Prunus persica* (L.) Batsch) rootstocks and their hybrids. No incompatibility between almond and peach has been reported so far in studies. In plums (*P. domestica* L. and *P. insitititia* L.), local incompatibility has been observed in hexaploid varieties and transferred incompatibility in diploid varieties (Myrobolan and Marianna) (Felipe, 1989). These differences show the importance of the choice of cultivar/rootstock combination when testing a new rootstock for compatibility.

Rootstocks are important factors affecting the fruit maturation process and juvenile period of fruit trees. The juvenile period and lifespan of trees vary depending on the growth vigor of the rootstocks used (Özçağıran, 1974). One of the productivity strategies in fruit cultivation is planting more trees per unit area by using dwarf or semi-dwarf rootstocks. These rootstocks form smaller canopies compared to trees growing on their own roots. Research shows that trees producing abundant and short shoots have smaller canopy volumes compared to those producing fewer but longer shoots (Basile & DeJong, 2018). Although tree size in almonds is not as critical as in other fruit species, certain growing conditions must be considered. For example, vigorous rootstocks are preferred in arid environments for resistance to unfavorable conditions. Rootpac 40, developed by Webster (2002), is an example of a new rootstock that stands out with its semi-dwarf characteristics. Rootstock selection also determines the lifespan of the orchard. While almond seedlings and almond × peach hybrids create long-lived orchards, peach rootstocks have shorter lifespans. The long-term effects of plum hybrids have not yet been sufficiently researched.

There are great differences between rootstocks in their ability to take up water and nutrients from the soil. High soil absorption power is desirable to maintain productivity even under less favourable conditions. Some rootstocks tend to give bottom shoots, but this undesirable trait can increase the risk of disease and pests due to increased labour as well as mechanical injuries during weed control.

Another desirable characteristic of a good rootstock is adaptation to unfavourable soil conditions and resistance to diseases and pests. The soil requirements of a rootstock limit its commercial use. It is desirable that rootstocks are resistant to heavy and calcareous soils. It is reported that almond and peach roots are susceptible to this problem, but plum roots show the lowest degree of susceptibility (Bayazit et al., 2023). Since almonds are largely grown on calcareous soils, resistance to lime-induced chlorosis and resistance to drought under non-irrigated conditions is also an important requirement. It is desirable that the rootstock is not contaminated with viruses, phytoplasmas and other vaccine-transmitted diseases as well as its ability to adapt to adverse soil conditions. Apart from these, resistance to areas with ground water problems, drought, soil-borne fungal and bacterial diseases and cold are among the characteristics sought in rootstocks in modern fruit growing.

So far, there is not a single rootstock that fulfils all of the above-mentioned characteristics of rootstocks. It may be possible to select the rootstocks that are best adapted to the conditions of that region in each growing region in the long term by monitoring the long-term performance of the rootstocks against factors such as different regions, soil, climate, etc. by conducting more studies on rootstocks and thus improving almond production by using the best genetic material.

2. ROOTSTOCK SPECIES

2.1. Almond seedling

Traditionally, bitter almond seedlings have been used without paying attention to their origin. Usually almond seeds were collected from natural almond populations that were cross-pollinated by the nearest orchards. The cultivars used as seed rootstocks are 'Marcona' in Spain, 'Mission' in California, 'Chellaston' in Australia and 'Don Carlo' in Italy (Fideghelli and Loreti, 2009). Almond seedlings are generally susceptible to nematodes, fungi and bacteria.

The most remarkable feature of almond seedling rootstocks is their hardiness and their ability to grow in poor soils with low rainfall and high lime content (Bayazit et al., 2023). Another characteristic is its deep root system. However, observations made in different soil types show that the depth of root growth is limited by the available oxygen in the soil pores. Therefore, roots reach deeper in porous soils than in more compact soils. A negative characteristic of seedling rootstocks is that they are not homogeneous in growth, development and behaviour and are sensitive to transplantation and handling from nursery to orchard, and generally have poor survival after planting (Karadeniz et al., 2020). They are also susceptible to soil pathogens such as nematodes, Agrobacterium, Phytophthora, Armillaria, etc. and to neck and root asphyxia. Therefore, they are not suitable for cultivation under irrigated conditions except where the irrigation system is localised (drippers, micro, etc.) and the soil has good drainage (Aktan and Soylu, 2020). As a general rule, almond seedling rootstocks are suitable for areas where rainfall is sufficient (Felipe, 1989).

2.2. Peach seedling

This rootstock can only be used on alluvial or sandy loam soils in areas with favourable rainfall or irrigated areas (Rubio-Cabetas et al., 2017). However, the compatibility of peach rootstock and almond is generally not good and swelling may occur at the grafting point as a result of incompatibility (Küden et al., 2000). However, early fruiting of the varieties grafted on it is among the advantages of peach rootstocks (Soylu, 2003). Good scions are obtained from INRA's 'GF-305', 'Montclar' and the USA's 'Lovell', 'Nemaguard', 'Nemared', which are widely recognised (Felipe, 1989) and have long been used for both peach and almond cultivars in different countries (Rubio-Cabetas, 2016).

One of the positive characteristics of peach rootstocks is that they are best adapted to cultivation in irrigated soils. In addition, they have good agronomic performance against some stresses such as tolerance to nematode species. In general, peach rootstocks cannot be considered as a definitive solution for almond cultivation. In contrast, they are highly susceptible to some common pathogens: Agrobacterium, Armillaria, Phytophthora, etc. Therefore, they have a shorter tree life than almond rootstocks. However, rootstocks such as 'Nemaguard' and 'Nemared' are resistant to *Meloidogyne* spp. (Rubio-Cabetas, 2016).

Under favourable conditions, peach rootstock produces strong trees like apricot rootstock. Although the lifespan of the trees is short (usually 15 years), 85-year-old apricot trees grafted on peach have been found in California (Hartmann et al., 1997). It comes into fruit in a short period of three years. In places with high ground water, the life of wild peach rootstocks is short. The ripening time, size and colour of the fruits are the same as those grafted on apricot rootstock (Eriş and Barut, 2000). In the Republic of South Africa, 90% of apricots are grafted on peach rootstock. Apricots grafted on peach rootstock show incompatibility in cold climates, especially in conditions where the temperature fluctuates in the middle of winter (Mehlenbacher et al., 1991).

2.3. Clonal rootstocks

Clonal rootstocks, although more expensive than rootstocks, have the advantage that the material produced is a sample and the growth characteristics are more consistent and better known.

The GF-677 rootstock was developed in 1939 by INRA in France as a hybrid of peach and almond. Its leaves and branches bear the characteristics of both species and have typical Rosaceae pink flowers (Rubio-Cebetas et al., 2017). It is drought resistant thanks to its spreading and multi-branched structure and strong root system (Denizhan and Karaat, 2019; Rubio-Cebetas et al., 2017). The rootstock is tolerant to iron chlorosis, resistant to Phytophthora but susceptible to Agrobacterium and nematodes. It performs well in arid and calcareous soils, but propagation is relatively difficult (Rubio-Cebetas et al., 2017; Rubio, 2016).

G×N series rootstocks were obtained by crossing Garfi almond with Nemared peach rootstock in Spain's CITA programme. It has three main variants, Garnem, Felinem and Monegro (Felipe, 2009). It has red-purple coloured shoots and typical Rosaceae pink flowers (Rubio-Cebetas et al., 2017). These rootstocks are tolerant to alkaline soils and are especially resistant to Root Ur Nematode (Rubio-Cebetas et al., 2017). It performs well in both irrigated and rainy conditions (Rubio, 2016) and is easier to propagate than GF-677 (Gómez-Aparisi et al., 2000).

Cadaman rootstock is a hybrid rootstock of Prunus persica and Prunus davidiana found in Hungary and developed in France. It has similar growth power to GF 677 and Barrier-1 rootstocks. It can be used in poor, calcareous and high pH soils. Although it is resistant to nematode, it does not perform well in heavy soils with high ground water. It is becoming widespread especially in Mediterranean countries due to its early fruit yield and positive effects on fruit quality (Anonymous, 2021a).

Rootpac series is a group of rootstocks developed by Agromillora between 1996 and 2012. Rootpac-R is resistant to nematodes and root rot and tolerant to salinity (Rubio-Cebetas et al., 2017; Pinoched, 2010). Rootpac-20 is suitable for dense planting, promotes earliness and shows moderate resistance to nematodes (Anonymous, 2021b; Rubio-Cebetas et al., 2017). Rootpac-40, on the other hand, is a peach×almond hybrid with low growth vigour and performs better in rich soils (Anonymous, 2021b).

Table 1. Resistance of rootstocks used in almond cultivation to biotic and abiotic factors

Rootstocks	Development Force	Drought Tolerance	Lime Tolerance	Agrobacterium	Pytophthora-Armillaria	Root-knot nematode	Lesion Nematode
Texas	4	T	T	-	-	-	-
Namaguard	5	S	S	S	S	R	S
Lovell	4	S	S	S	S/S	S	S
Garrigues	4	T	T	-	-	-	-
GF-677	4	T	R	S	S/S	S	-
Felinem	5	T	R	-	-	R	-
Nemared	4	S	S	S	S	R	S
Garnem	5	T	R	S	S/T	R	-
Monegro	5	T	R	-	-	R	-
Rootpac-20	1	-	T	-	-/T	MR	-
Rootpac-40	2	-	T	-	-	MR	-
Rootpac-R	1	-	R	S	MR/T	MR	-

Development Force: 1-Minimal, 2-Small, 3-Moderate, 4-Large, 5-Very Large; R: Resistant, T: Tolerant, S: Sensitive, MR: moderate resistance (Pujol, 2017).

2.4. Plum rootstocks

The root system of plums is shallowly developed and the roots are generally less numerous and thicker than those of peaches or almonds. Plums are generally more tolerant to certain pathogens and more resistant to ground water in heavy soils. Plum rootstocks perform better than almond and peach roots in heavy soils (Küden et al., 2000). Therefore, these rootstocks are used when soils are not sufficiently healthy, coarse textured and aerated. Graft compatibility with almonds is highly variable and therefore prior trials may be necessary before a particular almond combination can be used on plum (Kirca and Karadeniz, 2024). Generally the compatibility is good, but some clones may break at the point of grafting due to local incompatibility in the varieties to be grafted onto them. Varieties of well-known 'pollizos' origin are fully compatible if they are true 'pollizos' and free from infectious agents such as viruses (Rubio-Cabetas, 2016).

2.5. Interspecific hybrids

The Mediterranean region has a long tradition of almond tree cultivation. Among the interspecific hybrids of Prunus, almond and peach are the best known and most common. Especially 'Garnem' is the best known and widespread to date (Kankaya et al., 2021). In recent years some other peach x almond hybrid clones have been used with both species and several plum species. These hybrids can be of interest when they show compatibility and agronomic level characteristics. Recently propagated are the Myrobalan x almond hybrid 'Replantpac' (Pinochet, 2010), Rootpac 40 (complex almond x peach hybrid) and Root-Pac 20 (P. besseyi x P. cerasifera), whose compatibility with almond has also been studied.

'GF-677', one of the first rootstocks that comes to mind in almond cultivation, shows a very good compatibility with almonds. This rootstock makes the saplings grafted on it to yield in a short time. 'Garnem' (GN 15), another Almond x Peach hybrid, is a clone rootstock that grows vigorously and has good soil attachment. In addition, it has a slightly higher fruit yield than 'GF-677' and is resistant to stem nematodes (Finn and Clark, 2008; Coşkun, 2012). Almond x peach hybrids (GF-) are very vigorous rootstocks and adapt well to poor soils as their root systems are well attached to the soil (Soylu, 2003). This characteristic is important for almond cultivation for good growth in rainfed or irrigated conditions, which allows production to start earlier. Experience to date suggests that the same cultivar may also show developmental differences when grafted onto different clones of such hybrids. 'Garnem' (GN 15), another Almond x Peach hybrid, is a vigorous growing clone rootstock with good soil attachment. In addition, it has a slightly higher fruit yield than 'GF-677' and is resistant to root-knot nematodes (Finn and Clark, 2008; Coşkun, 2012). The clones used so far are acceptably adapted to different soil types and better support almond cultivation under irrigated conditions.

The selected existing clones have many good qualities, but there are also negative aspects that can and should be improved. Almost all of them share the common characteristic that propagation on good rootstock is not as easy as desired. Some techniques for propagation have been developed with acceptable results (Pascual and Felipe, 1988). However, normal nurseries still face some difficulties in propagating their own plants. Most of the clones used are still susceptible to Agrobacterium and Armillaria and are susceptible to varying degrees of root asphyxia. One negative aspect is their vigorous crown formation. In the last five years, rootstocks from a special breeding programme between different interspecific Prunus, 'Replant-R', 'Root-PAC-40' and 'Root-PAC-20' have been used as rootstocks to reduce tree vigour in some intensive orchard trials.

2.5.1. Clones of peach × almond hybrids

'INRA-GF677' is a natural hybrid of peach and almond from Lot et Garonne (France), introduced in 1939 and selected at the French resort of La Grande Ferrade (INRA, Bordeaux) (Bernhard and Grasselly, 1981). The leaves are intermediate between almond and peach in appearance and size. The flower is rosacea pink. Growth habit is open and branched. The root system consists of many strong roots. Since the almond rootstock is very strong, it quickly sets fruit and gives high yield (Çömlekçioğlu et al., 2020). Its behaviour with rain-fed almond rootstocks is very good, almond almost always prevails over almond sapling. Its resistance to asphyxia is similar to that of common peach seedlings and it is more resistant to chlorosis. It is also susceptible to Agrobacterium and nematodes. 'INRA-GF-677' is a standard rootstock for difficult soils (calcareous, arid, arid, exhausted). It also tolerates moderate salinity levels and has good tree growth and higher productivity than traditional varieties (Çömlekçioğlu et al., 2020). However, it does not perform well under replanting conditions and branching is common in the nursery. It is highly susceptible to Phythophtora, Armillaria, Agrobacterium and root-knot nematode and may not be compatible with modern cultivars, which are also very productive, at least under irrigated conditions (Arquero et al., 2002).

The GN series clones are acceptably adapted to different soil types and are a better option than almond rootstock for irrigated cultivation. Research shows that especially clones 'Garnem', 'Felinem' and 'Monegro' propagate successfully by wood and soft cuttings in aerated and well-drained soils (Felipe, 2009). In addition, successful results are obtained by in vitro propagation. Research shows that these rootstocks, especially selected for almonds, are compatible with a large number of almond cultivars (Felipe, 2019).

3. CONCLUSION

The main explanations for rootstock selection stem from the intensity and quality of fruit tree growth, tree vigour and the need to control management costs. Other considerations are high water and fertiliser use efficiency and specific soil and climatic conditions where soil-borne pathogens are present. In addition, the choice of rootstock for almond cultivation in hot-arid climates must be based on water scarcity, poor water quality or irrigation schedules recommended by irrigation boards. Therefore, rootstocks should be tolerant to water stress with deep and extensive root systems and adapt to poorly drained heavy soils and highly saline soils. Since the widespread cultivation of almonds in Turkey will contribute to the fruit growing of the country, it is important to cultivate with saplings grafted on suitable rootstocks in the new orchards to be established.

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CHAPTER 17

CHERRY LAUREL (*Prunus laurocerasus*) AS LANDSCAPE AND GARDEN PLANT

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Introduction

Cherry laurel (*Prunus laurocerasus* L.) is an evergreen fruit species native to Southeastern Europe and Southwestern Asia. The cherry laurel was first collected from Trabzon in 1546 by the Frenchman Pierre Belon and named Cerasus trapezentuna (Trabzon Cherry). The plant was brought to Italy via Istanbul in the same year; and to Vienna by Clusius in 1574, and from there it was sent to France and England. With its ability to be shaped by pruning, its shiny dark green leaves that do not fall off, and its fragrant white flowers, the cherry laurel began to be grown in parks and gardens throughout Europe from 1600 onwards. Today, there are about 20 cherry laurel cultivars that differ in terms of growth form, leaf size and shape, and winter resistance.

The plant naturally spreads in light, medium and heavy clay soils and shows better pest resistance than many species (Frohne and Pfander, 1984). Cherry laurel is a decorative plant when in full bloom; therefore, it is used in parks and gardens. Cherry laurel is a good park garden tree that filters the polluted air of cities in winter months and can be used as a perch for birds in winter and summer due to its evergreen nature. It is also pH compatible, grows well in full sun or deep shade, and can withstand heavy pruning (Posta, 2009). It is a good dietary fruit with high satiety value and is an important source of phenolic compounds and anthocyanins. Since it begins to bloom in March in the northern hemisphere, it is an important source of pollen and nectar for honeybees (Karadeniz, 2004; Sülüşoğlu and Çavuşoğlu, 2013). Its fruits can be used as table fruit or can be preserved by pickling. Its molasses is very valuable and is especially healing for digestive system diseases. Fresh leaves are used in pharmacies to prepare 'laurocerasus juice' for antispasmodic and respiratory diseases. It is gaining popularity on a commercial scale in the United States, Europe and Türkiye (Foley and Raulston, 1994). The first breeding studies began with the selection of superior black cherry genotypes from natural populations (Karadeniz and Kalkışım, 1996; Akbulut et al. 2007; Sülüşoğlu, 2011). It is an important resource for honey bees (Karadeniz, T., 2004). There are several excellent varieties of cherrylaurel: `Magnofolia' has very large leaves, can be trained into a tree; `Otto Luyken' is compact with abundant flowers, grows to 1 m, spreads up to 2 m; `Schipkaensis' is the hardiest, wide spreading, smaller leaves; `Zabeliana' has narrow, willow type leaves, a good shade ground cover (Anonymous, 2024a). Rooting of Cherry laurel is quite easy (Bak ve ark., 2018).

The plant is given different regional names in our country. The most commonly used of these is "Taflan". *Laurocerasus officinal*is is given local names such as "Gürcü kirazı", "karayemiş", "Laz kirazı", "Laz üzümü", "Laz yemiş", especially in the east of Ordu, and "taflan" in Giresun. The plant takes its place in the folk songs, poems and in short in the folklore of Northeastern Anatolia.

The fruit is round, single-seeded, sour-astringent, less juicy, 8-10 mm long, green at first, turns red, yellow-red-mottled, dirty white-yellowish, almost black when ripe.

There are 20 dwarf species and 9 important varieties abroad in terms of their habitat, leaf length, shape and resistance to cold. In our country, there are 7 Cherry laurel varieties and thousands of genotypes according to the fruit shape and ripening season of the fruit. The homeland of the cherry laurel (*Laurocerasus officinalis* Roemer) plant is shown as the eastern shores of the Black Sea, the Balkans (Former Yugoslavia, Bulgaria), Western Caucasus and Northern Iran. The species grows both naturally and as a cultivated plant in the north-facing Black Sea Mountains and at altitudes ranging from 0 to 1700 m above sea level. In our country, three cultivated forms and one wild form of *Laurocerasus officinalis* have been identified. Of these forms, the "Angustifolia" form in particular is widely distributed and is used as an ornamental plant in gardens in Europe (Anonymous, 2024b).

In our country, in the Black Sea Region; It is found in the vicinity of Rize, around Trabzon, in the Maçka Meryemana Valley, in the leafy forests and forest coasts around Giresun, Sinop (Ayancık), Zonguldak (Devrek), Kastamonu, Bartın and Bolu. In the Marmara Region; It is located in İzmit (Keltepe), Adapazarı, in the Belgrad Forests and Alemdağ around Istanbul, in Bursa Uludağ, in Southern Anatolia; in the Gavur Mountains in Osmaniye and locally in the Amanos Mountains.

There are no economically large black cherry orchards in our country. However, the Eastern Black Sea region consumes black cherry with pleasure, and the trees are mostly found on the edges of houses, gardens, generally tea and hazelnut gardens, on the sides of roads and in forests.

It is found as a tall shrub or tree that does not shed its leaves in summer and winter (evergreen). The wild ones are usually in the form of a bush. Cultivated varieties can grow up to 5 - 8 m tall. It has a strong root system that goes deep. It forms a smooth and usually upright trunk. The trunk is grayish black, dull black in color. It has a hard wood texture and a strong branch system. Flower clusters are seen towards the ends of the branches. These emerge from the leaf axil.

The propagation methods of Cherry laurel are listed below.

1. By seed,

2. By root suckers,

3. By cuttings,

4. By dipping,

5. By grafting,

6. By tissue culture.

Root suckers and cuttings are widely used in the propagation of types with good quality. Production is done with seeds, albeit in very small quantities. However, this method is not preferred because it will open up.

Cherry laurel fruits are eaten as fruit among the people, and their leaves are brewed like tea and used against nervous disorders, as a cough suppressant and antispasmodic. Cherry laurel fruits are easy to digest and are eaten fresh or dried or roasted. They keep people full. Cherry laurel fruits, which are eaten alone or with hazelnuts and walnuts as a snack, are added to cakes, pies and especially compotes to add smell and taste. Jam and pickles are also prepared.

Use of Cherry Laurel in Landscaping and Gardens

Cherry laurel is widely used in landscaping works, city parks, road afforestation, and home garden fences (Foto 1).

Photo 1. Use of Cherry laurel in landscape (Anonymous, 2024d).

The shrub is low in allergens, therefore, suitable for home gardening. Cherry laurel abiotic stress tolerant plant. Tolerates partly shade to full sun, drought and salt spray. Fertile, well-drained soil and not too acid (pH 5-7) is optimum for its growth.

Evergreens that stop growing at a perfect 2.5-5 m. At times when other shrubs aren't performing to their maximum potential, the Cherry laurel is there to do its job. Although Cherry laurel are not very picky about soil, they do not like very calcareous soils. The soil in which they will grow best is deep, humusy, acidic and neutral soils. Cherry laurel that have been grown in deep soil for at least three years and have shown good growth can tolerate drought. In shallow soils or very sandy soils, they should not be left without water throughout the summer.

Excellent varieties abroad

- Magnofolia: Has very large leaves, can be trained into a tree.
- Otto Luyken: Compact with abundant flowers, grows to 2.5 m, spreads up to 4 m.
- Schipkaensis: The hardiest, wide spreading, smaller leaves.
- Zabeliana: has narrow, willow type leaves, a good shade ground cover (Anonymous, 2024c).

How to Use?

- Excellent hedge and home privacy protector
- Wind breaker
- Healthy fruit
- Fruit is good for diabetes patients
- Responds well to pruning and is easy to shape
- Clean the environment
- Since it is evergreen, it does not pollute the environment.
- Used as forage
- Alleviates the acid rain effects
- Planting at highways protects from lights of opposite side vehicles at night
- Due to strong deep root system protects from soil erosion.
- As a nest and perch for birds
- Cleans the polluted air of the city
- It has a relaxing effect on the human spirit.
- Looks beautiful as an evergreen
- Its white flowers provide a good decorative effect in March-April
- Its fruits that ripen in July-August look nice
- Its flowers are a good source of nectar and pollen for honey bees

- Its wood is hard and can be used as solid timber
- Its fruits are good food for humans and wildlife
- Its fruits are used to make molasses, jam and pickle
- It is important in landscaping due to its shiny and strong leaves.
- Suitable for solitary or group landscaping
- Its leaves are used in folk medicine
- It is easily propagated by cuttings, seeds, root suckers and seeds (Photo 2-25).

Photo 2. Use of cherry in landscape (Anonymous 2024e).

Photo 3,4. Use of cherry in landscape (Struga/Nort Macedonia) (Original photo: Turan Karadeniz)

Photo 5,6. Use of cherry in landscape Capricana /Italy (Original photo: Turan Karadeniz)

Photo 7,8. Use of cherry in landscape Struga/Nort Macedonia (Original photo: Turan Karadeniz)

Photo 9,10. Use of cherry in landscape Struga/Nort Macedonia (Original photo: Turan Karadeniz)

Photo 11,12. Use of cherry in landscape Struga/Nort Macedonia (Original photo: Turan Karadeniz)

Photo 13. Use of cherry in landscape Anonymous, (2024f).

Photo14. Use of cherry in landscape (Anonymous, (2024g).

Photo 15,16. Cherry laurel flower bud, pollination and bees, Bolu /Türkiye (Original photo: Turan Karadeniz)

Photo 17,18. Cherry laurel flowers, Bolu/Türkiye (Original photo: Turan Karadeniz)

Photo 19. Cherry laurel flowers (Anonymous, 2024h).

Photo20,21. Cherry laurel fruits / Giresun/Türkiye (Original photo: Turan Karadeniz)

Photo 22,23. Cherry laurel fruits/Giresun/Türkiye (Original photo: Turan Karadeniz)

Photo 24. Cherry laurel seedlings/ Capricana/Italy; Foto 25. Cherry laurel seedlings (Anonymous, 2024ı).

As a result, Cherry laurel is a good hedge plant that can protect home gardens from privacy, noise and dust. It is a good windbreak to protect home gardens, parks and recreation areas, and orchards from wind. Being evergreen, it allows the light coming from the opposite side of the highways to be broken, road safety, and the use of birds as perches in parks and gardens, and the ability to raise their young safely by making nests. It cleans the polluted air of the city, and its white flowers provide decorative visuals. It responds well to pruning and can be shaped in any desired way. With these features and many other areas of use, Cherry laurel deserves to be seen and seen more in our environment. It deserves to be preferred more in landscaping works.

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CHAPTER 18

MICROPLASTICS: LARGE-SCALE PROBLEMS FROM SMALL PARTICLES

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Introduction

A crucial resource, water, sustains human activities and biological existence, playing a pivotal role in key agricultural and industrial sectors. On a global scale, freshwater constitutes about 3.5% of total water resources, with only 0.3% being readily available and suitable for human consumption. The rational and sustainable management of this limited resource is critically dependent on effective conservation strategies. Nevertheless, a growing disregard for environmental issues, combined with the significant overexploitation of water across various sectors, has resulted in a rapid decline in water quality. This deterioration highlights the urgent need for comprehensive and integrated approaches to protect this essential resource for future generations.

Among the myriad pollutants contributing to water contamination, one particularly salient concern in contemporary discourse is plastic pollution, which stems from synthetic organic polymers adversely affecting aquatic ecosystems. The global production of plastics is escalating at an alarming rate, consequently catalyzing the proliferation of microplastics within environmental matrices. Microplastic pollution represents a significant environmental challenge that threatens aquatic ecosystems worldwide. These minute particles, resulting from the degradation of plastic waste, infiltrate water bodies such as lakes, rivers, and oceans, adversely affecting both water quality and the health of aquatic organisms. Microplastics are often inadvertently ingested by fish and other marine life, leading to serious risks that extend through the food chain to human health. Furthermore, the presence of these pollutants disrupts ecosystem balance, poses a threat to biodiversity, and undermines the ecological integrity of water resources. Consequently, addressing microplastic pollution is of paramount importance for both environmental conservation and public health, necessitating urgent and concerted efforts to mitigate its impacts.

The majority of plastics that transition into marine environments and subsequently into the oceans predominantly originate from terrestrial ecosystems in the form of fragmented plastic debris. These fragments undergo degradation into microplastics, measuring less than 5 mm, through processes involving ultraviolet radiation, wave action, and wind dynamics, enabling their translocation to rivers, lakes, seas, and ultimately, the oceans.

The waste generated during the production and utilization of plastics poses significant threats to both ecosystems and human health in the aquatic environments they infiltrate. Microplastics can disperse readily under environmental conditions and facilitate the transport of deleterious organic compounds within water sources through their absorption into the food chain. While research on microplastic pollution has predominantly concentrated on marine ecosystems, investigations into freshwater systems remain markedly sparse. A limited number of studies suggest that microplastics ultimately accumulate in sediments within aquatic environments.

Turkey encompasses a freshwater area of approximately 10,000 km², comprising rivers and lakes. Among the 135 wetlands of international significance in the country, 12 have been designated as Ramsar Sites. Over 80% of the solid waste entering Turkey's water resources is derived from plastic fragments. These plastics can infiltrate freshwater ecosystems via surface runoff, treated or untreated wastewater, combined municipal waste, industrial effluents, fragmented plastic debris, and atmospheric deposition. Research concerning microplastic pollution within Turkey's freshwater ecosystems is exceedingly limited. In this context, the present study aims to elucidate: i) the sources of plastic pollution in aquatic ecosystems, ii) the implications of microplastic contamination on water-sediment-focused ecosystems within Turkey's freshwater systems, and iii) the necessary measures to be implemented at the national level to mitigate plastic pollution.

Microplastics have emerged as a significant environmental concern, particularly in aquatic ecosystems. Their presence poses various macro-level problems that affect both water bodies and sediments, leading to profound ecological consequences. This section explores these interactions and their implications. In this chapter, the following topics below have been discussed comprehensively.

1. Microplastic Accumulation in Sediments

- **Sedimentation Process**: Microplastics can settle in sediments due to their small size and density, leading to their accumulation in riverbeds, lake bottoms, and ocean floors.

- **Impact on Sediment Quality**: The presence of microplastics alters the physical and chemical properties of sediments, affecting nutrient cycling and sediment structure.

2. Bioaccumulation and Biomagnification

- **Trophic Transfer**: Microplastics can be ingested by benthic organisms, leading to bioaccumulation in the food web. As predators consume prey contaminated with microplastics, these pollutants can biomagnify, increasing in concentration at higher trophic levels.

- **Impact on Aquatic Life**: This process can lead to adverse effects on fish and other aquatic organisms, including reduced growth, reproductive issues, and increased mortality rates.

3. Chemical Contaminant Transfer

- **Adsorption of Pollutants**: Microplastics can adsorb harmful chemicals (e.g., pesticides, heavy metals, and persistent organic pollutants) from the surrounding water. This process enhances the toxicity of microplastics, making them carriers of environmental contaminants.

- **Sediment-Water Interface**: The interaction between microplastics and sediments can facilitate the release of these adsorbed pollutants back into the water column, posing risks to aquatic organisms and potentially entering the human food chain.

4. Disruption of Ecosystem Functions

- **Habitat Alteration**: The accumulation of microplastics in sediments can disrupt habitats for benthic organisms, leading to changes in community structure and function.

- **Impact on Nutrient Cycling**: Microplastics can interfere with the natural processes of nutrient cycling, affecting the availability of essential nutrients for aquatic plants and organisms.

5. Implications for Human Health

- **Consumption of Contaminated Seafood**: The biomagnification of microplastics and associated toxins poses risks to human health through the consumption of contaminated seafood.

- **Potential Health Risks**: Research indicates that the ingestion of microplastics can lead to various health issues, including endocrine disruption, inflammation, and other chronic conditions.

6. Mitigation Strategies

- **Monitoring and Research**: Enhanced monitoring of microplastic levels in water and sediments is crucial for understanding their distribution and impact.

- **Improved Waste Management**: Effective waste management practices can reduce the entry of microplastics into aquatic ecosystems.

- **Public Awareness and Policy**: Raising public awareness about microplastic pollution and implementing policies to reduce plastic use can significantly mitigate this issue.

Microplastic Determination Uses and Classifications

Organic and inorganic elements, including carbon (C), hydrogen (H), nitrogen (N), and oxygen (O), converge to form molecular structures known as "monomers." The cleavage of bonds within these fundamental monomeric units facilitates the transformation into elongated, chain-like structures termed "polymers," collectively referred to as plastics (Cantemur 2022). The etymology of the term "plastic" is rooted in the Greek words "Platikos," meaning moldable or shapeable, and "Plastos," meaning molded (Tutoğlu 2019).

The inaugural synthetic plastic, known as Bakelite, was synthesized in 1907 by American chemist Leo H. Baekeland (Yurtsever 2018). Bakelite is classified as a phenol-formaldehyde resin. The first synthetic plastic was produced in 1909, and by the 1930s, polymers such as polystyrene (PS) and polyvinyl chloride (PVC) were being manufactured. Subsequently, polyethylene was introduced in 1933, followed by polypropylene and polyethylene terephthalate in 1954. The global expansion of the plastic industry commenced in the 1950s. Over the decades, global plastic production has exhibited a consistent upward trajectory, culminating in 349 million tons in 2017 and 390 million tons in 2021 (Anonymous 2021).

Plastics are extensively utilized in industrial applications due to their lightweight, flexible, durable, strong, and cost-effective nature, as well as their resistance to water and corrosion (Tutoğlu 2019). Consequently, they have become integral as industrial consumer materials in the global marketplace. Microplastics are defined as synthetic solid particles or polymer structures ranging in size from 1 μm to 5 mm, exhibiting either regular or irregular geometries (Frias and Nash, 2019). The widespread application of plastic products has resulted in a broad distribution of primary microplastics produced within this size range, alongside secondary microplastics generated through the fragmentation or degradation of plastic-containing items (Anonymous 2015).

Millimeter-scale plastics were first documented in marine environments and ichthyological studies during the 1970s, as noted by Carpenter et al. (1972). However, the term "microplastics" was formally defined by Thompson et al. (2004) (Cantemur 2022). Approximately 10% of plastic waste that enters the oceans can be transformed into microplastics via mechanical abrasion in aquatic environments (Moore 2008). It is estimated that over 5.25 trillion plastic particles are present on the surface of the world's oceans (Eriksen et al. 2014). In marine ecosystems, the presence of microplastics is estimated to range between 15 to 51 trillion particles, weighing approximately 93,000 to 236,000 tons (Ioakeimidis et al. 2016).Due to their low density, microplastics can also contribute to pollution on the ocean floor (Van Cauwenberghe et al. 2013). According to Plastic Europa (2016), over 300 million metric tons of plastic are produced globally each year, with more than 12 million tons permanently transitioning into marine environments and accumulating in sediments (Conkle et al. 2018).The plastic industry is characterized by continuous growth. Projections indicate that market demand for plastic products will reach approximately 600 million tons by 2025 and exceed 1 billion tons by 2050 (Iheanacho and Odo 2020).

Types of Plastics and Production Distribution

The raw materials employed in plastic production, such as cellulose, coal, natural gas, salt, and crude oil, are derived from natural sources. Crude oil is a complex mixture composed of thousands of different compounds and requires processing to render it suitable for use (Anonymous 2015).

The predominant types of plastic polymers that dominate the global market include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyamide (PA), and polyester (PES). Furthermore, plastic particles are classified into four distinct categories based on their size: nano, micro, meso, and macro, respectively.

Since the 1950s, the adoption of plastic products has been prevalent across numerous sectors, attributed to their durability against biological, chemical, and environmental conditions, as well as their flexibility, strength, and lightweight properties. To enhance the durability and flexibility of plastics for specific applications, various additives are incorporated. Among these additives, substances such as bisphenol A and heavy metals (including lead (Pb), cadmium (Cd), and copper (Cu)) can exhibit toxic effects on living organisms. Furthermore, microplastics possess the ability to absorb persistent organic pollutants (POPs) on their surfaces due to their lipophilic characteristics, including compounds such as DDT (Dichloro-Diphenyl-Trichloroethane), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Plastics find extensive application in diverse industries, including automotive, textiles, cosmetics, and infrastructure, such as water supply pipelines and beverage containers (Anonymous 2016).

According to the World Bank, global plastic production is estimated at approximately 300 million tons annually. However, plastic pollution in marine and coastal environments is estimated to reach around 9.5 million tons per year, which is equivalent to the volume of one garbage truck every minute (Bahri 2020). In 2021, global plastic production surged to 390 million tons, with 8.3% attributed to recycling and 1.5% categorized as bio-based or biodegradable. European countries are responsible for 57.2 million tons of this total, with 10% derived from recycling initiatives. China stands as the leading producer of plastic, accounting for one-third of global production.

Classification of Microplastics

Microplastics are classified based on various characteristics, including their size, raw materials, structure, shape, and color. In ecosystems worldwide, microplastics are categorized into two groups: primary and secondary.

-Primary Microplastics

Primary microplastics primarily consist of small spherical microbeads used in cosmetics, cleaning agents, and personal care products. They also include pellets utilized in the industry for molding and melting into larger plastic products. These pellets have been entering the environment since the 1950s, coinciding with the mass production of plastics. In personal care products, substantial amounts of primary microplastics are found in facial cleansers, hand soaps, abrasive agents, and toothpaste, as well as in various sectors such as textiles, where they are often used in glitter-like structures (Anonymous 2021).

-Secondary Microplastics

Secondary microplastics are pollutants that arise from the degradation, wear, and fragmentation of larger plastic items commonly used in daily lives, influenced by natural conditions such as wind and ultraviolet radiation. These pollutants are known to originate from all plastic products used indoors and outdoors, as well as from textile products. Additionally, tire wear from vehicles contributes to these contaminants, which can consist of synthetic polymer-based residues (Özkor 2023).

Types, Colors, and Shapes of Microplastics

Environmental pollutant plastic particles primarily begin as primary microplastics, which include pellets, flakes, clumps, and powders. Plastic pellets are commonly found in spherical, disc, cylindrical, and predominantly oval shapes. Physically, microplastics can be categorized into six groups: fragments, microbeads, pellets, fibers, films, and foams. They exist in various forms within environmental settings. The shapes of microplastics can vary depending on their duration in the environment and the nature of the degradation processes they undergo.A study conducted by Wu et al. (2023) identified that microplastics are generally transparent, blue, purple, red, or other colors. The most prevalent colors of microplastics are classified as transparent, white, and black.

Applications of Microplastics

Plastics have supplanted materials such as steel and glass in various industrial applications due to their durability against chemical, biological, and physical effects, lightweight nature, low production costs, and flexibility. The emergence of the first synthetic plastics in the early 20th century, particularly after World War II, led to increased production and utilization in military contexts.

Today, plastics are employed in a diverse array of applications, including water bottles, cigarette filters, dental floss, toothbrushes, single-use gloves, pharmaceutical capsules, electrical transmission cables, medical products, and essential items in daily life such as disposable forks, spoons, and PET water bottles. Additionally, plastics are frequently used in water supply systems within buildings (Strafella et al. 2021).

The chemical and physical properties of the polymers used in plastic production, including their crystalline structure and molecular weights, render them particularly suitable for food packaging and the packaging of various products (Akçay et al. 2020).

Approximately 44% of plastic production was allocated for packaging purposes, followed by 18% for construction materials, automotive components, electrical and electronic goods, home entertainment devices, as well as agricultural and gardening products (Anonymous 2020).

Methodologies for the Identification of Microplastics and Their Chemical Compositions

With the increasing prevalence of microplastic pollution globally, recent advancements have emerged in scientific studies regarding the use of comparative, straightforward, and effective methodologies (Çakmak and Acaröz 2021). The analysis of microplastics is contingent upon acceptable, appropriate, and analytical methodologies.

To detect the presence of microplastics in water samples, five key steps are involved: sampling, separation, purification, identification, and verification (Pico and Barcelo2019). During this process, it is essential to identify microplastics following the sampling, separation, and purification procedures. For sediment samples, a sediment scoop is submerged into the water at a designated site to collect samples from the uppermost layer at depths ranging from 1 to 5 cm. The collected samples are dried at room temperature to avoid contamination. Dried samples are then sieved using Folk classification through sieves of 8 mm, 5 mm, 4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, and 63 µm; this sieving process determines the percentages of gravel, sand, and silt, thereby identifying the composition and classifications of the sediment. Samples for microplastic analysis are extracted from the fraction below 5 mm (Gül et al. 2022).

While larger particles can be directly sorted visually, smaller fragments often require more than visual examination for accurate identification. Due to the variations in type, structure, size, and color of microplastics, their precise identification can be challenging. Consequently, reliable technologies and applications are essential for determining the chemical composition and concentration of microplastics. To accurately ascertain the chemical structure and identification of microplastics, techniques such as Scanning Electron Microscopy (SEM-EDS), Fourier Transform Infrared Spectroscopy (FT-IR), Raman Spectroscopy, Stereo Microscopy, and Near Infrared Spectroscopy (NIR) are employed. Currently, complex methodologies that predominantly involve microscopy and spectroscopy analyses are favored for microplastic detection; however, there remains a pressing need for novel techniques to reduce the detection time for microplastics (Çakmak and Acaröz 2021).

Sources of Plastics and Mechanisms of Microplastic Formation

It is crucial to accurately identify the entry points of plastics and microplastics into aquatic environments, as well as to correctly ascertain the agents responsible for pollution to facilitate an effective assessment of contamination.

Microplastics can enter water systems through various pathways and from diverse sources. The primary sources of plastics typically include industrial activities, wastewater and sewage treatment facilities, agricultural runoff, and practices related to fishing or aquaculture. These pathways enable plastics to reach rivers, lakes, seas, and even oceans, thereby impacting aquatic habitats.

Plastics entering marine systems from multiple sources can lead to increased concentrations of plastic in the environment, potentially affecting the lifespans of aquatic organisms (Anonymous 2016).

Terrestrial Sources of Plastic Waste and Mechanisms of Microplastic Formation

Terrestrial sources of plastic waste are the primary contributors to microplastics in aquatic environments (Lebreton et al. 2017). Plastics are predominantly produced and utilized on land; however, a significant portion of post-consumer plastic waste and soil-derived microplastics directly enters water bodies (Thompson 2015).

Approximately 80% of plastic and microplastic pollution in aquatic environments originates from terrestrial sources, while the remaining 20% is attributed to marine sources. Plastics, which are commonly used in packaging and construction materials, are employed across various anthropogenic sectors, including agriculture, tourism, and land-based fishing activities (Duis and Coors 2016; Issac and Kandasubramanian 2021).

Microplastics in the atmosphere can also originate from terrestrial sources. These include synthetic plastics, textile fibers produced and used in manufacturing, landfill and incineration processes, exhaust emissions, wear from road surfaces and tires, degradation of plastics, and the resuspension of dust (Dris et al. 2016).

Microplastic particles are also utilized in cosmetic products such as scrubs, sunscreen, eyeliner, and deodorants, as well as in personal care items like soaps, shampoos, hand and facial cleansers, and toothpaste, where they serve as exfoliants. It is estimated that 4,130 tons of microbeads are used annually in European countries, with over 500 distinct microplastic ingredients identified in these cosmetic products. Microbeads intentionally added to cosmetics represent a significant source of microplastics, contributing to approximately 2% of total plastic pollution from personal care products (Wieczorek et al. 2021).

In the agricultural sector, plastic products are employed to ensure that vegetables and fruits are available year-round, often yielding higher productivity than those grown in open fields. Various types of plastics, including polyolefins (PO), polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate copolymer (EVA), polyvinyl chloride (PVC), and occasionally polycarbonate (PC) and polymethyl methacrylate (PMMA), are utilized in agriculture. These plastic products constitute a significant source of microplastics in agricultural activities (Anonymous 2015).

Wastewater treatment facilities also serve as sources of microplastics for both aquatic and terrestrial environments (Alvim et al. 2020). Common microplastics entering urban wastewater treatment plants include microbeads from personal care products, synthetic fibers shed from washing machines, and both primary and secondary microplastics (Kenan and Teksoy 2022). It has been reported that between 4.8 and 12.7 million metric tons of the 275 million metric tons of plastic waste produced in 2010 ended up in the oceans (Jambeck et al. 2015).

A study conducted in 2021 found that despite achieving a 90% removal rate at large-scale municipal wastewater treatment plants, treated effluents still discharged high concentrations of microplastics (Ziajahromi et al. 2021). Research conducted in various countries, including the United States (Mason et al. 2016), the Netherlands (Leslie et al. 2017), Germany (Mintenig et al. 2017), the United Kingdom (Murphy et al. 2016), Sweden (Magnusson and Norén 2014), Australia (Ziajahromi et al. 2021), and Turkey (Akarsu et al. 2021), has reported the presence of microplastics in effluents from wastewater treatment facilities. In Germany, samples taken from the effluents of 12 wastewater treatment plants revealed microplastic particles both larger and smaller than 500 µm, with a majority composed of polyethylene (Bilgin 2019; Cantemur 2022). A study at Finland's largest wastewater treatment plant indicated substantial discharges of micro debris and microplastics into the Baltic Sea (Talvitie et al. 2017). These findings support the conclusion that microplastics pose a significant threat to water resources.

Tourism activities, following the food, fuel, and chemical sectors, represent a major commercial activity. Plastic waste generated from tourism contributes to aquatic pollution (Zhou et al. 2020). The influx of tourists to coastal areas leads to increased temporary populations, resulting in waste from plastic bags, beverage containers, food packaging, and similar items being transported to rivers, lakes, coastlines, and oceans (Wang et al. 2018). Seasonal surges in human density in tourist areas exacerbate the preference for single-use plastics, negatively impacting the environment (Anonymous 2015).

The washing of textile products is a significant source of synthetic fibers in the microplastic size range (<5 mm). Textiles lose approximately 2% of their fibers with each wash. Studies have shown that synthetic garments release an average of 0.3% of their mass as microfibers with each wash (Balpetek et al. 2022). A single garment can release over 1,900 fibers in a household washing machine cycle, and a load of 6 kg can shed up to 700,000 microfibers (Wieczorek et al. 2021). In road transportation, the wear and tear of tires, particularly due to acceleration and braking, is a significant source of microplastics (Anonymous 2015). Currently, tires are produced from a combination of 24% synthetic rubber and 19% natural rubber, along with fillers and vulcanization agents that enhance tire durability. Tire particles disperse through various weather conditions. A study conducted in 2020 reviewed the effects of plastic debris in the water and aquatic systems from various literature and on how COVID-19 has become a reason for microplastic pollution. In addition, considered the role of COVID-19 pandemic in microplastic pollutions, they concluded the highneed for environmentally responsible solutions so more and more study on biodegradable PPEs is needed to be done in order to prevent a potential pandemic of microplastics (Issac and Kandasubramanian 2021).

Marine-Based Sources of Microplastics

The most commonly encountered types of microplastic polymers in marine environments include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyamide (nylon, PA), and polyethylene terephthalate (PET). Generally, PE and PP can remain on the water's surface for extended periods, being transported over long distances by currents and winds. In contrast, polymers such as PVC, PS, PET, and PA, which have densities greater than that of water, tend to sink and accumulate in benthic zones. However, all types of microplastics can be observed throughout marine ecosystems (Anonymous 2015).

Rivers are among the most significant sources transporting plastics from terrestrial environments to the oceans. Additionally, uncontrolled or illegal discharges along coastlines and river valleys, coastal reclamation projects, inadequate waste management, sewage systems, urban and industrial wastewater treatment facilities, leachate, and ports are other major sources of plastic pollution. Marine sources include activities related to both amateur and commercial fishing, shipping, aquaculture facilities, and offshore oil and mineral platforms. Some microplastics originating from urban dust, vehicle tires, and paints are transported to marine environments via the atmosphere, while others reach the ocean through sewage systems. Microplastics are frequently found in coastal areas of marine and oceanic ecosystems with high human populations, and they can be carried by currents to oceanic gyres (Cole et al. 2011).

Microplastics Generated from Maritime Transport Activities

International maritime transport represents one of the most advanced logistics networks today, enabling goods to be moved from any point in the world to another at low costs and with lower energy expenditures compared to other global transportation methods. The expansion of international maritime trade has been driven by the growth of the global economy. In 2021, global maritime transport facilitated the trade of 11 million tons of goods. In 2022, it generated a value of $344 billion, with approximately 86.58% of the volume of goods transported worldwide being carried by sea (Anonymous 2021).

Both tourist and cargo vessels produce solid waste containing plastics during their time at sea. The discharge of waste and plastic materials into marine environments, whether due to adverse weather conditions or the actions of careless or intentional individuals, constitutes a significant source of marine plastic debris.

In the shipping industry, abrasives containing plastics are commonly used during the maintenance and repair of vessels. These abrasives are considered a significant source of microplastics in maritime activities (Tutoğlu 2019). Furthermore, maritime transport contributes to the transfer of microplastics into aquatic environments due to plastic waste discarded from ships (Wang et al. 2018).

The increasing traffic of vessels worldwide heightens the pollution risk associated with daily shipping operations. Activities that pose risks of marine pollution include waste generated from passenger ships, loading and unloading processes, fuel transfers, and ballast water management. Ship-generated waste accounts for approximately 11% of total marine environmental pollution (Bayazit and Kaptan 2023).

Accidents occurring during maritime transport can lead to significant pollution events in the oceans. For instance, a storm-related incident in Germany resulted in the opening of a container, dispersing over 10 tons of plastic pellets into the German Bight, located in the southeastern part of the North Sea (Wieczorek et al. 2021).

A passenger ship carrying 3,000 passengers and crew produces approximately 8 tons of solid waste during a week-long journey. This waste typically comprises organic and inorganic compounds, as well as hazardous materials such as cleaners, pharmaceuticals, and paints. Due to limited storage space on passenger vessels, waste management becomes a critical issue. These ships manage solid waste through source reduction strategies (for recycling) and waste minimization principles. Approximately 75% of solid waste generated onboard is incinerated, with the resulting ash and residues prohibited from being discharged into the sea in accordance with MARPOL Annex V (Regulations for the Prevention of Pollution by Garbage from Ships). However, gray water can be discharged directly into the ocean without any treatment (Anonymous 2016).

Microplastics Generated by Aquaculture and Fisheries Sectors

The consumption of aquatic products is a preferred choice for many individuals due to its numerous nutritional and health benefits. Aquatic products are rich sources of protein, essential fatty acids, and other vital micronutrients (Onyeneke et al. 2020). The aquaculture industry stands out as a prominent sector in global food production (Tidwell and Bright 2019). Multinational aquaculture companies can achieve annual revenues exceeding $1 billion (Ogunji et al. 2021).

During the aquaculture process, microplastics originating from fishmeal and aquaculture feeds are considered primary pollutants (Iheanacho et al. 2023). Additionally, fish medications, antibiotics, and other chemicals used to treat and prevent diseases, as well as to enhance the quality of water and products in aquaculture, have been reported as further sources of microplastic pollution (Zhou et al. 2020).

Plastic debris from fishing activities, including fishing nets, traps, ropes, buoys, bait containers, plastic bags, and gloves, also contributes to marine plastic pollution (Anonymous 2015). Each year, a significant amount of plastic enters aquatic environments due to the end of life of fishing gear and inadequate maintenance (Macfadyen et al. 2009). In Norway, it is estimated that over 46,000 tons of lost and discarded fishing gear are present in commercial fishing areas (Deshpande et al. 2020). The primary materials used in the aquaculture sector include nylon, polystyrene, polyvinyl chloride, polyurethane foam, and polypropylene. It is estimated that 5.7% of fishing nets, 29% of longlines, and 8.6% of traps are lost in this sector, which represents a market worth billions of euros. These lost plastics contribute to the formation of secondary microplastics due to degradation caused by environmental factors such as seawater, sunlight, temperature, salinity, and wind (Wieczorek et al. 2021).

Notably, relatively sheltered aquaculture areas that are not open sea are particularly affected by microplastic pollution. The bioaccumulation of microplastics in aquatic environments has been observed to be greater in aquaculture settings compared to natural habitats. The presence of closed or semi-closed water environments in aquaculture facilities hinders the transfer of microplastics from one environment to another, leading to their accumulation in the water column and sediments (Chen et al. 2018). A study comparing the microplastic levels in farmed mussels with those from natural environments found that farmed mussels contained approximately 178 microplastic particles per individual, while natural mussels contained about 116 particles per individual (Mathalon and Hill 2014).

Microplastic inputs are present in the feeds used in aquaculture and the production areas of aquatic products. A study investigating the microplastic levels derived from fishmeal found an average of approximately 0.72 microplastic particles per individual in samples taken from the digestive tracts of fish (Thiele et al. 2021).

The widespread use of antibiotics in aquaculture has been associated with significant levels of antibiotic-resistant genes (ARGs) (Wang et al. 2018). Recirculating aquaculture systems (RAS) are also considered a source of microplastics in aquaculture (Mnyora et al. 2022). These systems utilize biofilters that contain plastic materials such as polyethylene and polyvinyl chloride, which are viewed as primary sources of microplastics in such aquaculture environments (Hammer 2020). A study aimed at detecting microplastics and antibiotic-resistant genes in RAS found that all water samples contained between 0.58 and 0.72 microplastic particles (both microplastic and mesoplastic) per liter. These results suggest that microplastics in RAS farms may represent a significant reservoir of ARGs (Lu et al. 2019).

As a continuation of the EU Plastics Strategy, the "Directive of the European Parliament and Council on Reducing the Environmental Impact of Certain Plastic Products" proposes the legal restriction of the use of abandoned and lost fishing gear, as well as single-use plastic products. It is believed that the incorporation of similar legal measures into national legislation could be beneficial.

Microplastic Removal Methods

Various types of microbeads, fibers, and other microplastics are primary contaminants entering wastewater treatment facilities. The discharge of wastewater from domestic, industrial, and sewage systems, as well as the drainage of stormwater, serves as pathways for microplastics to reach these treatment plants. Similarly, one of the main sources of microplastics entering aquatic environments is wastewater treatment facilities. It has been noted that municipal wastewater treatment plants are significant receivers of microplastics (Ngo et al. 2019). Consequently, these facilities play a crucial role in the entry, treatment, and control of microplastics in aquatic environments. Waste plastics generated from filters, equipment, and other components within wastewater treatment plants also contribute to the introduction of microplastics into aquatic systems (Carr et al. 2016). Although approximately 83-95% of microplastics are removed in wastewater treatment facilities, 5-17% of these contaminants are released into the environment (Dris et al. 2015).

In urban areas, domestic wastewater discharges are treated within wastewater treatment systems, whereas in rural regions, such discharges are often released into receiving water systems without any treatment or mitigation (Dey et al. 2021).

While wastewater treatment facilities are not specifically designed to remove microplastics, significant removal rates are achieved during primary, secondary, and particularly advanced treatment processes. However, it has been demonstrated that high volumes of microplastic discharge occur when large quantities are released into receiving environments (Ceylan 2017).

Studies on Microplastics in Aquatic Ecosystems: Water-Sediment Interactions

Recent years have seen a surge in research concerning the sources and mobility of microplastics in aquatic environments. Plastic products enter these environments as waste from a variety of sources. Terrestrial pollutants pose significant environmental challenges, with approximately 75-90% of microplastic pollution in marine environments attributed to land-based origins. These sources include industrial activities, domestic discharges, illegal dumping, and land-based fishing operations. The high durability of plastic polymer structures contributes to the ability of microplastics to reach the oceans and persist in these environments (Li et al. 2018). It is estimated that 2.5-5% of the plastic produced annually enters oceanic and marine systems. Currently, this figure is approximately 12.7 million tons, with projections suggesting it could reach 250 million tons by 2025 (Aytan and Çağlayan 2020).

A report published by GESAMP in 2015 indicated that gyre movements in both the Southern and Northern Hemispheres influence the transport of plastics to water bodies. The high population density in the region between North America and East Asia, which accounts for 33-35% of the total oceanic plastic concentration, is a significant factor contributing to the northern gyres. Evidence of plastic and microplastic accumulation has even been found in deep sea regions, such as at a depth of 5766 meters in the Northwest Pacific (Anonymous 2015).

The ocean's water column is stratified into layers—surface, pycnocline, and deep zones—based on properties such as salinity, dissolved oxygen, temperature, pressure, pH, and water density. Larger plastic structures break down, melt, and degrade into smaller fragments, which tend to have lower density than larger plastic pieces. Consequently, microplastics are more prevalent at the ocean and sea surfaces compared to deeper water layers. The surface region of the ocean, representing a low-density area, constitutes about 2% of the total ocean volume. High concentrations of plastic particles have been reported in the water column of the North Pacific Ocean, commonly referred to as the "Great Pacific Garbage Patch" (Isobe et al. 2017). Field studies conducted in the Southern Ocean aimed at detecting microplastics found lower densities compared to the northern hemisphere's oceanic sections. The pycnocline region comprises approximately 18-20% of ocean waters, with its density varying with depth, salinity, and temperature changes. Beneath the pycnocline lies the deep zone, which constitutes about 80% of ocean volume and is characterized by slowly moving cold water (Strafella et al. 2021).

A study conducted in 2014 found that denser plastic particles, such as acrylic and PET, were present at the sea surface at a rate of 5%, while their prevalence increased to 77% at greater depths. The vertical distribution of microplastics in the water column can be influenced by hydrodynamic factors such as wind, temperature, and UV radiation from sunlight (Strafella et al. 2021). Microplastics can be found in various forms within aquatic environments, including aggregation, biofilm formation, ingestion by aquatic organisms, and movement to deeper regions through excretion (Desforges et al. 2014).

Numerous studies have reported the presence of microplastics in freshwater systems and sediments (Strafella et al. 2021). Riverine sources, such as streams and rivers, transport plastics and microplastics from land to seas and even oceans, with the flow conditions of these waterways playing a crucial role in microplastic transport. In rivers with high flow rates, microplastics and plastic fragments are rapidly transported, while lower flow rates can lead to the slowing, dispersal, and eventual sedimentation of these materials. The movement of plastic and microplastic fragments in water is influenced by their size, shape, and density.

Plastics can persist in aquatic environments for extended periods, affecting light permeability and gradually degrading due to various chemical and mechanical influences. This slow degradation process leads to accumulation, which can adversely affect aquatic organisms. Microplastics can enter the bodies of aquatic organisms through drinking, respiration, feeding, and adherence (D'Avignon et al. 2022). It is estimated that plastics affect millions of organisms annually, with reports indicating that over 700 species in aquatic environments are impacted (Önder et al. 2020).

Chlorinated additives like PVC associated with microplastics can have toxic effects on microalgae in water. Additionally, some chlorinated plastics can release HCl during photodegradation reactions activated by light radiation, leading to the acidification of aquatic environments. Microplastics, with their extensive surface area, can be colonized by microorganisms, forming biofilms that facilitate the release of persistent organic pollutants (POPs) into the aquatic environment due to the hydrophobicity arising from the repulsive forces between non-polar compounds and polar environments like water. Consequently, the contaminants and harmful additives associated with microplastics can easily leach into aquatic ecosystems, increasing the risk of toxic substances being absorbed by aquatic organisms.

Microplastics can also impact microbial communities in aquatic environments, facilitating the transmission of infectious diseases and enabling resistance to antibiotics introduced during polymer manufacturing. These factors contribute to the degradation of aquaculture environments, leading to increased oxidative stress, adverse effects on the behavior, growth, and reproduction of cultured species, and limiting the economic benefits of aquaculture (Wu et al. 2023). The presence of larger food particles that are more difficult to digest can induce physical stress in aquatic organisms due to microplastic ingestion (Besseling et al. 2015). Depending on their size and shape, angular particles can cause more significant digestive tract blockages, gill obstructions, and irritation compared to smooth, spherical particles.

Microplastics have been reported to induce oxidative stress in fish metabolism, adversely affecting carbohydrate and lipid metabolism, and facilitating toxin uptake (Jacob et al. 2020). One study indicated that microplastics influence fish metabolism and could trigger the production of reactive oxygen species (ROS), which not only exacerbates oxidative stress (the imbalance between free radicals and antioxidants in the body) but also negatively impacts cholesterol levels and lipid metabolism in fish due to elevated ROS production (Wu et al. 2023).

Global Research on Microplastics

Studies on plastic pollution have highlighted the significance of rivers in terms of plastic accumulation and retention (He et al. 2021). Global research indicates serious microplastic accumulation in river sediments, with plastic pollutants accumulating in riverbeds. Ten rivers worldwide are responsible for 90% of plastic waste entering the oceans, with two of these rivers located in Africa and eight in Asia (Wieczorek et al. 2021). The Yangtze River, the longest river in Asia, ranks first in transporting microplastics to the oceans, followed by the Indus River, which drains into the Arabian Sea. The exposure of these rivers to plastic pollution is exacerbated by the presence of millions of people living in their vicinity and inadequate infrastructure. Other notable rivers include the Yellow River (China), Hai River (China), Nile River (Egypt), Ganges River (India), Pearl River (China), Amur River (China), Niger River (Nigeria), and Mekong River (Vietnam) (Anonymous 2017; Cantemur 2022). In many countries, rivers are utilized for the disposal of solid and liquid waste. Numerous studies have reported that inadequate wastewater treatment facilities, urbanization, population density, and insufficient infrastructure contribute to increased concentrations of plastic in water bodies (Yang et al. 2021). Additionally, atmospheric events have been shown to influence the increase of plastic in water sources. A study conducted in 2019 reported a 14-

fold increase in microplastic concentrations in Mersin Bay, Turkey, following flooding and storms, attributing this rise to atmospheric events (Anonymous 2018; Cantemur 2022). Another study identified the presence of microplastics in snow samples collected from various high-altitude locations (the Swiss Alps, the Arctic, Germany, and Mount Everest), suggesting that this occurrence is linked to atmospheric phenomena (Dris et al. 2016; Wieczorek et al. 2021).

In Thailand, a study conducted on the Tapi-Phumduang River assessed the distribution, abundance, sources, and endpoints of microplastics. This research aimed to explore ways to prevent the transport of microplastics to Bandon Bay, one of Thailand's key shellfish farming areas. Water, sediment, and marine organism samples were collected from the river and bay for analysis. The microplastic concentrations obtained from water samples were compared with data from other rivers and bays worldwide. Rivers such as the Murray River (Australia), Loire River (France), Hudson River (USA), Dutch rivers and Amsterdam Canals (Netherlands), Yangtze River (China), Teltow Canal (Germany), Wei River (China), Ciwalengke River (Indonesia), Mississippi River (USA), Sea of Japan (Japan), Rostock Coast (Germany), Southeastern Coast (South Africa), Mediterranean (Israel), Cilacap Coast (Indonesia), Tuscany (Italy), coastal waters (China), Maowei Sea (China), Guanabara Bay (Brazil), Jiaozhou Bay (China), South Yellow Sea (China), Mannar Bay, and Tuticorin coasts (India) reported lower microplastic concentrations than those observed in Bandon Bay. Sediment samples were similarly compared with data from other rivers and bays, including the Rhine River (Netherlands), Thames River (UK), Rhine and Meuse Rivers (Netherlands), Nakdong River (South Korea), Yangtze River (China), Huangpu River (China), Antua River (Portugal), Pearl River (China), Yonfeng River (China), Brisbane River (Australia), Shuangtaizi River (China), Qin River (China), Chao Phraya River (Thailand), Tapi-Phumduang River (Thailand), Mediterranean (Spain), Gulf of Thailand (Thailand), Tokyo Bay (Japan), Arabian Gulf (Iran), Bohai Sea and Yellow Sea (China), Southeastern US coasts (USA), Tunisian coasts (Tunisia), Bohai Sea (China), Torquay and Whitsand Bays (UK), and the Tuticorin coast of Mannar Bay (India), which also exhibited lower microplastic content.

In the last group of organisms studied, two commercially significant bivalve species, *Perna viridis* (green mussel) and *Meretrix lyrata* (saltwater oyster), were sampled from Bandon Bay. When compared with reference studies, these species showed lower average microplastic counts than other aquatic organisms such as *Mytilus edulis* (Netherlands), *Perna viridis* (Indonesia), *Perna viridis* and *Mytilus edulis* (China), *Mytilus edulis* (France), *Mytilus edulis* (UK), *Mytilus spp.* (Norway), *Perna canaliculus* (New Zealand), *Mytilus spp.* (Spain), *Mytilus galloprovincialis*, *Choromytilus meridionalis*, and *Aulacomya ater* (South Africa), *Venerupis philippinarum* (Colombia), *Corbicula fluminea* (China), *Siliqua patula* (Poland), and *Donax cuneatus*

(India). The study highlighted that the input of microplastics into Bandon Bay primarily originates from the Phumduang and Tapi Rivers, which are situated near agricultural areas and are under significant urban pressure (Chinfak et al. 2021).

A study conducted in three major lakes in Dhaka, Bangladesh, aimed to determine the abundance and characteristics of microplastics in water, sediment, and fish. The findings revealed high levels of microplastics in all matrices, with film, fiber, and fragment types prevalent in water and sediment samples due to anthropogenic activities. In fish, foam-type microplastics were found to be dominant. This study emphasized that the predominant structural polymer of the microplastics was polyethylene (PE) (Mercy et al. 2022).

In 2018, a study investigated whether microplastics could be transferred to large organisms such as marine mammals. Seals were kept in a controlled environment and fed mackerel caught from their natural habitat. Subsequent analyses detected microplastic particles in their digestive tracts and feces, indicating the potential for microplastic transfer from fish to top marine mammal predators (Nelms et al. 2019).

A laboratory study conducted in 2016 assessed the effects of microplastics on *Daphnia magna*. No significant effects were observed from primary microplastics; however, exposure to high levels of secondary microplastics (105,000 particles L^{-1}) and suspended solids (74%) resulted in decreased reproduction and increased mortality (Ogonowski et al. 2016).

Another study in 2018 utilized *Xenopus laevis* tadpoles, which were exposed to polystyrene (PS) for four days, from the 36th to the 46th stage (approximately from the second day onward). The study aimed to monitor the development of *Xenopus l.* and reported no impact on body growth or swimming activity due to polystyrene exposure (Pekmezekmek 2022).

Microplastics have been shown to have toxic effects on fish immune systems, with particles sized 24 nm and 27 nm adversely affecting brain development. Smaller particles can be found in the blood vessels and tissues surrounding the brain, potentially causing damage. In a study using zebrafish as a model organism, microplastics of 51 nm (PS) were reported to induce oxidative stress, negatively impacting cardiac and gill functions (Wu et al. 2023).

A separate study on blue crabs found that ingested plastics had detrimental effects on immune systems and respiratory functions (Johnson et al. 2011). Additionally, it was reported that in some crab species, ingested microplastics could enter the circulatory system, leading to oxidative stress and lysosomal dysfunctions after cellular uptake (Ajith et al. 2020).

Microplastics do not only affect animals; seagrasses, which play a crucial role in climate change mitigation and biodiversity conservation, may also be negatively impacted by developmental changes. Seagrasses, which are primary producers and cover 0.2% of the oceans, can have their carbon fixation capabilities reduced by microplastics, which compete with phytoplankton for light, subsequently hindering phytoplankton photosynthesis (Aytan and Çağlayan 2020).

Laboratory studies have examined the effects of microplastics and nanoplastics on the growth of macrophytes. Over one to two weeks at 20 °C, species such as *Myriophyllum spicatum* and *Elodea sp.* were exposed to water containing six different doses of polystyrene nanoplastics and microplastics. The study assessed changes in root and shoot dry weight, relative growth rate, shoot-to-root ratio, main shoot length, and lateral shoot length. While microplastics did not exhibit significant negative effects beyond a reduction in main shoot length for *Myriophyllum spicatum*, nanoplastics caused substantial changes between endpoints. In *Elodea sp.*, exposure to microplastics resulted in increased biomass in shoots and roots, a higher relative growth rate, and increased lateral shoot length, whereas nanoplastics led to a significant reduction in the shoot-to-root ratio as a result of increased root biomass (Van weert et al. 2019).

Some Recent Microplastic Studies Conducted in Turkey

Research on the accumulation and effects of microplastics in surface waters and sediments in Turkey is relatively recent compared to global studies. This section summarizes various investigations conducted in Turkey regarding microplastics.

- **Erzurum Crater Lake (2020)**: A study conducted at an elevation of 280 meters revealed that microplastics were exposed to sunlight and ultraviolet radiation, leading to oxidation and fragmentation into smaller particles capable of traveling long distances through atmospheric events. The presence of polyethylene and polypropylene was identified, attributed to anthropogenic activities and topographical factors (Çomaklı et al. 2020).

- **Cevdet Pond, Yozgat (2020)**: In surface waters, an average of 233 microplastic particles per cubic meter was detected, with polypropylene (PP) constituting 50% of the findings. The majority of identified microplastics were fibers (91%), with 36% being blue in color. The study emphasized the need to investigate the sources of microplastics in this low anthropogenic activity pond (Erdoğan 2020).

- **Süreyya Bey Dam Lake (2020)**: Five different types of microplastics were identified in a study assessing microplastic density in surface waters, with fibers being the most abundant type. The primary components included polyethylene terephthalate, polyvinyl chloride, polystyrene, polyethylene, and polypropylene. The color distribution of the microplastics was reported as black > blue (Tavşanoğlu et al. 2020).

- **Manavgat River, Aksu Stream, and Köprü Stream (2021)**: A study by Güven (2021) investigated the abundance and spatio-temporal distribution of microplastics across three freshwater systems, collecting 106 water samples. It was found that the presence of microplastics decreased with increasing depth, with more than half of the samples containing fiber-type microplastics, and polypropylene particles constituting 50% of the findings. Comparisons with European rivers such as the Danube, Po, Rhine, and Dalalven indicated a lower microplastic load in the studied rivers.

- **Susurluk Basin (2022)**: In this study, sediment samples from Uluabat Lake (38 samples) and Kocaçay Delta (17 samples) were collected using coring tubes. The research aimed to determine whether sediment records reflected microplastic accumulation and anthropogenic activities over time. The results indicated an increasing trend in microplastic concentration compared to a study conducted in 2006 (Almas et al. 2022).

- **Kocaçay River and Nilüfer Creek (2023)**: This research highlighted high levels of microplastics in surface water and sediment samples collected during both dry and rainy seasons, indicating significant anthropogenic pollution. The study noted that while this situation is considered normal from a global perspective, it could not conclusively determine whether the microplastic sources were due to fishing, anthropogenic activities, or industrial processes (Filazi et al. 2023).

- **Fish Studies**:

✓ Research focused on *Mullus barbatus* and *Trachurus mediterraneus*, which are indicator species in national monitoring efforts. A total of 169 microplastic particles were identified in the digestive organs, with microplastic levels ranging from 30%-69% for *Mullus barbatus* and 46%-60% for *Trachurus mediterraneus*, indicating significant exposure (Güven et al. 2017).

✓ Atamanalp et. al (2022) conducted a study representing the inaugural research aimed at measuring and characterizing microplastics (MPs) within freshwater ecosystems in Turkey, focuses on the identification and characterization of MPs in the gastrointestinal systems of three fish species *Squalius cephalus*, *Cyprinus carpio*, and *Alburnus mossulensis,* inhabiting the Karasu River in Erzurum. The results yielded a total of 232 microplastics detected across all three fish species' gastrointestinal systems. The predominant color identified was black, accounting for 39–58% of the findings, while the most common morphological form was fiber (88%), followed by fragments (6%) and pellets (6%). Notably, microplastics sized between 1001 and 2000 μm were observed. The plastics identified included polyethylene, polyester, poly(vinyl stearate), polyethylene terephthalate, polypropylene, and cellulose. Among the species studied, *S. cephalus* exhibited the highest prevalence of plastic pollutants. These findings underscore the presence of microplastics in dominant fish species and provide foundational information for future investigations into the interactions between living organisms and microplastics in inland aquatic environments.

- **Microplastics in Salt (2018)**: A study found microplastics in salt samples from 16 brands, with concentrations of 16-84 particles/kg in sea salt, 8-102 particles/kg in lake salt, and 9-16 particles/kg in rock salt. Polyethylene (PE) and polypropylene (PP) were the most common polymers detected (Gündoğdu 2018).

Some Recent Researches Related with the Effects of Microplastics on Human Health

Microplastic pollution is a pervasive global issue that impacts all living organisms. The health impacts of microplastics have become a subject of extensive research. Microplastics can enter the human body through inhalation, ingestion (via drinking water, food, etc.), and even through damaged skin (Lehner et al. 2019). The presence of microplastics has been observed in commonly consumed foods and beverages (Yurtsever 2018).

- **Lung Disease:** A current study represents the first exploration of the relationship between interstitial lung disease and microplastics, revealing a notable prevalence of MPs in the bronchoalveolar lavage (BAL) of interstitial lung disease (ILD) patients, particularly among those exhibiting a fibrotic phenotype. These findings underscore the need for further investigation into the cumulative effects of MPs on human health, with a particular emphasis on the respiratory system, which is highly susceptible to environmental pollutants (Özgen et al. 2024).

- **Body Effects**: A study conducted in 2023 concluded that microplastics smaller than 100 nanometers could reach almost all organs in the human body. Additionally, microplastics were found in blood, lung, heart tissues, and placentas of unborn babies (Cox et al. 2019).

- **Chemical Substances**: The chemicals carried by microplastics pose health threats. For instance, Bisphenol A, a harmful substance commonly used in food packaging, has been associated with early puberty, thyroid disorders, and various cancers (Ari and Öğüt 2021).

- **Food Sources**: The consumption of microplastic-contaminated seafood, such as fish, mussels, and squid, can adversely affect human health Long-term consumption of these products has been linked to health issues like first evidence of microplastics in human placenta (Ragusa et al. 2021).

- **Sediments:** The interaction between microplastics and sediments can facilitate the release of these adsorbed pollutants back into the water column, posing risks to aquatic organisms and potentially entering the human food chain and the hazard index should be assessed especially as a source from sediments (Akarsu et al. 2024).

- **Paper Cups**: Research conducted in 2020 indicated that immersing paper cups in boiling water (85-90 °C) for 15 minutes resulted in the formation of approximately 25,000 microplastic particles in a 100 ml cup (Goel et al. 2020).

- **Tea Bags**: A study in 2019 revealed that boiling a single tea bag at 95 °C released approximately 11.6 x 10^9 microplastic particles and 3.1 billion nanoplastic particles into a cup of tea (Hernandez et al. 2019).

The effects of microplastics on human health raise significant concerns regarding food safety and environmental health. The increase in microplastic research in Turkey is essential for better understanding and addressing this pressing issue. Further studies are needed to elucidate the sources, pathways, and long-term impacts of microplastics on both environmental and human health.

Alternatives to Synthetic Plastics and Strategies for Reducing Their Use

Synthetic chemicals are ubiquitous in our daily lives, present in numerous products we encounter regularly. We are surrounded by hundreds, if not thousands, of synthetic chemicals daily; they can be found in our food, clothing, tools, furniture, toys, cosmetics, and pharmaceuticals. Increasing research highlights the potential adverse effects of synthetic chemical products on our health and the environment.

According to Eurostat data, over 300 million tons of chemicals were consumed in the EU in 2018, with more than two-thirds classified as harmful to health. Under the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), more than 20,000 distinct chemicals have been registered in the EU. Plastic pollution is a growing environmental issue impacting not only the globe but also Turkey. The inadequate disposal and management of plastic waste lead to various environmental problems. While studies have elucidated the impacts of synthetic plastics on nature and human health, research in this area is ongoing, revealing numerous topics that require further exploration. Various studies have been conducted on alternative products to synthetic chemical plastics. This section aims to provide information about these alternatives.

Polymers

Polymers are structures widely used in various industrial products due to their ease of shaping, corrosion resistance, lightweight, and low cost. The demand for polymer products continues to grow. Polymers are adapted to meet the diverse needs of industry. Approximately 5% of fossil fuels are utilized to produce polymers, which have become the most preferred materials in the industry due to their superior properties (Hamamcı et al., 2018). However, the environmental impacts of polymers, which are not biodegradable and derived from petroleum resources, are well-documented. As a result, there is an emerging search for new organic polymers that are environmentally friendly and beneficial to living organisms.

Biopolymers / Bioplastics

A significant portion of natural polymers typically resides within living organisms, such as keratin in nails, wool, hair, and the polymeric structures of carbohydrates, deoxyribonucleic acid (DNA), and ribonucleic acid (RNA). These polymers are responsible for various characteristics in living organisms, including mobility, aging, and sensory functions, and are referred to as "biopolymers" (Baysal, 1994).

The first known bio-based plastic, polyhydroxybutyrate (PHB), was discovered by French researcher Maurice Lemoigne in 1926 while studying the bacterium *Bacillus megaterium*. At the time, this discovery was overlooked due to the abundance of petroleum. However, subsequent oil crises brought the need for alternative products to petroleum-based materials to the forefront. Since then, numerous production methods and applications have emerged.

Biopolymers are biodegradable polymers, and thus, the use of biodegradable polymers is recommended instead of petrochemical-derived polymers. Biopolymers are produced from unprocessed biological materials, which can be derived from plants such as starch and corn, or microorganisms like bacteria and yeast (Hamamcı et al., 2018).

Bioplastics can generally be classified into two categories: biodegradable and non-biodegradable. Although these can be further subdivided, the fundamental distinction lies in materials that degrade, disintegrate, and break down through biological processes versus those that do not degrade through biological means. Non-biodegradable polymers cannot be broken down by living organisms and remain in the environment for extended periods due to physical factors (sunlight, temperature, wind, etc.). In contrast, biodegradable materials can be decomposed by living organisms under specific environmental conditions. The examples of raw materials for bioplastics are listed below: (Anonymous, 2020).

-Chitin

Chitin, a hard substance found in the exoskeletons of insects and crustaceans (such as crabs and shrimp) as well as in the cell walls of fungi, is a natural raw material used as a thickening agent in wastewater treatment, in the food and pharmaceutical industries, and as a binding agent in paper production. Its derivative, chitosan, is also utilized.

-Fungi

Fungi are emerging as a promising alternative raw material source for plastics. They are recognized for their potential to replace both synthetic and animal-based traditional products.

-Cacti

Various cactus species, particularly *Opuntia ficus-carica*, known as "mother-in-law's tongue" in Turkey, are regarded as strong sources of fiber and are being utilized in textiles.

-Hemp

The diverse applications and benefits of hemp fibers have been recognized for centuries. Products such as ropes, clothing, and sails have been produced and used since the Middle Ages. Hemp is preferred for its durability and longevity compared to cotton or synthetic fibers. When subjected to various chemical treatments, it can gain waterproof properties and enhanced flexibility and durability. It can also be processed into pulp for paper and cardboard production. Additionally, a construction material known as hempcrete can be produced in brick form, and a wide range of disposable materials can be manufactured as biodegradable plastic alternatives. The cultivation process of hemp is rapid and easy, and it absorbs significantly more carbon dioxide from the atmosphere than many other plants, thus playing an important role in combating greenhouse gas emissions.

-Algae

The rapid and easy production of seaweed presents significant potential for bioplastic manufacturing. After processing, seaweed-based bioplastics can be formed into films and tested for use in single-use items such as packaging, forks, cups, plates, and straws, even edible materials. However, compared to other alternatives, they are not as robust or durable, necessitating reinforcement with other materials. Besides known seaweeds, microalgae can also be utilized for bioplastic production.

-Olive Pits

Olive pits are collected and ground into granules for bioplastic production. These granules behave similarly to petroleum-based plastics, representing an alternative source for nearly all types of plastic. It has been reported that this could reduce production costs by up to 90% without requiring plastic manufacturers to change their production infrastructure.

-Waste

According to the Food and Agriculture Organization of the United Nations (Anonymous, 2018), approximately 1.3 billion tons of food are wasted globally each year, equivalent to one-third of the food produced for human consumption within a year. Food waste originates from domestic, commercial, industrial, and agricultural sources (Özen and Erdem İşmal, 2022). The process of producing bioplastics from food waste involves capturing the food before it reaches landfills and extracting proteins and starch from the plant waste. In Turkey, bioplastic products are primarily starch- and cellulose-based. Starch-based polymers obtained by wet grinding agricultural products such as corn, potatoes, wheat, and rice can be biologically degraded due to the presence of oxygen and nitrogen in their molecular structure, compared to traditional plastics.

Technological Approaches to Combat Synthetic Microplastics

Technological innovations and advancements should focus on new initiatives to combat synthetic chemical microplastics. A study conducted in the United States in 2020 developed artificial organisms called "Xenobots" from the larval cells of *Xenopus laevis* (African clawed frog). These organisms, developed by expert biologists and computer scientists, were endowed with certain capacities, including memory, self-healing, and cell collection abilities. The aim of this product is to aid in disease detection within the human body and to address chemical pollutants and reactive contaminants. Future studies suggest that these organisms could potentially combat various pollutants, including microplastics, in aquatic environments or soil (Antomarini, 2022).

Conclusion

Currently, sources of potable freshwater are increasingly polluted due to global warming, human activities, and various pollutants. The impact of plastic waste on this pollution is unavoidable. Plastic waste degrades into microplastics for various reasons in the environment. Microplastic-producing plastic products are widely used in daily life by humans. Through the use of these products, microplastics enter the human body via various pathways. Scientific research has demonstrated that these ingested microplastics can lead to various issues in living organisms, such as endocrine disruption, vascular occlusion, and brain damage. Additionally, due to their lipophilic properties, microplastics can absorb various chemicals, including PCT, PCB, and DDT, thereby transporting these hazardous substances into nature and aquatic environments. Microplastics can be found not only in the surface waters of rivers, seas, and oceans but can also accumulate in the sediments of these environments. This study focuses on how microplastics can accumulate in predator species through the consumption of organisms that feed in both surface waters and sediments, ultimately reaching humans.

The removal of microplastics from the ecosystem is as crucial as their entry. Although existing wastewater treatment facilities can eliminate up to 85% of microplastics, some still escape into aquatic environments or become part of the treatment sludge. The microplastics remaining in this sludge can be utilized in agricultural activities, leading to the accumulation of microplastics in agricultural soils. It is known that if wastewater treatment facilities are equipped with newer technologies, the discharge of microplastics can be reduced to negligible levels. This study also presents information on biopolymers, which are alternative products to synthetic plastics. However, due to their plant-based origins, biopolymer products require specific cultivation conditions, necessitating the allocation of existing agricultural land for their production. The restriction of agricultural land represents a loss of land used for human consumption. This issue compounds the global problem of food scarcity. To address the current challenge, the utilization of advancing technologies should be encouraged. A noteworthy example is the development of programmable biological cells from the larval cells of the African clawed frog (*Xenopus laevis*), termed "Xenobots," by American scientists in 2020. These biological robots could potentially be used for the removal of microplastics from surface waters or sediments (Antomarini, 2022). Another technological advancement includes remote microplastic detection technologies (Martinez-Vicente et al., 2019) and the use of portable sensors (Asomoah et al., 2019) in aquatic environments (Wu et al. 2023).

In addition to technological approaches, another option for reducing microplastic pollution is to guide individuals toward decreasing their use of synthetic plastic products through legal means or awareness campaigns. Some recommendations in this regard have been presented below:

- **Public Education**: Individuals should be informed about the pollution caused by plastic usage through public service announcements and educational initiatives.

- **Legal Regulations**: Restrictions should be imposed on the use of pellets, microbeads, and plastic glitter in all consumer products, including clothing, children's toys, cosmetics, cleaning agents, and personal care items.

- **Research Support**: Detailed research should be conducted and supported to better understand the concentrations of microplastics that adversely affect organisms, particularly in freshwater systems.

- **Material Preference**: Natural biodegradable materials should be favored over synthetic plastic products.

- **3R Implementation**: The 3R rule (Reduce, Reuse, Recycle) should be actively implemented to minimize and limit plastic waste production.

- **Source Contamination Prevention**: Measures should be taken to prevent the transition of plastic pollution to water sources by eliminating contamination at the source.

- **Sewage System Protections**: Efforts should be made to prevent or reduce microplastics before they enter the sewage system and subsequently wastewater treatment facilities.

- **Advanced Treatment Technologies**: Wastewater treatment facilities should adopt advanced and effective treatment technologies to enhance microplastic removal and implement regular waste management practices.

- **Textile Fiber Control**: The introduction of synthetic textile fibers into wastewater from washing and drying machines should be curtailed.

- **Standardized Detection Methods**: A standardized analysis method should be established for the detection and identification of microplastics.

- **Consumer Awareness**: Consumers should avoid products containing endocrine-disrupting plastics, such as polyvinyl chloride (PVC), polyethylene terephthalate (PET), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and bisphenol A (BPA) by scrutinizing product labels.

- **Climate Impact Research**: The effects of plastic-induced pollution on climate change and greenhouse gas emissions should be thoroughly investigated.

- **Single-Use Plastics Ban**: A ban on single-use plastics, such as forks, spoons, and knives, should be enforced unless absolutely necessary, with biodegradable alternatives provided.

- **Fishing and Aquaculture Monitoring**: The effects of microplastics in fishing and aquaculture should be assessed and monitored.

- **Alternative Protein Development**: Alternative protein sources should be developed for fishmeal used in aquaculture.

- **Pharmaceutical Limitations**: The use of pharmaceuticals in aquaculture should be restricted.

- **Coastal Tourism Studies**: Monitoring and evaluation studies should be conducted within coastal tourism sectors.

- **Innovative Material Contributions**: Contributions should be made toward the development of alternative tire designs, fuel additives, brake pads, and friction materials to reduce particle emissions from vehicles such as cars, buses, and trucks.

- **Knowledge Dissemination**: A publicly accessible information pool should be created to enhance knowledge about microplastic research (Iheanacho et al. 2023; Wu et al., 2023; Anonymous, 2021; Cantemur, 2022; Skirtun et al., 2022; Chen et al., 2021; Liu et al., 2019).

This study compiles research focused on preventing pollution by considering the production and entry pathways of microplastics into aquatic ecosystems, as well as their effects on human health. In this context, bioplastic and biopolymer products emerge as viable alternatives, underscoring the need for intensified efforts in their development and dissemination. It is anticipated that, in the coming years, more complex studies focusing on microplastic pollution will contribute to the global reduction of synthetic plastic product usage and facilitate the mitigation of microplastic pollution, particularly in aquatic environments.

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CHAPTER 19

WORLD OAK TREES (QUERCUS): SILENT GUARDIANS OF THE FOREST ECOSYSTEMS

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1. INTRODUCTION

Oak trees are of indispensable importance for the balance of nature and human life. The ecological benefits they provide constitute a unique resource for both nature and people by preserving biodiversity and providing economic value. The protection of oak species is key to ensuring the sustainability of not only these durable trees, but also the entire ecosystem that can exist thanks to them.

The genus Oak (*Quercus* L.) is the most prominent genus in the Fagaceae Dumort. family due to both its taxon richness worldwide and the size of the forest areas it covers (Anşin and Özkan 2006). Oaks, which are deciduous in winter or have the form of evergreen trees or shrubs, have leaves of very different sizes and appearances. The leaf margins are mostly lobed, toothed and rarely entire. The cupula, which contains the fruit (acorn) and consists of the receptacle, is usually covered with cup scales (Anşin and Özkan, 2006; Yılmaz, 2018).

Oaks emerged approximately 56 million years ago (Ma) and later spread throughout the Northern Hemisphere (Kremer and Hipp, 2020). Oaks are taxonomically surprising due to their high hybridization ability, interspecific morphological features and intraspecific morphological diversity (Šijačic-Nikolic et al. 2021). Oak taxa play important roles in providing forest products (timber, firewood, mushrooms, extracts and derivatives, etc.), preserving biodiversity, and have high species diversity, ecological and economic importance (Grossoni et al. 2021).

The genus *Quercus* includes a large number of species, and the classification of Oak species has been debated for centuries. The genus has diversified into many species in America and Asia, with the highest diversity observed in Mexico and East Asia (Grossoni et al. 2021; Kremer and Hipp, 2020). Although Europe exhibits relatively low species richness (about 30 species), it is as widespread here as in North America and East Asia, because the limited number of species of the genus are distributed almost throughout the continent (Camus, 1936). While Camus (1936-38) mentioned about 800 taxa worldwide, the most recent studies determined the diversity of oaks to be about 435 species (Denk et al. 2017). According to POWO, there are 656 Oak taxa (473 species) in the world's forests and woodlands, 183 of which are hybrids (28.9%). This number is much higher than other tree genera. The America is the world's leading continent in terms of oak taxa richness. It hosts a total of 241 oak species (51%), excluding hybrids (103). The leading two countries with the most taxa on this continent are Mexico with 173 taxa and the USA with 91 taxa. 34 taxa are common between these two countries. A total of 147 taxa are endemic (77 not) to this continent and the endemism ratio is 61% (compared to 241). East Asia ranks second in terms of the number of taxa (185 species, 39%). In this regard, China is the leading country in this continent with 130 oak taxa (POWO, 2024).

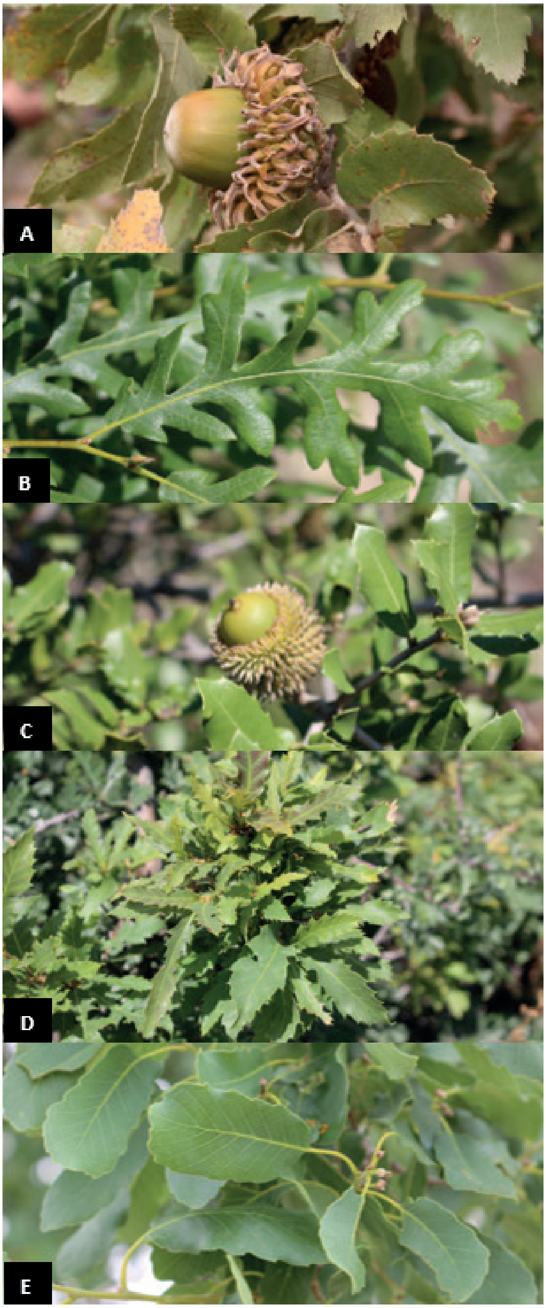

Figure 1. A) Quercus brantii, B) Quercus cerris, C) Quercus coccifera, D) Quercus libani, E) Quercus infectoria subsp. boissierii

Rapid climate change and habitat degradation threaten the distribution of many oak species (Backs and Ashley, 2021). The 2020 Oak Red List recognizes that an estimated 41% of the world's oak species are of conservation concern and nearly a third (31%) are at risk of extinction. The report also states that the countries with the most threatened oak species are Mexico (32 species), China (36), Vietnam (20) and the United States (16) (Carrero et al. 2020).

Oak is an important natural resource in different geographies and is also of great importance in terms of the forest ecosystems. Due to its durability, aesthetic appearance and workability, oak timber is widely used in many areas, such as construction, furniture, flooring, woodworking, wine barrels, boat building, library shelves and storage products. Here are the main areas of use of oak timber: Oak timber is used for building structures. Due to its strength and durability, it is frequently preferred in frame construction and support elements. Oak is quite popular in furniture production because it offers a quality and aesthetic appearance. It is used in white goods and decorative items such as tables, chairs, cabinets. Oak parquet is a common choice in flooring with its durability and natural appearance. It creates a warm atmosphere, especially in interior spaces. Oak is also ideal for carpentry and handicrafts. It is easy to process and is frequently used in various handmade products, ornaments and works of art. Oak timber plays an important role in winemaking. It is a preferred material especially for wine barrels because oak enters into chemical interaction with the wine inside and enriches the taste of the drink. The resistance of oak wood to water allows it to be used in boat construction. It is a preferred material in traditional and modern sailboats or motorboats. Oak timber is frequently used in libraries, bookshelves and other storage units due to its durable structure. These various areas of use of oak timber are due to both its practical benefits and aesthetic properties.

2. MATERIALS AND METHODS

2.1. The study area

Quercus is the plant genus that represents the oak species and is native to the Northern Hemisphere, found in regions such as North America, Asia, Europe and North Africa (Figure 2). Oak trees are widespread in various parts of the United States and Canada, especially in the eastern and southeastern regions. For example, species such as Northern Red Oak (*Quercus rubra*) and White Oak (*Quercus alba*) are abundant in these regions. Oaks also grow naturally throughout much of Europe, especially in Western and Central Europe. Prominent species include European Oak (*Quercus robur*) and Spanish Oak (*Quercus pyrenaica*). Oak trees are also found in various parts of Asia. For example, different species of oak grow in countries such as China and Japan. Oak trees also grow naturally in parts of North Africa, especially in areas with a Mediterranean climate.

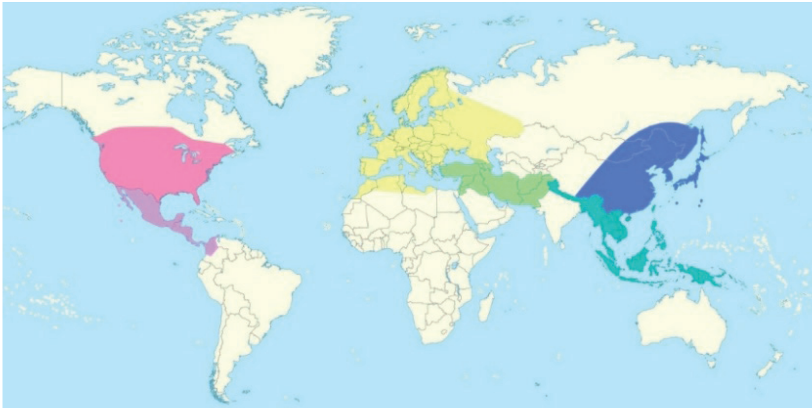

Figure 2. Global distribution of world oaks (Url-1)

This study covers the distributions of oak species throughout the world. The endemic oak trees and their sectional distributions were investigated. Additionally, studies on oaks (Figure 3) and their population status were compiled.

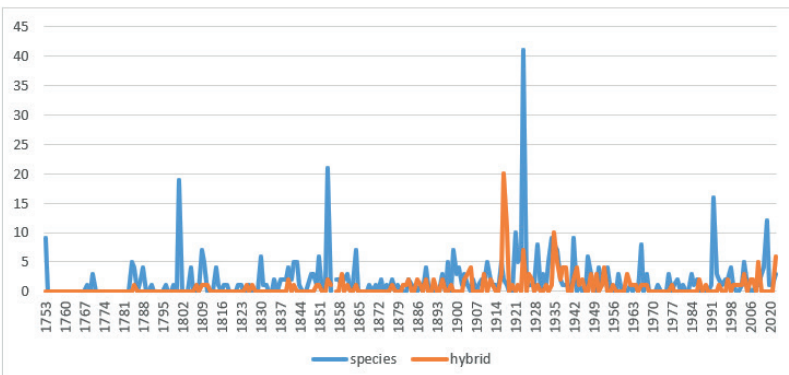

Figure 3. Abundance of oak studies between 1753-2020

2.2. Methods

Compilation of plant names

Plant names were compiled from several online sources (POWO, IPNI) and mainly from regional studies; Flora Orientalis (Boissier, 1867-88), Flora Europe (Tutin et al. 1964-1980), Flora of Russia (Komarov 1934-1978), Flora of China (Huang et al. 1999; Flora of China, 2024), Flora of Mexico (Sánchez, 1980), Flora of Turkey (Davis 1965-1985; Davis et al. 1988; Güner et al. 2000, Güner et al. 2012), Flora of Iran (Rechinger, 1965-1977). Additionally, new species names were added to the list after extensive literature review including many published papers and checklists (Spellenberg 1992; Nixon and Barrie, 2017; Binh et al. 2018; Carrero et al. 2020).

Up to date knowledge of Latin and vernacular names of the taxa were searched in online botanical databases such as World Online Flora (WFO, 2024), Kew-Plants of the World Online (POWO, 2024), World Checklist of Vascular Plants (Govaerts, 2024), The Plant List (2013 onwards) and Euro+Med Plantbase (2006-), Oaks of the world (2024), Oaktopia (2024) iNaturalist United Kingdom (2024), Flora Malesiana Data Portal (2024), Botany Research and Development Group of Vietnam (2024), and papers (González-Espinosa, 2011). As a result, the latest updated nomenclatures were noted.

Determination of IUCN threat categories

IUCN online databases and regional red data book checklists were searched for the threat categories of the oak species (Ekim et al. 2000, IUCN 2001, 2024).

3. RESULTS AND DISCUSSION

Oak trees (*Quercus* species) are widespread throughout the world, both in the Northern Hemisphere and in the tropics. Oaks are known for their wood durability, leaf diversity, and adaptability to environmental conditions. According to geographical distribution worldwide, main oak species can be grouped as follows.

1. European Oaks

• Pedunculated Oak (**Quercus robur**): Common in Central and Western Europe. Also found in the Black Sea and Marmara regions of Turkey.

• Sessile Oak (**Quercus petraea**): Found mostly in mountainous regions, common in the Black Sea region and Central Anatolia.

• Hungarian Oak (**Quercus frainetto**): Found in Southeastern Europe and western Turkey.

2. Asian Oaks

• Turkey Oak (**Quercus cerris**): Common in Turkey and Southeastern Europe. Known for its hard leaves.

• Chinese Cork Oak (**Quercus variabilis**): Common in China, Japan, and Korea, cork is obtained from its bark.

• Banjh Oak, Banj Oak (**Quercus leucotrichophora**): Grows in high altitude regions such as India and Nepal.

3. North American Oaks

• Northern Red Oak (**Quercus rubra**): Very common in the USA and Canada. Known for its fast growth.

• White Oak (**Quercus alba**): A species with valuable timber, common in the eastern USA.

• Southern Live Oak (**Quercus virginiana**): Grows in the southern USA and Mexico. Does not shed its leaves in winter (evergreen).

• Bur Oak (**Quercus macrocarpa**): A species known for its large acorns that grows in the central regions of America.

4. African and Middle Eastern Oaks

• Mount Tabor Oak (**Quercus ithaburensis**): Grows in South and Eastern Mediterranean countries such as Italy, Albania, Bulgaria, Turkey-in-Europe, Greece, Crete and East islands region, Lebanon-Syria, Palestine, Turkey (Anatolia).

• Algerian Oak (**Quercus canariensis**): Common in North Africa, especially in Morocco, Tunisia and Algeria.

5. Tropical and Subtropical Oaks

• Mexican Oak (**Quercus magnoliifolia**): Grows in tropical regions, attracts attention with its large leaves.

• Canyon Live Oak (**Quercus chrysolepis**): Grows in the mountainous areas of California and Mexico.

According to another alternative classification, a grouping can be made as sectional classification.

Subgenus *Quercus* – the New World clade (or high-latitude clade), mostly native to North America

· **Section Lobatae** Loudon – North American red oaks

· **Section Protobalanus** (Trelease) O.Schwarz – North American intermediate oaks

· **Section Ponticae** Stef. – with a disjunct distribution between western Eurasia and western North America

· **Section Virentes** Loudon – American southern live oaks

· **Section Quercus** – white oaks from North America and Eurasia

Subgenus *Cerris* Oerst. – the Old World clade, exclusively native to Eurasia

· **Section Cyclobalanopsis** Oerst. – cycle-cup oaks of East Asia

· **Section Cerris** Dumort. – cerris oaks of subtropical and temperate Eurasia and North Africa

· **Section Ilex** Loudon – ilex oaks of tropical and subtropical Eurasia and North Africa

1. **Lobatae (113 species)**

Critically Endangered

- Cambodian Oak (**Quercus cambodiensis**, endemic, IUCN: CR)
- Chisos Oak, Slender Oak (**Quercus graciliformis**, endemic, IUCN: CR)
- Muller's Oak (**Quercus mulleri**, endemic, IUCN: CR)
- Sarah Maria Oak (**Quercus sarahmariae**, endemic, IUCN: CR)

Endangered

- Maple-leaved Oak (**Quercus acerifolia**, endemic, IUCN: EN)
- Mexican Oak (**Quercus carmenensis**, IUCN: EN)
- Mexican Oak (**Quercus cualensis**, endemic, IUCN: EN)
- Eastern Mexican Oak (**Quercus delgadoana**, endemic, IUCN: EN)
- Encino negro Oak (**Quercus devia**, endemic, IUCN: EN)
- Nuevo Leon Oak (**Quercus flocculenta**, endemic, IUCN: EN)
- Charascillo Oak (**Quercus galeanensis**, endemic, IUCN: EN)
- Georgia Oak (**Quercus georgiana**, endemic, IUCN: EN)
- Encino prieto (**Quercus hintonii**, endemic, IUCN: EN)
- Puebla Oak (**Quercus hirtifolia**, endemic, IUCN: EN)
- Tamaulipas Oak (**Quercus miquihuanensis**, endemic, IUCN: EN)
- Nixonian Oak (**Quercus nixoniana**, endemic, IUCN: EN)
- Durango Oak (**Quercus radiata**, endemic, IUCN: EN)
- Mexican Stone Oak (**Quercus runcinatifolia**, endemic, IUCN: EN)

Vulnerable

- Encino de asta (**Quercus acutifolia**, IUCN: VU)
- Arkansas Oak (**Quercus arkansana**, endemic, IUCN: VU)
- Costa Rican Oak (**Quercus costaricensis**, IUCN: VU)
- Hidalgo Oak (**Quercus furfuracea**, endemic, IUCN: VU)
- Trelease's Oak (**Quercus gulielmi-treleasei**, IUCN: VU)
- Coahuila Oak (**Quercus hintoniorum**, endemic, IUCN: VU)
- Jorge Meave Oak (**Quercus meavei**, endemic, IUCN: VU)
- Mexican Red Oak (**Quercus rubramenta**, endemic, IUCN: VU)
- Jalisco Oak (**Quercus tuitensis**, endemic, IUCN: VU)

Near Threatened

- Bentham Oak (**Quercus benthamii**, IUCN: NT)
- Cortes Oak (**Quercus cortesii**, syn. *Quercus brenesii*, IUCN: NT)
- Saltill Oak (**Quercus charcasana**, endemic, IUCN: NT)
- Crispy leaf Oak (**Quercus crispifolia**, IUCN: NT)
- Durable Oak (**Quercus crispipilis**, IUCN: NT)
- Encino Colorado (**Quercus durifolia**, endemic, IUCN: NT)
- Jalisco Oak (**Quercus iltisii**, endemic, IUCN: NT)
- Black Oak (**Quercus mcvaughii**, endemic, IUCN: NT)
- Pacific Emory Oak (**Quercus peninsularis**, endemic, IUCN: NT)
- Sierra Madre Oriental Oak (**Quercus pinnativenulosa**, endemic, IUCN: NT)
- Loquat leaf Oak (**Quercus rysophylla**, endemic, IUCN: NT)
- Saltillo Oak (**Quercus saltillensis**, endemic, IUCN: NT)
- Sartor's Oak (**Quercus sartorii**, endemic, IUCN: NT)
- Cloud Forest Oak (**Quercus skinneri**, IUCN: NT)

Least Concern

- Acatenango Oak (**Quercus acatenangensis**, IUCN: LC)
- Bronze Leaf Oak (**Quercus affinis**, endemic, IUCN: LC)
- Coast Live Oak (**Quercus agrifolia**, IUCN: LC)
- Cusi Oak (**Quercus albocincta**, endemic, IUCN: LC)
- Encino Manzano (**Quercus aristata**, endemic, IUCN: LC)
- Buckley Oak (**Quercus buckleyi**, endemic, IUCN: LC)
- Ash Oak (**Quercus calophylla**, endemic, IUCN: LC)
- Chisos, Slender, Canby or Graceful Oak (**Quercus canbyi**, endemic, IUCN: LC)
- Mexican Red Oak (**Quercus castanea** IUCN: LC)
- Scarlet Oak (**Quercus coccinea**, endemic, IUCN: LC)
- Crowded Leaf Oak (**Quercus confertifolia**, endemic, IUCN: LC)
- Conzatt Oak (**Quercus conzattii**, endemic, IUCN: LC)
- Leather Leaf Mexican Oak (**Quercus crassifolia**, IUCN: LC)
- Capulincillo Oak (**Quercus crassipes**, endemic, IUCN: LC)
- Hidalgo Oak (**Quercus depressa**, endemic, IUCN: LC)

- Apple Oak (**Quercus eduardi**, endemic, IUCN: LC)
- Hill's Oak (**Quercus ellipsoidalis**, IUCN: LC)
- Elliptic Oak (**Quercus elliptica**, IUCN: LC)
- Emory Oak (**Quercus emoryi**, IUCN: LC)
- Southern Red Oak (**Quercus falcata**, endemic, IUCN: LC)
- Wheat Oak (**Quercus fulva**, endemic, IUCN: LC)
- Chisos Red Oak (**Quercus gravesii**, IUCN: LC)
- Darlington Oak (**Quercus hemisphaerica**, endemic, IUCN: LC)
- Andean oak, Colombian oak or Roble (**Quercus humboldtii**, IUCN: LC)
- Silverleaf Oak (**Quercus hypoleucoides**, IUCN: LC)
- Chinese white Oak (**Quercus hypoxantha**, endemic, IUCN: LC)
- Scrub Oak (**Quercus ilicifolia**, IUCN: LC)
- Shingle Oak (**Quercus imbricaria**, endemic, IUCN: LC)
- Bluejack Oak (**Quercus incana**, endemic, IUCN: LC)
- Sandhill Oak (**Quercus inopina**, endemic, IUCN: LC)
- Palo manzano (**Quercus jonesii**, endemic, IUCN: LC)
- California Black Oak (**Quercus kelloggii**, IUCN: LC)
- Turkey Oak (**Quercus laevis**, endemic, IUCN: LC)
- Swamp Laurel Oak (**Quercus laurifolia**, endemic, IUCN: LC)
- Uricua Oak (**Quercus laurina**, IUCN: LC)
- Blackjack Oak (**Quercus marilandica**, endemic, IUCN: LC)
- Mexican Oak (**Quercus mexicana**, endemic, IUCN: LC)
- Myrtle Oak (**Quercus myrtifolia**, endemic, IUCN: LC)
- Water Oak (**Quercus nigra**, endemic, IUCN: LC)
- Cherrybark Oak (**Quercus pagoda**, endemic, IUCN: LC)
- Pin Oak (**Quercus palustris**, IUCN: LC)
- Willow Oak (**Quercus phellos**, endemic, IUCN: LC)
- Red Oak (**Quercus planipocula**, endemic, IUCN: LC)
- Runner Oak (**Quercus pumila**, endemic, IUCN: LC)
- Northern Red Oak (**Quercus rubra**, IUCN: LC)
- Willow Oak (**Quercus salicifolia**, IUCN: LC)
- Brownleaf Oak (**Quercus sapotifolia**, IUCN: LC)
- Scytophylla Oak (**Quercus scytophylla**, endemic, IUCN: LC)
- Shumard Oak (**Quercus shumardii**, IUCN: LC)

- Santa Rosa Oak (**Quercus sideroxyla**, endemic, IUCN: LC)
- Tarahumara Oak (**Quercus tarahumara**, endemic, IUCN: LC)
- Nuttall Oak (**Quercus texana**, endemic, IUCN: LC)
- Spoon-shaped Oak (**Quercus urbani**, endemic, IUCN: LC)
- Jalisco Oak (**Quercus uxoris**, endemic, IUCN: LC)
- Black Oak (**Quercus velutina**, IUCN: LC)
- Mexican Willow Oak (**Quercus viminea**, IUCN: LC)
- Interior Live Oak (**Quercus wislizeni**, IUCN: LC)
- Xalapa Oak (**Quercus xalapensis**, IUCN: LC)

Data Deficient

- Mexican Oak or Acherdo Oak (**Quercus acherdophylla**, endemic, IUCN: DD)
- Capulincillo Oak (**Quercus aerea**, endemic, IUCN: DD)
- Breedlove Oak (**Quercus breedloveana**, endemic, IUCN: DD)
- Coahuila Oak (**Quercus coahuilensis**, endemic, IUCN: DD)
- Brown Oak (**Quercus coffeicolor**, endemic, IUCN: DD)
- Ghiesbreght Oak (**Quercus ghiesbreghtii**, endemic, IUCN: DD)
- Graceful Oak (**Quercus gracilior**, IUCN: DD)
- Graham Oak (**Quercus grahamii**, endemic, IUCN: DD)
- Ignacio or Sonora Oak (**Quercus ignaciensis**, endemic, IUCN: DD)
- Blanco or Colorado Oak (**Quercus mexiae**, endemic, IUCN: DD)
- Paxtal Oak (**Quercus paxtalensis**, endemic, IUCN: DD)
- Robust Oak (**Quercus robusta**, endemic, IUCN: DD)
- Chisos Mountains Oak (**Quercus tardifolia**, endemic, IUCN: DD)
- Acute Leaf Oak (**Quercus acutangula**)
- Panama Oak (**Quercus panamandinaea**)

2. Protobalanus (4 species)

Near Threatened

- Palmer Oak (**Quercus palmeri**, IUCN: NT)

Vulnerable

- Cedros Island Oak (**Quercus cedrosensis**, endemic, IUCN: VU)

Least Concern

- Canyon Live Oak, Golden Cup Oak or Maul Oak (**Quercus chrysolepis**, IUCN: LC)
- Huckleberry Oak (**Quercus vacciniifolia**, endemic, IUCN: LC)

3. Cyclobalanopsis (119 species)

Critically Endangered

- White Stem Oak (**Quercus albicaulis**, endemic, IUCN: CR)
- Bani Oak or Bani Chinkapin Oak (**Quercus baniensis**, IUCN: CR)
- Bao Lam Oak (**Quercus baolamensis**, endemic, IUCN: CR)
- Bidoup-Nui Ba Oak (**Quercus bidoupensis**, endemic, IUCN: CR)
- Blao Oak (**Quercus blaoensis**, endemic, IUCN: CR)
- Camus Oak (**Quercus camusiae**, endemic, IUCN: CR)
- Lam Dong Oak (**Quercus dankiaensis**, endemic, IUCN: CR)
- Vietnam Oak (**Quercus dilacerata**, endemic, IUCN: CR)
- Dinghu Shan Oak (**Quercus dinghuensis**, endemic, IUCN: CR)
- Donnai Oak (**Quercus donnaiensis**, endemic, IUCN: CR)
- Mount Hon Ba Oak (**Quercus honbaensis**, endemic, IUCN: CR)
- Dragon Oak (**Quercus lungmaiensis**, endemic, IUCN: CR)
- Qing Dynasty Oak (**Quercus motuoensis**, endemic, IUCN: CR)
- Yunnan Oak (**Quercus pinbianensis**, endemic, IUCN: CR)
- Wu chi qing gang Oak (**Quercus semiserratoides**, endemic, IUCN: CR)
- Sichuan Oak (**Quercus sichourensis**, endemic, IUCN: CR)
- Thomson Oak (**Quercus thomsoniana**, endemic, IUCN: CR)
- Mao mai qing gang Oak (**Quercus tomentosinervis**, endemic, IUCN: CR)
- Xuan Lien Oak (**Quercus xuanlienensis**, endemic, IUCN: CR)
- Guizhou Oak (**Quercus argyrotricha**, endemic, IUCN: CR)

Endangered

- Arbutus Leaf Oak (**Quercus arbutifolia**, IUCN: EN)
- Asymmetric Oak (**Quercus asymmetrica**, IUCN: EN)
- Bamboo-leaf Oak (**Quercus bambusifolia**, IUCN: EN)
- Sarawak Oak (**Quercus chrysotricha**, endemic, IUCN: EN)
- Daming Shan Oak (**Quercus daimingshanensis**, endemic, IUCN: EN)
- Shang si qing gang Oak (**Quercus delicatula**, endemic, IUCN: EN)
- Guangdong Oak (**Quercus disciformis**, endemic, IUCN: EN)
- Editha Oak (**Quercus edithiae**, IUCN: EN)
- Borneo Oak (**Quercus kinabaluensis**, endemic, IUCN: EN)
- Jiujiang evergreen Oak (**Quercus kiukiangensis**, endemic, IUCN: EN)

- Guang xi qing gang Oak (**Quercus kouangsiensis**, endemic, IUCN: EN)
- Lenticel Oak (**Quercus lenticellata**, endemic, IUCN: EN)
- Libo Oak (**Quercus liboensis**, endemic, IUCN: EN)
- West Yunnan evergreen Oak (**Quercus lobbii**, IUCN: EN)
- Nivea Oak (**Quercus nivea**, endemic, IUCN: EN)
- Obconic Oak (**Quercus obconicus**, endemic, IUCN: EN)
- Sarawak Oak (**Quercus percoriacea**, endemic, IUCN: EN)
- Petelot Oak (**Quercus petelotii**, endemic, IUCN: EN)
- Liang ye qing gang Oak (**Quercus phanera**, endemic, IUCN: EN)
- Mount Kinabalu Oak (**Quercus pseudoverticillata**, endemic, IUCN: EN)
- Thailand Oak (**Quercus ramsbottomii**, IUCN: EN)
- Rocky Oak (**Quercus rupestris**, endemic, IUCN: EN)
- Steenis Oak (**Quercus steenisii**, endemic, IUCN: EN)
- Hainan Oak (**Quercus tiaoloshanica**, endemic, IUCN: EN)
- Yellow Hair Oak (**Quercus xanthotricha**, IUCN: EN)

Vulnerable

- Southern Oak (**Quercus austro-cochinchinensis**, IUCN: VU)
- Hairy Oak or Braian Oak (**Quercus braianensis**, IUCN: VU)
- Gaharu Oak (**Quercus gaharuensis**, IUCN: VU)
- Kyushu Island Oak (**Quercus hondae**, endemic, IUCN: VU)
- Sarawak Oak (**Quercus kerangasensis**, IUCN: VU)
- Mu-Jiang-Ye-Qing-Gang (**Quercus litseoides,** endemic, IUCN: VU)
- Merrill Oak (**Quercus merrillii**, IUCN: VU)
- Quảng trị Oak (**Quercus quangtriensis**, IUCN: VU)
- Melchior Treub Oak (**Quercus treubiana**, endemic, IUCN: VU)

Near Threatened

- Bella Oak (**Quercus bella**, endemic, IUCN: NT)
- Elmer Oak (**Quercus elmeri**, IUCN: NT)
- Silvery Oak (**Quercus hypargyrea**, endemic, IUCN: NT)
- Dark leaf Oak (**Quercus hypophaea**, endemic, IUCN: NT)
- Fujian Oak (**Quercus jenseniana**, endemic, IUCN: NT)
- Bull Oak (**Quercus lamellosa**, IUCN: NT)
- Guoi or Lang Bian Oak (**Quercus langbianensis**, endemic, IUCN: NT)
- Hugh Low Oak (**Quercus lowii**, endemic, IUCN: NT)

- Ko muak Oak (**Quercus oidocarpa**, IUCN: NT)
- Silken Hair Oak (**Quercus subsericea**, IUCN: NT)
- Sumatran Oak (**Quercus sumatrana,** endemic, IUCN: NT)
- Brunei Oak (**Quercus valdinervosa**, endemic, IUCN: NT)

Least Concern

- Japanese evergreen Oak (**Quercus acuta**, IUCN: LC)
- Blue Japanese Oak (**Quercus annulata**, IUCN: LC)
- Pinang-pinang Oak (**Quercus argentata**, IUCN: LC)
- Narrow-leaf evergreen Oak (**Quercus augustini**, validated name; *Quercus augustinei*, IUCN: LC)
- Lizi qing gang Oak (**Quercus blakei**, IUCN: LC)
- Thailand Oak (**Quercus brandisiana**, IUCN: LC)
- Graceful evergreen Oak (**Quercus oxyodon**, syn. *Quercus breviradiata*, IUCN: LC)
- Lingnan Oak (**Quercus championii**, IUCN: LC)
- Fujian Oak (**Quercus chungii**, endemic, IUCN: LC)
- Xi ye qing gang Oak (**Quercus ciliaris**, endemic, IUCN: LC)
- Yellow-haired evergreen Oak (**Quercus delavayi**, endemic, IUCN: LC)
- Gamblean Oak (**Quercus gambleana**, IUCN: LC)
- Gemelliflora Oak (**Quercus gemelliflora**, IUCN: LC)
- Gae-ga-si-na-mu (**Quercus gilva**, IUCN: LC)
- Japanese blue Oak (**Quercus glauca**, IUCN: LC)
- Mao Zhiqinggang Oak (**Quercus helferiana**, IUCN: LC)
- Maoye qinggang Oak (**Quercus kerrii**, IUCN: LC)
- Strip leaf Oak (**Quercus lineata**, IUCN: LC)
- Long-fruited evergreen Oak (**Quercus longinux**, endemic, IUCN: LC)
- Fleury Oak (**Quercus macrocalyx**, IUCN: LC)
- Miyagi Oak (**Quercus miyagii,** endemic, IUCN: LC)
- Taiwan evergreen Oak (**Quercus morii**, endemic, IUCN: LC)
- Bamboo-leaved Oak, Chinese evergreen Oak, Chinese Ring-cupped Oak (**Quercus myrsinifolia**, IUCN: LC)
- Thick-scaled Oak (**Quercus pachyloma**, IUCN: LC)
- Yellow-backed evergreen Oak (**Quercus poilanei**, IUCN: LC)
- Galucus Oak (**Quercus rex**, IUCN: LC)

- Japanese willowleaf Oak (**Quercus salicina**, IUCN: LC)
- Schottky's Oak (**Quercus schottkyana**, endemic, IUCN: LC)
- Half-Toothed-Leaf Oak (**Quercus semiserrata**, IUCN: LC)
- Asian Sessile Oak (**Quercus sessilifolia**, IUCN: LC)
- Arisan Oak (**Quercus stenophylloides**, endemic, IUCN: LC)
- He Ye Qing Gang Oak (**Quercus stewardiana**, endemic, IUCN: LC)

Data Deficient

- Light steel Oak (**Quercus brevicalyx**, IUCN: DD)
- Blue steel Oak (**Quercus chevalieri**, IUCN: DD)
- Asian Ring-cupped Oak (**Quercus chrysocalyx**, IUCN: DD)
- Conduplicate Oak (**Quercus conduplicans**, endemic, IUCN: DD)
- Dongfang Oak (**Quercus dongfangensis**, endemic, IUCN: DD)
- Tumai qinggang Oak (**Quercus elevaticostata**, endemic, IUCN: DD)
- Myanmar Oak (**Quercus eumorpha**, endemic, IUCN: DD)
- Hainan Oak (**Quercus fuliginosa**, endemic, IUCN: DD)
- Velutina Oak (**Quercus gomeziana**, IUCN: DD)
- Mao Guoqinggang Oak (**Quercus gracilenta**, endemic, IUCN: DD)
- Jin ping qing gang Oak (**Quercus jinpinensis**, endemic, IUCN: DD)
- Taiwan Oak (**Quercus liaoi**, endemic, IUCN: DD)
- Batna Oak (**Quercus mespilifolia**, IUCN: DD)
- Ninggang Qinggang Oak (**Quercus ningangensis**, endemic, IUCN: DD)
- Wuhu Anqing Port Oak (**Quercus pentacycla**, endemic, IUCN: DD)
- Platycalyx Oak (**Quercus platycalyx**, endemic, IUCN: DD)
- Overnight Oak (**Quercus saravanensis**, IUCN: DD)
- Ring-cupped Oak (**Quercus thorelii**, IUCN: DD)
- Maoye Oak (**Quercus vestita**, endemic, IUCN: DD)
- Vietnam Cycle-cup Oak (**Quercus xanthoclada**, IUCN: DD)
- Anqing Port Oak (**Quercus yonganensis**, endemic, IUCN: DD)

4. **Ilex (40 species)**

Critically Endangered

- Ba wang li Oak (**Quercus bawanglingensis,** endemic, IUCN: CR)
- Fimbriated Oak (**Quercus fimbriata,** endemic, IUCN: CR)
- Ba dong li Oak (**Quercus marlipoensis,** endemic, IUCN: CR)
- Dawanshan Oak (**Quercus pseudosetulosa** endemic, IUCN: CR)

- Trungkhan Oak (**Quercus trungkhanhensis** endemic, IUCN: CR)
- Shangxi Oak (**Quercus shangxiensis**, endemic, IUCN: CR)

Endangered

- Lan cang li Oak (**Quercus kingiana,** IUCN: EN)
- Lodicosa Oak (**Quercus lodicosa,** IUCN: EN)
- Xizang Oak (**Quercus tungmaiensis,** IUCN: EN)
- Chinese evergreen Oak (**Quercus utilis,** endemic, IUCN: EN)

Near Threatened

- Jian ye li Oak (**Quercus oxyphylla,** endemic, IUCN: NT)

Least Concern

- Chinese Oak (**Quercus acrodonta,** endemic, IUCN: LC)
- Golden Oak (**Quercus alnifolia,** endemic, IUCN: LC)
- Hengduan Mountain Oak (**Quercus aquifolioides,** IUCN: LC)
- Bozpırnal Oak (**Quercus aucheri,** endemic, IUCN: LC)
- Holy Oak (**Quercus baloot,** IUCN: LC)
- Kermes Oak (**Quercus coccifera,** IUCN: LC)
- Tie xiang li Oak (**Quercus cocciferoides,** endemic, IUCN: LC)
- Chi ye li Oak (**Quercus dolicholepis,** endemic, IUCN: LC)
- Engler's Oak (**Quercus engleriana,** endemic, IUCN: LC)
- Mohru Oak (**Quercus floribunda,** IUCN: LC)
- Zhui lian li evergreen Oak (**Quercus franchetii,** IUCN: LC)
- Gill's Oak (**Quercus gilliana,** endemic, IUCN: LC)
- Guava Oak (**Quercus guyavifolia,** endemic, IUCN: LC)
- Holm Oak (**Quercus ilex,** IUCN: LC)
- Ban Oak (**Quercus lanata,** IUCN: LC)
- Long spicate Oak (**Quercus longispica,** endemic, IUCN: LC)
- Chinese Dwarf Oak (**Quercus monimotricha,** IUCN: LC):
- Yellowback Oak (**Quercus pannosa,** endemic, IUCN: LC)
- Ubame Oak (**Quercus phillyreoides,** IUCN: LC)
- Mao mai gao shan li Oak (**Quercus rehderiana,** IUCN: LC)
- Holm Oak, Ballota Oak (**Quercus rotundifolia,** IUCN: LC)
- Brown Oak (**Quercus semecarpifolia,** IUCN: LC)
- Hui bei li Oak (**Quercus senescens,** IUCN: LC)
- Fu ning li Oak (**Quercus setulosa,** IUCN: LC)

• Ci ye gao shan li Oak (**Quercus spinosa,** IUCN: LC)

Data Deficient

• Shangxie Oak (**Quercus shangxiensis,** endemic, IUCN: DD)

• Taroko Oak (**Quercus tarokoensis,** IUCN: DD)

• Tataka Oak (**Quercus tatakaensis,** IUCN: DD)

• Banjh Oak, Banj Oak (**Quercus leucotrichophora,** IUCN: DD)

5. **Cerris (15 species)**

Endangered

• Look Oak (**Quercus look**, IUCN: EN)

Vulnerable

• African Oak (**Quercus afares**, IUCN: VU)

Near Threatened

• Chestnut-leaved Oak (**Quercus castaneifolia** IUCN: NT)

• Saw-tooth Oak, (**Quercus chenii,** endemic, IUCN: NT)

• Persian Oak (**Quercus persica**, IUCN: NT)

Least Concern

• Japanese Chestnut Oak (**Quercus acutissima**, IUCN: LC)

• Brant Oak (**Quercus brantii**, IUCN: LC)

• Turkey Oak (**Quercus cerris**, IUCN: LC)

• Mount Tabor Oak, (**Quercus ithaburensis,** IUCN: LC)

• Lebanon Oak (**Quercus libani**, IUCN: LC)

• Cork Oak (**Quercus suber**, IUCN: LC)

• Macedonian Oak (**Quercus trojana**, IUCN: LC)

• Chinese cork Oak (**Quercus variabilis**, IUCN: LC)

Data Deficient

• Unger's Oak (**Quercus ungeri**, endemic, IUCN: DD)

• Caucasian or Carduchian Oak (**Quercus carduchorum**, endemic, IUCN: DD)

6. **Quercus (128 species)**

Critically Endangered

• Boynton Oak (**Quercus boyntonii**, endemic, IUCN: CR)

• Hinckley's Oak (**Quercus hinckleyi**, endemic, IUCN: CR)

• Bao li Oak (**Quercus monnula**, endemic, IUCN: CR)

• Guatemala Oak (**Quercus oocarpa**, IUCN: CR)

Endangered

• Encino de Chalma (**Quercus diversifolia**, endemic, IUCN: EN)

• Coastal Sage Scrub Oak (**Quercus dumosa**, IUCN: EN)

• Engelmann Oak (**Quercus engelmannii**, IUCN: EN)

• Shinnery Oak (**Quercus havardii**, endemic, IUCN: EN)

• Chicalaba Oak (**Quercus insignis**, IUCN: EN)

• Kotschy Oak (**Quercus kotschyana**, endemic, IUCN: EN)

• Oaxaca Oak (**Quercus macdougallii**, endemic, IUCN: EN)

• Oglethorpe Oak (**Quercus oglethorpensis**, endemic, IUCN: EN)

• Island Scrub Oak (**Quercus pacifica**, endemic, IUCN: EN)

• Island Oak (**Quercus tomentella**, IUCN: EN)

Vulnerable

• Ajo Mountain Scrub Oak (**Quercus ajoensis**, IUCN: VU)

• Bluff Oak (**Quercus austrina**, endemic, IUCN: VU)

• Vicentensis Oak (**Quercus vicentensis**, IUCN: VU)

Near Threatened

• Algerian Oak (**Quercus ariifolia**, endemic, IUCN: NT)

• Algerian Oak, Mirbeck's Oak or Zean Oak (**Quercus canariensis**, IUCN: NT)

• Valley Oak (**Quercus lobata**, endemic, IUCN: NT)

• Santa Cruz Island Oak (**Quercus parvula**, endemic, IUCN: NT)

• Belize Oak (**Quercus purulhana**, IUCN: NT)

• Durango Oak (**Quercus xylina**, endemic, IUCN: NT)

Least Concern

• White Oak (**Quercus alba**, IUCN: LC)

• Oriental White Oak (**Quercus aliena**, IUCN: LC)

• Arizona White Oak (**Quercus arizonica**, IUCN: LC)

• California Scrub Oak (**Quercus berberidifolia**, IUCN: LC)

• Swamp White Oak (**Quercus bicolor**, IUCN: LC)

• Chapman Oak (**Quercus chapmanii**, endemic, IUCN: LC)

• Chihuahua Oak (**Quercus chihuahuensis**, endemic, IUCN: LC)

• Sicily Oak (**Quercus congesta**, endemic, IUCN: LC)

• Encino (**Quercus convallata**, endemic, IUCN: LC)

- Muller Oak (**Quercus cornelius-mulleri**, IUCN: LC)
- White Oak (**Quercus corrugata**, IUCN: LC)
- Daimyo Oak (**Quercus dentata**, IUCN: LC)
- Davis Mountain Oak (**Quercus depressipes**, IUCN: LC)
- Tecux Oak (**Quercus deserticola**, endemic, IUCN: LC)
- Blue Oak (**Quercus douglasii**, endemic, IUCN: LC)
- Leather Oak (**Quercus durata**, endemic, IUCN: LC)
- Faber's Oak (**Quercus fabrei**, endemic, IUCN: LC)
- Portuguese Oak (**Quercus faginea**, IUCN: LC)
- Hungarian Oak (**Quercus frainetto**, IUCN: LC)
- Hidalgo evergeen Oak (**Quercus frutex**, endemic, IUCN: LC)
- Gambel Oak (**Quercus gambelii**, IUCN: LC)
- Oregon White Oak (**Quercus garryana**, IUCN: LC)
- Mexican royal Oak (**Quercus germana**, endemic, IUCN: LC)
- Quebracho Oak (**Quercus glabrescens**, endemic, IUCN: LC)
- Encino Blanco (**Quercus glaucescens**, IUCN: LC)
- Lacey Oak **(Quercus glaucoides**, endemic, IUCN: LC)
- La Siberia (**Quercus greggii**, endemic, IUCN: LC)
- Paisang Oak (**Quercus griffithii**, IUCN: LC)
- Gray Oak (**Quercus grisea**, IUCN: LC)
- Ichnusae White Oak (**Quercus ichnusae**, endemic, IUCN: LC)
- Mazı Oak, Cyprus Oak (**Quercus infectoria**, IUCN: LC)
- Dwarf Oak (**Quercus intricata**, IUCN: LC)
- Coahuila Oak **(Quercus invaginata**, endemic, IUCN: LC)
- Tucker's Oak (**Quercus john-tuckeri**, endemic, IUCN: LC)
- Lacey Oak (**Quercus laceyi**, IUCN: LC)
- Cottonwood Oak **(Quercus laeta**, endemic, IUCN: LC)
- Veracruz Oak (**Quercus lancifolia**, IUCN: LC)
- Guerrero Oak (**Quercus liebmannii**, endemic, IUCN: LC)
- Lusitanian, Portuguese or Gall Oak (**Quercus lusitanica**, IUCN: LC)
- Overcup Oak (**Quercus lyrata**, endemic, IUCN: LC)
- Caucasian Oak (**Quercus macranthera**, IUCN: LC)
- Bur Oak (**Quercus macrocarpa**, IUCN: LC)

- Mexican Oak, Yellow Oak (**Quercus magnoliifolia**, endemic, IUCN: LC)
- Sand Post Oak (**Quercus margaretta**, endemic, IUCN: LC)
- Cortitucuz Oak (**Quercus martinezii**, endemic, IUCN: LC)
- Swamp Chestnut Oak (**Quercus michauxii**, endemic, IUCN: LC)
- Little leaf Oak **(Quercus microphylla**, endemic, IUCN: LC)
- Mohr Oak (**Quercus mohriana**, IUCN: LC)
- Mongolian Oak (**Quercus mongolica**, IUCN: LC)
- Chestnut Oak (**Quercus montana**, endemic, IUCN: LC)
- Chinkapin Oak (**Quercus muehlenbergii**, IUCN: LC)
- Mexican Blue Oak (**Quercus oblongifolia**, IUCN: LC)
- Calicahuac Oak (**Quercus obtusata**, endemic, IUCN: LC)
- Black vulture Oak (**Quercus peduncularis**, IUCN: LC)
- Sessile Oak (**Quercus petraea**, IUCN: LC)
- Net-leaf white, Mexican white or Monterrey Oak (**Quercus polymorpha**, IUCN: LC)
- Quebracho Oak (**Quercus potosina**, endemic, IUCN: LC)
- Antler Oak (**Quercus praeco**, endemic, IUCN: LC)
- Coahuila Oak (**Quercus pringlei**, endemic, IUCN: LC)
- Dwarf Chinquapin Oak (**Quercus prinoides**, endemic, IUCN: LC)
- Downy Oak (**Quercus pubescens**, IUCN: LC)
- Sandpaper Oak (**Quercus pungens**, IUCN: LC)
- Pyrenean Oak or Spanish Oak (**Quercus pyrenaica**, IUCN: LC)
- San Luis Potosi Oak (**Quercus repanda**, endemic, IUCN: LC)
- Aguascalientes Oak (**Quercus resinosa**, endemic, IUCN: LC)
- Pedunculated Oak or European Oak (**Quercus robur**, IUCN: LC)
- Netleaf Oak (**Quercus rugosa**, IUCN: LC)
- Chiapas Oak (**Quercus sebifera**, endemic, IUCN: LC)
- K'antulán Oak (**Quercus segoviensis**, IUCN: LC)
- Jolcham Oak (**Quercus serrata**, IUCN: LC)
- Swamp Post Oak (**Quercus similis**, endemic, IUCN: LC)
- Durand Oak (**Quercus sinuata**, IUCN: LC)
- Sinaloa Oak (**Quercus sororia**, endemic, IUCN: LC)
- Post Oak (**Quercus stellata**, endemic, IUCN: LC)
- Sierra Madre Oak (**Quercus striatula**, endemic, IUCN: LC)

- Sheep Oak (**Quercus subspathulata**, endemic, IUCN: LC)
- Aguascalientes Oak (**Quercus tuberculata**, endemic, IUCN: LC)
- Sonoran Scrub Oak (**Quercus turbinella**, IUCN: LC)
- Vasey Oak (**Quercus vaseyana**, IUCN: LC)
- Kasnak Oak (**Quercus vulcanica**, endemic, IUCN: LC)
- Liaoning Oak (**Quercus wutaishanica**, endemic, IUCN: LC)

Data Deficient

- Alpescens Oak (**Quercus alpescens**, endemic, IUCN: DD)
- Chakira Oak (**Quercus barrancana**, endemic, IUCN: DD)
- Borneo Oak (**Quercus centenaria**, endemic, IUCN: DD)
- Dalechamps Oak (**Quercus dalechampii**, IUCN: DD)
- Chihuahua White Oak (**Quercus deliquescens**, endemic, IUCN: DD)
- Canyon Oak (**Quercus edwardsiae**, endemic, IUCN: DD)
- Strandzha Oak, Istranca Oak (**Quercus hartwissiana**, IUCN: DD)
- Melissa Oak (**Quercus melissae**, IUCN: DD)
- Ninggang Qinggang Oak (**Quercus ningqiangensis**, endemic, IUCN: DD)
- Tamaulipas Oak (**Quercus opaca**, endemic, IUCN: DD)
- Mexican White Oak (**Quercus pauciradiata,** endemic, IUCN: DD)
- Sonora Oak (**Quercus perpallida**, endemic, IUCN: DD)
- Lacey Oak (**Quercus porphyrogenita**, endemic, IUCN: DD)
- Rila Oak (**Quercus protoroburoides**, endemic, IUCN: DD)
- Rekonis White Oak (**Quercus rekonis**, endemic, IUCN: DD)
- Fine-leaf Oak (**Quercus shennongii**, endemic, IUCN: DD)
- Swamp Post Oak (**Quercus shingjenensis**, endemic, IUCN: DD)
- Nuevo Leon Oak (**Quercus supranitida**, endemic, IUCN: DD)
- Potosi Oak (**Quercus tinkhamii**, endemic, IUCN: DD)
- Toumey Oak (**Quercus toumeyi**, IUCN: DD)
- Puebla Oak (**Quercus toxicodendrifolia**, endemic, IUCN: DD)
- Tsinglingen Oak (**Quercus tsinglingensis**, endemic, IUCN: DD)
- Mexican Leathery Oak (**Quercus undata**, endemic, IUCN: DD)
- Verde Oak (**Quercus verde**, endemic, IUCN: DD)
- Acultzingo Oak (**Quercus aculcingensis**, IUCN: DD)

7. Virentes (8 species)

- Encino Arroyero (**Quercus brandegeei,** endemic, IUCN: EN)
- The Cuban Oak (**Quercus sagraeana,** endemic, IUCN: EN)
- Olive Oak (**Quercus oleoides,** IUCN: NT)
- Baron's Oak (**Quercus baronii,** endemic, IUCN: LC)
- Texas Live Oak (**Quercus fusiformis,** IUCN: LC)
- Sand Live Oak (**Quercus geminata,** endemic, IUCN: LC)
- Dwarf Live Oak (**Quercus minima,** endemic, IUCN: LC)
- Southern Live Oak (**Quercus virginiana,** endemic, IUCN: LC)

8. Ponticae (2 species)

- Eastern Black Sea or Pontic Oak (**Quercus pontica,** IUCN: EN)
- Sadler's Oak (**Quercus sadleriana,** endemic, IUCN: NT)

The richest oak section is the Quercus, and the section containing the most endemic species is the Lobatae (Figure 4).

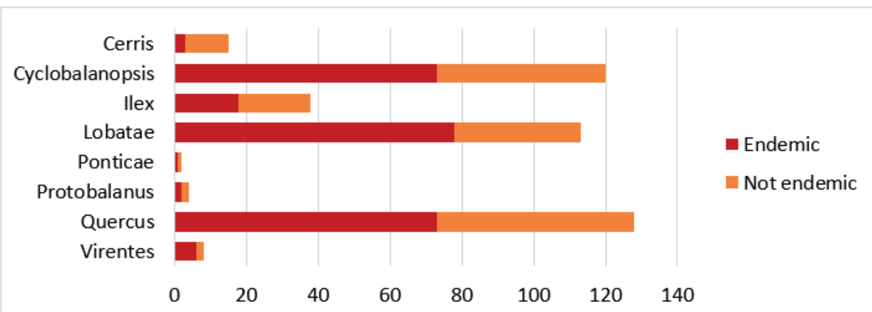

Figure 4. Distribution of species numbers to the oak sections

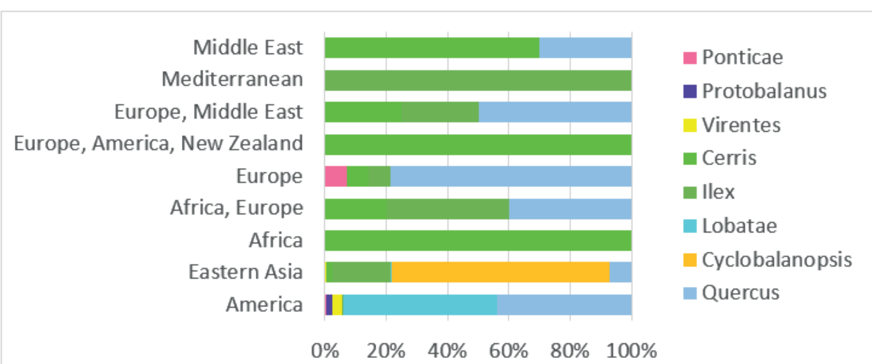

Figure 5. Distribution of IUCN threat categories to the main continents

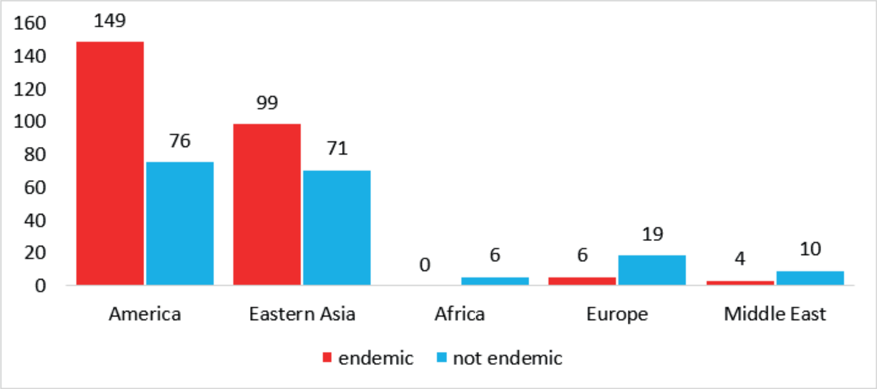

Figure 6. Distribution of endemic taxa numbers to the main continents

Although the American continent is the richest in terms of total endemic oak species (149), East Asia hosts many more taxa (99) than the American continent when compared according to the CR category. Of the 473 oak species assessed, 260 (55%) are of both endemic and of conservation concern. Of the non-endemic 174 oak species, 2 CR, 17 EN and 12 VU species are under threat. Totally 48 endemics and 15 non-endemic species are in Data Deficient category.

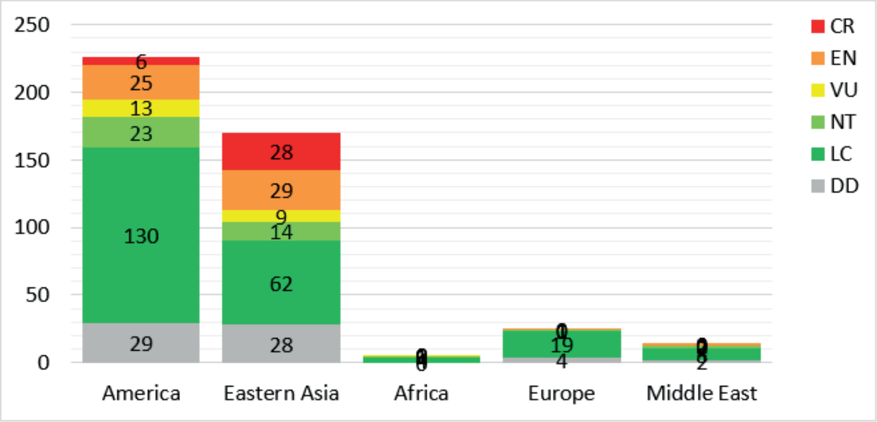

Figure 7. Distribution of IUCN threat categories to the main continents

The richest section in terms of the CR category is Cyclobalanopsis (20 species), this section is followed by Ilex (with 6 species), Lobatae (with 4 species), and Quercus (with 4 species), respectively (Figure 8).

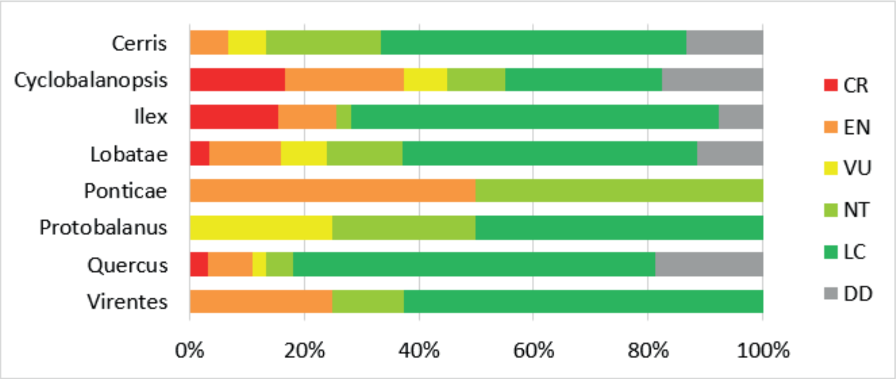

Figure 8. Sectional distribution of endemic oak species

Conclusions

The threats facing oaks are primarily deforestation and habitat loss, climate change, pests and diseases. Expansion of agricultural lands and increase in settlements have led to a decrease in oak forests. Changes in temperature and precipitation regimes negatively affect the habitats of oak species. Oak trees can also be affected by fungal diseases and insect pests. For example, diseases such as "oak wilt" threaten the health of some species. The protection of oak trees is vital for the sustainability of ecosystems. In this regard, the following measures should be taken: 1) Protection and rehabilitation of oak forests, 2) Protection of the genetic diversity of local oak species, especially endemic ones, 3) Raising public awareness about the importance of oak ecosystems through education and awareness activities.

The oak species mentioned here have many ecological roles and economic income-generating features, as well as cultural importance among various societies. They support biodiversity. Oak trees provide habitat for hundreds of species of birds, mammals, insects and fungi. Their acorns are an important food source for animals such as squirrels, deer and birds. The cracks formed in tree trunks provide shelter for insects and small animals. They protect soil and regulate climate. The root systems of oaks prevent erosion by holding the soil. Thanks to their large leaf surface, they play an important role in carbon sequestration and reduce carbon dioxide in the atmosphere. In addition, oak forests contribute to the regulation of local climate. They contribute to ecosystem cycles. The shedding of oak leaves increases the formation of organic matter in the soil. These leaves are a food source for insects and microorganisms under the forest, which enriches the soil. They provide wood and fuel materials.

Oak wood is known for its durability and hardness. This wood, which is used in furniture, flooring and shipbuilding, is also valuable as fuel. Oak bark and acorns are rich in tannin, a substance used in the leather industry. Oak trees have cultural symbolic values. Oak has symbolized strength and durability throughout history. It is frequently found in mythology and folk culture. For example, the oak tree was considered the sacred tree of Zeus in Greek mythology.

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CHAPTER 20

POSSIBILITIES OF REUSE OF AGRICULTURAL WASTE WATER[1]

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Global freshwater consumption surged 20% from 1990 to 2014. By 2050, per capita resources may plummet 50%. Climate change could create a 15.7 billion m^3 annual deficit, affecting 40% of the world's population (FAO, 2016). Water use for food is projected to increase from 1,300 m^3/year per capita in 2000 to 1,500 m^3/year by 2100. Total use may reach 16,500 km^3/year, raising concerns about Earth's capacity. Innovative irrigation systems offer a solution, boosting crop yields in water-scarce regions. These hydrological approaches promise increased food production and economic growth. By 2050, 3.9 billion people—40% of Earth's population—will face severe water scarcity in their river basins. This crisis stems from dwindling global resources, which dropped 25% to 6,064,160 m^3 by 2014. Climate change exacerbates the problem, creating a projected annual deficit of 15.7 billion m^3 between supply and demand. Urgent action is needed to address this growing mismatch and secure future water availability worldwide (GWF, 2012).

Water scarcity threatens global food security. In 2000, average water use for food was 1,300 m^3/year per capita. By 2100, it's projected to reach 1,500 m^3/year. Total water use will spike to 16,500 km^3/year, raising concerns about Earth's capacity to meet demand (De Marsily & Marsily, 2021). The solution? Tap into hidden potentials. Develop innovative hydrological approaches. Implement advanced irrigation systems in water-scarce regions. These strategies can significantly boost crop yields and agricultural productivity. The benefits extend beyond food production. Economic growth accelerates. Nutrition improves. Community well-being rises. But challenges remain. Can Earth's water resources sustain this demand? Will these solutions bridge the food gap?

Sustainable management practices are crucial. We must explore scenarios and develop solution-oriented applications. By unlocking new opportunities in food production, we can feed a growing population. The future of global food security depends on our actions today.

As demand for food rises, water scarcity poses a critical challenge. Innovative irrigation systems offer hope, boosting crop yields in water-stressed regions. These hydrological solutions tap hidden potential, bridging the food gap and enhancing agricultural productivity. Beyond increasing food production, such approaches spark economic growth and improve nutrition. By developing scenarios to maximize water resources, we can meet growing needs sustainably. This ripple effect benefits communities worldwide, contributing to global food security and overall well-being. Unlocking these opportunities is crucial for feeding our expanding population.

Rainfall dwindles, triggering a water crisis. This causes water managers to spring into action. As a result, they meticulously examine every potential source. Their scrutiny leads to cost-effective planning. Consequently, resource development becomes a priority. This intensifies the search for solutions. The managers' dedication produces innovative thinking. Their thorough examination ensures no option remains unexplored. Economic viability guides their decisions, ultimately shaping water's future. These professionals' efforts may determine our ability to overcome the unfolding drought.

Reuse of agricultural wastewater is a vital solution to the growing concern of water scarcity, particularly in regions where freshwater resources are depleting at an alarming rate. The practice involves collecting, treating, and reusing water used in agricultural activities, such as irrigation, to reduce the demand on freshwater sources. For instance, in Israel, a country facing severe water scarcity, the reuse of agricultural wastewater has been instrumental in reducing the nation's water deficit. In fact, it is estimated that Israel reuses over 80% of its wastewater, with a significant portion being used for agricultural purposes. This approach not only helps conserve water but also reduces the environmental impact of wastewater disposal. Furthermore, reusing agricultural wastewater can also reduce energy consumption, as it requires less energy to treat and transport than extracting freshwater from natural sources. By adopting this practice, countries can alleviate water scarcity while promoting sustainable agriculture and environmental stewardship (Figure 1).

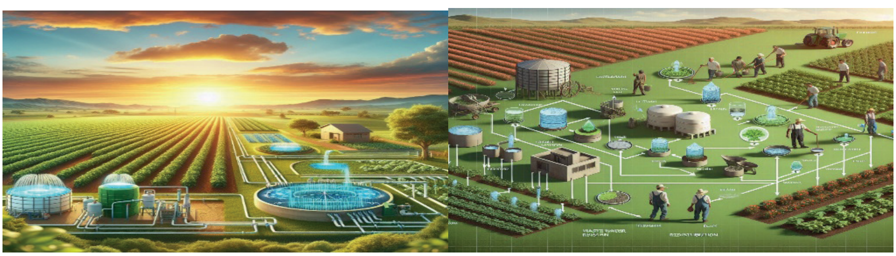

Figure 1. Agricultural wastewater treatment plants and reuse

From field to stream, agricultural wastewater undergoes a multi-step cleansing journey. Sedimentation basins trap soil particles, while wetlands filter out excess nutrients. Biological processes break down organic matter. Chemical treatments neutralize harmful substances. Advanced filtration systems remove microscopic contaminants. UV disinfection eliminates pathogens. Monitoring ensures water quality meets standards before reuse or release. These methods work in concert to protect ecosystems and conserve precious water resources.

Agricultural wastewater treatment is a lifeline for sustainable farming. It nurtures the land and fosters growth. Here are its key benefits:

- It recycles water, reducing waste and conserving precious resources (Qadir, Wichelns, Raschid-Sally, Mccornick, & Drechsel, 2008).

· It enriches soil health, enhancing productivity and resilience (Urra, Alkorta, & Garbisu, 2019).

· It curbs pollution, safeguarding ecosystems and natural habitats (Asano & Levine, 1996).

· It ensures crop quality, leading to healthier yields and reduce cost (Gholami-Shabani, Nematpour, Gholami-Shabani, & Nematpour, 2024).

· It promotes biodiversity, creating a thriving environment for all(Hsu et al., 2011; Silva, 2023).

1. Physical Treatment

Wastewater treatment begins with physical methods, including sedimentation and filtration, to remove solid particles from the wastewater. These techniques are essential for eliminating suspended solids and debris, laying the groundwork for most wastewater treatment processes.

Sedimentation, also known as settling, is a process that relies on gravity to remove solid particles from a suspension. It's commonly used to eliminate impurities that have become settleable after coagulation and flocculation, such as turbidity and color. A classic example is water softening, where chemical precipitation produces precipitates that are then removed through sedimentation. In primary treatment, sedimentation plays a starring role, removing 50 to 70% of suspended solids (which contain 25-40% of the Biological Oxygen Demand or BOD) from the wastewater. Later, after biological treatment, sedimentation is used again to remove the biological floc produced by microorganisms, ensuring the effluent quality meets standards for discharge into inland waterways(Jover-Smet, Martín-Pascual, & Trapote, 2017; Novikov, Filimonov, Khadzhidi, & Dugin, 2021)

The removal of grit in the preliminary stage of treatment is a prime example of differential sedimentation in action, where heavy grit settles while lighter organic matter remains suspended. In tertiary treatment, sedimentation may be used once more after coagulation. When phosphorus removal is achieved separately from primary or secondary treatment through chemical precipitation, sedimentation is an essential step. Additionally, sedimentation finds applications in secondary sludge digesters, where it separates digested sludge from supernatant liquor, and in sludge lagoons. A deep understanding of sedimentation principles is vital for designing and operating effective sedimentation tanks (Bezirgiannidis et al. 2019; Topare, Attar, and Manfe 2011; Yagna Prasad 2019).

Particle characteristics dictate sedimentation efficacy in wastewater treatment. Larger, denser particles descend swiftly, while smaller, lighter ones linger. Treatment plants employ coagulation and flocculation to enlarge particles, boosting sedimentation efficiency. Yet, some particles resist settling. Colloidal particles, minuscule and buoyant, defy natural sedimentation. These stubborn remnants necessitate advanced treatment methods like filtration or disinfection for complete removal. The interplay of size, density, and treatment processes thus shapes wastewater purification outcomes.

Primary Sedimentation

Wastewater treatment commences with primary sedimentation, a vital initial stage that effectively eliminates a substantial 60% of suspended solids and 30-40% of biochemical oxygen demand (BOD). This critical process takes place in rectangular or circular tanks, specifically designed to provide a serene environment that allows solids to settle peacefully. As particles slowly sink to the bottom, scrapers carefully collect them for further treatment, preventing any interference with the settling process. Meanwhile, the clearer water, now devoid of most contaminants, advances to the next purification phase, where it undergoes additional treatment. This process is instrumental in separating contaminants, significantly reducing organic matter, and preparing wastewater for the subsequent treatment steps that lie ahead. The efficiency of primary sedimentation in removing bulk pollutants sets a solid foundation for the production of cleaner water downstream, a concept supported by numerous studies (Makhmudov, Kuziev, & Student, 2020; Quach-Cu et al., 2018). For instance, a study conducted by the World Health Organization (2019) revealed that proper primary sedimentation can reduce wastewater's organic load by up to 50%, significantly decreasing its environmental impact.

Secondary Sedimentation

Secondary sedimentation, also referred to as final sedimentation, is a crucial step that follows the biological treatment stage in the wastewater treatment process. Its primary objective is to remove bio-solids or biological floc that are produced during treatment. These bio-solids are incredibly rich in microorganisms that work tirelessly to decompose organic matter in wastewater. For instance, a single gram of bio-solids can contain up to 10 billion microorganisms, including bacteria, viruses, and protozoa.

While secondary sedimentation tanks share a similar design with primary ones, they are generally smaller and have a shorter detention time. This is because the microorganisms in the bio-solids have already started breaking down organic matter during the biological treatment stage, so they require less time to settle. The settled bio-solids are then either recycled back into the biological treatment process to maintain a healthy microbial population or removed from the system for further processing, such as thickening, dewatering, or disposal (Figure 2). This recycling process helps to reduce the amount of waste generated and creates a more sustainable treatment process. (Bhattacharjee, Datta, and Bhattacharjee 2007; Quach-Cu et al. 2018).

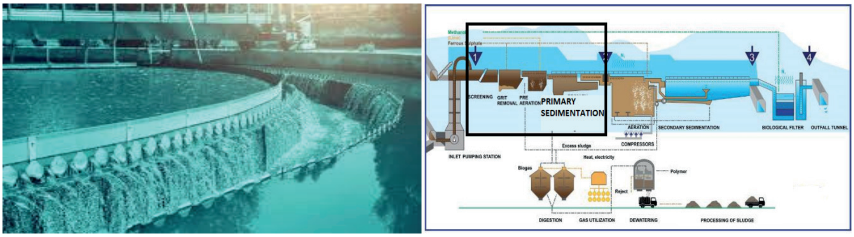

Figure 2. Sedimentation applications of agricultural wastewater

2. Biological Treatment

Organic matter contaminates our waterways, posing a significant threat to the environment and public health. However, microorganisms offer a promising solution to this pressing issue. These tiny cleaners can decompose waste through biological treatment, reducing the amount of pollutants in our water.

Aerobic methods, which rely on oxygen, and anaerobic processes, which don't, can both be effective in breaking down organic matter. Constructed wetlands, for example, provide a natural and efficient way to remove pollutants from wastewater. These artificial ecosystems mimic the natural process of decomposition, using a combination of microorganisms, plants, and sunlight to purify the water. Bacteria play a crucial role in this biochemical breakdown, converting waste into stable products like carbon dioxide and water. As more microbes form, they continue to feed on the organic matter, producing a clean and safe effluent. The ultimate goal is to remove enough solids to ensure safe discharge into our waterways (Figure 3).

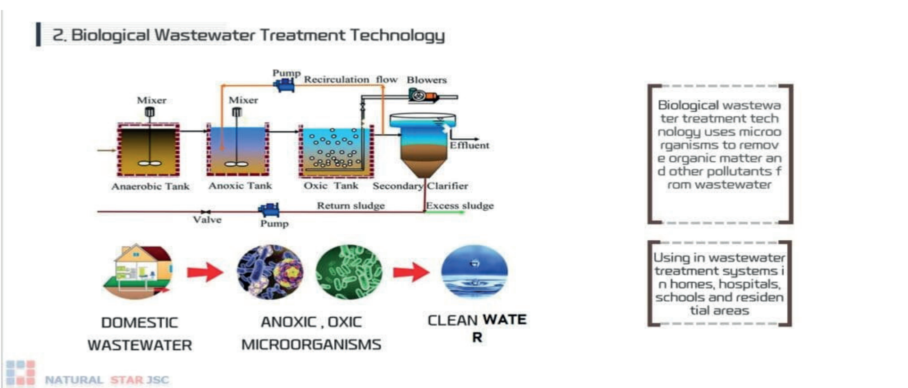

Figure 3. Biological treatment of agricultural wastewater

The primary target of biological treatment is organic solids, but it can also remove some inorganic materials. However, challenges persist. The sludge produced during treatment requires additional processing, and strong odors need to be controlled. Furthermore, biological activity must be slowed to prevent the growth of pathogens, which demand destruction to prevent the spread of disease.

To overcome these challenges, treatment strategies are adapted to each unique situation. This ensures that the receiving waters are clean and safe, protecting both ecosystems and public health. From natural wetlands to advanced treatment plants, nature and technology unite to transform wastewater into a valuable resource, rather than a menace (Mareddy, 2017).Aerobic bacteria form the core of activated sludge treatment. These microorganisms devour organic pollutants, creating flocs in a suspended growth system. As the bacteria feast, they clump together, allowing easy separation from purified water. This efficient process harnesses nature's power to cleanse wastewater, transforming contaminants into settleable biomass (Metcalf & Eddy Inc., Tchobanoglous, Burton, & Stensel, 2003)

The activated sludge process is a complex, multi-step innovation that has revolutionized the treatment of wastewater (Leu et al., 2012). It begins with aeration, a crucial step where wastewater is expertly blended with oxygen-rich microbial cultures, creating an ideal environment for aerobic bacteria to thrive. These microorganisms then get to work, breaking down organic matter into simpler compounds like carbon dioxide, water, and biomass through a process that requires meticulous precision.

As the wastewater advances to the sedimentation stage, the microbial flocs settle apart from the now-treated water, much like how a skilled chef separates the ingredients of a masterfully crafted dish (Bradu et al., 2023). Some of this settled sludge is cleverly recycled back into the aeration tank, preserving a robust community of microorganisms that keeps the process humming along seamlessly. Meanwhile, any excess sludge that accumulates is carefully removed for further treatment or proper disposal, ensuring that the entire system runs like a well-oiled machine. This intricate system has a profound impact on the environment, cutting down on organic pollutants and effectively removing nitrogen and phosphorus – key players in the prevention of eutrophication in our precious water sources. The final phase, methanogenesis, allows methanogenic bacteria to generate methane and carbon dioxide from the organic residues left behind, much like how a master craftsman extracts the finest details from a raw material (Modin, Persson, Wilén, & Hermansson, 2016).

The resulting digestate produced from anaerobic digestion is a nutrient-rich treasure trove, making it ideal for use as fertilizer or soil amendment – offering a practical economic benefit alongside its numerous environmental advantages. Particularly well-suited for dealing with high-strength wastewater and sludge, anaerobic digestion handles significant organic loads with ease, producing valuable by-products that can be harnessed to fuel our future. Furthermore, it produces less excess sludge than aerobic processes, dramatically simplifying the demands of sludge handling and disposal, and making it a preferred choice for wastewater treatment facilities around the world (Rong Chew et al., 2021).

Temperature, pH, and substrate concentration: three pillars of biological treatment processes. Each factor plays a crucial role. Temperature influences microbial metabolism, with mesophilic and thermophilic conditions favoring different bacteria. pH affects microbial activity and nutrient solubility. Substrate concentration determines organic matter availability for microbes. Together, these elements shape process efficiency (González Peña, López Zavala, & Cabral Ruelas, 2021; Khalidi-idrissi et al., 2023). Recent studies highlight their interconnected nature. Optimizing one factor impacts the others. Researchers have shown that fine-tuning these parameters enhances treatment stability and effectiveness. Balancing the triad prevents system overload and ensures efficient degradation. As our understanding deepens, so does our ability to improve biological waste management systems, paving the way for more sustainable environmental solutions (Gonzalez & Aranda, 2023).

3. Chemical Treatment

Chemical treatment is the crucial first step in the purification of wastewater, laying the groundwork for clean drinking water and a healthy environment. Coagulants and flocculants work their magic by binding contaminants together, while pH balancers and disinfectants further enhance the cleansing process. This powerful combination tackles both organic and inorganic pollutants, drastically reducing toxicity and significantly improving overall water quality (Figure 4).

Figure 4. Coagulation and flocculation applications to wastewater

One major obstacle in the quest for clean water is the presence of suspended particles, particularly tiny colloids that possess negative charges. These charges cause them to repel each other, remaining indefinitely suspended and making it difficult to remove them. This is where coagulation and flocculation come into play as essential processes in the pursuit of clean water.

Coagulation cleverly neutralizes the charges of these particles, while flocculation encourages their binding, forming larger clusters. Together, these processes counteract the forces that keep suspended particles stable, resulting in easily separable clusters. For instance, in the Jersey City Water Treatment Plant, coagulation and flocculation processes reduced suspended solids by a whopping 85%, making the plant's output water cleaner and safer for consumption (Sahu & Chaudhari, 2013).

These techniques are equally effective in both drinking water and wastewater treatment, significantly reducing turbidity—a key indicator of water quality—and lowering suspended solids and organic loads by up to 90%. Take, for example, the Orange County Water Treatment Plant in California, which uses chemical treatment to remove up to 95% of suspended solids, making its output water crystal clear.

From murky to clear and from contaminated to safe, chemical treatment plays a vital role in transforming wastewater. It is an essential step in ensuring that our water resources remain clean and usable for future generations. By understanding the intricacies of coagulation and flocculation, we can better appreciate the importance of chemical treatment in providing us with clean drinking water and a healthier environment (Iqbal et al., 2022).

4. Advanced Oxidation Processes (AOPs)

Discover the sophisticated dance of advanced oxidation techniques. These methods harness powerful oxidizing agents that break down organic pollutants with flair. Think ozone, hydrogen peroxide, and UV light—all working in harmony. Advanced oxidation processes revolutionized water treatment in the 1980s. Advanced oxidation processes (AOPs) revolutionized potable water treatment. Over time, these standout solutions have found their calling in wastewater treatment. Their potent hydroxyl and sulfate radicals tackle recalcitrant organic pollutants with ease. Strong oxidants effortlessly degrade stubborn organic matter while purging certain inorganic pollutants. AOPs are the champions of clean water, transforming waste into a brighter future (Deng and Zhao 2015).

Aqueous environments harbor resistant organic molecules, threatening water quality. Advanced oxidation processes (AOPs) tackle this problem by generating highly reactive radicals. These radicals assault stubborn compounds, initiating breakdown. Partial degradation yields organic intermediates, while complete mineralization destroys pollutants entirely. AOPs thus offer an effective solution, purifying water by eliminating persistent chemical contaminants and ensuring cleaner aquatic ecosystems (Mangla, Annu, Sharma, & Ikram, 2022; Stasinakis, 2008). AOPs break down stubborn pollutants with ease, transforming resilient contaminants into harmless components. These new compounds dissolve more readily in water and biodegrade faster. With fewer electrons and less mass, they differ markedly from the original pollutants. Nature can then process these altered substances more efficiently (Ghime, Ghosh, Ghime, & Ghosh, 2020). These compounds glide effortlessly into the next stages of treatment technology (Coha et al., 2021). Advanced oxidation processes shine in fascinating classifications. They can be grouped by the method that generates reactive radicals: chemical, electrochemical, sonochemical, or photochemical. Alternatively, they may be categorized by their reactive phase—homogeneous or heterogeneous (Baker, 2024; Sagle & Freeman, 2004).

Advanced oxidation processes using solar energy show promise but face hurdles. High efficiencies remain elusive, prompting some to combine solar with ultrasonic or microwave fields. This hybrid approach, however, increases operational costs. The core challenge lies in the non-selective nature of generated radicals. These reactive species attack both target compounds and natural organic material indiscriminately (Aiyera, Ramach, S.B, & B.G.A, 1970; Ortiz, Rivero, & Margallo, 2019). Consequently, overall organic degradation may appear high, while specific contaminant removal lags behind. This efficiency gap underscores the need for further research and development. As the field evolves, balancing cost-effectiveness with performance becomes crucial. Overcoming these obstacles could unlock solar energy's full potential in water treatment technologies.

The advanced oxidation process dances with stubborn organic pollutants, those resistant to nature and low on biodegradability. These chemical contrarians demand a robust response, generating reactive oxygen species (ROS) like hydroxyl radicals (•OH), superoxide radicals (•O2–), and sulfate radicals (SO4•–) (Kurian 2021; Mangla et al. 2022).

To outsmart these challenges, researchers have orchestrated an ensemble of advanced oxidation processes (AOPs). By cleverly combining methods like UV/H2O2, ultrasonic/photocatalytic oxidation, UV/O3, and UV/Fe2+/H2O2, they enhance ROS production and improve operating efficiency. The magic lies in the synergy—each paired AOP boosts oxidation efficiency, tackling contaminants more effectively than any lone warrior could (Gkika, Mitropoulos, Lambropoulou, Kalavrouziotis, & Kyzas, 2022).

5. Membrane Technologies

Membrane filtration techniques like microfiltration, ultrafiltration, and reverse osmosis remove contaminants from water based on size and charge. Membranes fall into two categories: isotropic and anisotropic. Uniform isotropic membranes can be microporous or nonporous. Microporous types, often used in microfiltration, have high permeation fluxes. Dense nonporous varieties see limited use due to low fluxes. Anisotropic membranes vary in structure and composition across layers. They feature a thin selective layer atop a thicker, permeable support. This design suits reverse osmosis applications. The membrane's structure determines its filtration capabilities and best uses (Baker, 2024; Sagle & Freeman, 2004). Synthetic organic polymers revolutionized membrane technology. These materials now form the backbone of pressure-driven separation processes. Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis all rely on organic membranes. Polyethylene, polytetrafluorethylene, polypropylene, and cellulose acetate are key players (figure 5). Their versatility enables a wide range of filtration applications. In contrast, inorganic membranes occupy a smaller niche. This organic-inorganic divide defines the primary classification of membrane materials in modern separation science (Aliyu, Rathilal, & Isa, 2018).

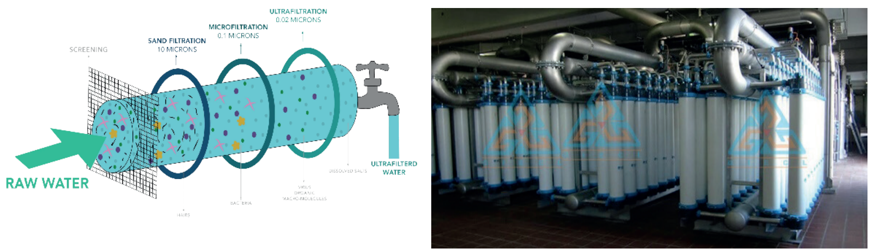

Figure 5. Membrane applications for waste water treatment

Ceramics, metals, zeolites, and silica form the backbone of inorganic membranes. These robust materials excel in chemical and thermal stability, making them ideal for diverse industrial uses. From hydrogen separation to ultra- and microfiltration, inorganic membranes tackle complex tasks with precision and resilience. Their versatility and durability ensure widespread adoption across various sectors, revolutionizing separation processes in demanding environments (Baker, 2024; Mallada & Menéndez M, 2008). Membrane processes employ diverse driving forces. Equilibrium-based methods balance concentrations. Non-equilibrium techniques maintain gradients. Pressure-driven systems push media across barriers. Non-pressure approaches use alternative mechanisms. Each force type enables specific membrane applications, from filtration to separation(Jhaveri & Murthy, 2016).

Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis dominate pressure-driven membrane processes in wastewater treatment. These four methods, differentiated by pore size and pressure needs, span the entire treatment cycle. Hydraulic pressure powers their separation capabilities, making them invaluable from pre- to post-treatment stages. Their widespread application stems from versatility in addressing various contaminant sizes. As the most common membrane techniques, they offer tailored solutions for diverse wastewater challenges, ensuring efficient pollutant removal across different treatment phases (Chollom, 2015).

Constructed wetlands are engineered ecosystems that purify wastewater like natural marshes. They funnel polluted water through layers of substrate, plants, and microbes. This artificial habitat sparks a chain of cleansing reactions. Physical, chemical, and biological processes work in concert to strip contaminants from the flow. Precise design is crucial for optimal performance. Key factors include wetland type, configuration, and plant selection. Engineers must also fine-tune the substrate composition, water flow rate, and retention period. These technical elements determine how effectively the system mimics nature's water-cleaning prowess (Figure 6).

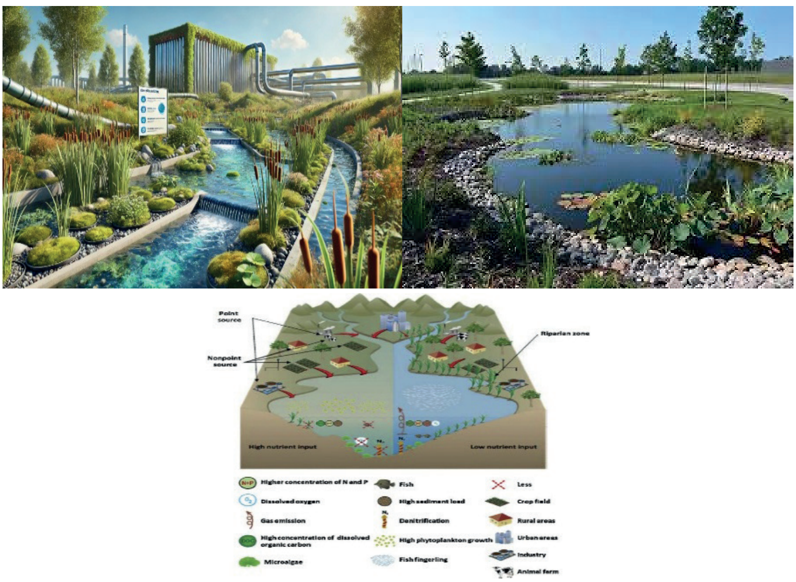

Figure 6. Construction and application of wetlands

In crafting these systems, a pivotal choice emerges: surface flow (SF) or subsurface flow (SSF) wetlands. This decision shapes the effectiveness, operation, and ecological footprint of the design. Engineers and planners must grasp the nuances, benefits, and limitations of each option. Only then can they forge a system that meets unique environmental, climatic, and treatment goals.

Wetlands are bastions of ecological importance, providing unique and irreplaceable functions that underpin essential ecosystem services. They play a pivotal role in biodiversity conservation, climate change mitigation, and the well-being of human populations. Additionally, wetlands support vital economic activities, such as tourism, enriching local economies (Hambäck et al., 2023a).

These dynamic ecosystems manage hydrological cycles, expertly controlling floods and alleviating droughts (Ferreira et al., 2020; Wu et al., 2023). Beyond that, they ensure soil moisture retention and contribute to groundwater generation (Rojas, Soto, Rojas, & López, 2022). Wetlands assume the roles of natural purifiers, enhancing water quality and regulating air around us (Fang et al., 2023). They facilitate nutrient cycling (Malerba et al., 2022) and act as carbon sinks, sequestering greenhouse gases (Kreplin et al., 2021). Supporting an array of biodiversity, wetlands create habitats that nurture countless species (Hambäck et al., 2023b). They also boost local aesthetics and recreational opportunities, making landscapes more inviting (Bergamo, Ward, Joyce, Villoslada, & Sepp, 2022). The critical ecosystem services provided by these multifunctional landscapes arise from the interplay of individual wetlands within their catchments. Impressively, the value of wetland ecosystem services represents over 20% of the total global ecosystem service value (Thorslund et al., 2017).

Wetlands—nature's indispensable treasures—are one of Earth's three major ecosystems (Fang et al., 2023, 2019). Spanning every continent, they cover a remarkable area of around 12.1 million square kilometers (Davidson et al., 2018). However, these vibrant ecosystems face a dual threat from human actions and natural forces. Changing land use, including the push for agriculture and urbanization (Thorslund et al., 2017), disrupts these watery wonders (Jamali et al., 2022). Compounding this crisis are fluctuating water supplies and the daunting specter of climate change, with sea level rise and extreme weather events like floods and droughts looming large (Bergamo et al. 2022; Rojas et al. 2022). The relentless warming of our planet adds to this precarious situation (Dingaan, 2018). Moreover, escalating pollution is a poison draining the vitality from our wetlands (Turcios et al., 2021). Human activities, particularly land drainage, have fragmented these critical areas, severing the connectivity vital for healthy ecosystems (Bi et al. 2022). Since 1700, global wetland area has plummeted by a staggering 87% (Davidson et al., 2018). From 1900 to the present, losses range from 64% to 71%, while the last five decades have seen a decline of 35% Rojas et al. 2022). Though constructed wetlands offer a glimmer of hope, providing some ecosystem services, they can never fully replace the richness of natural environments (Turcios et al., 2021)

Wetlands offer promising nature-based solutions to global water challenges. As climate change and human activities disrupt water patterns, these ecosystems can regulate flows during floods and droughts. They also excel at purifying contaminated waters, efficiently removing various pollutants (García-Herrero et al., 2022). Wetland types and their dual potential for flow regulation and water quality improvement. With more extreme weather and rising pollution, wetlands may help address urgent issues of water availability and contamination. Their natural processes could prove vital for sustainable water management in a changing world.

Sustainable water management has become an urgent challenge due to irregular water availability patterns (e.g., more frequent and intense hydrometeorological extreme events) and water quality issues (eutrophication, increasing wastewater), driven by both anthropogenic and climate changes.

Wetlands are essential for balancing water flow, especially during nature's mood swings like floods and droughts. These thriving ecosystems serve as crucial buffers, managing the surge and scarcity with grace. Not only do they regulate water levels, but they also improve water quality by combating pollution. With their natural filtration systems, wetlands effectively remove harmful pollutants, showcasing their indispensable role in our environment.

6. Nutrient Recovery

By harnessing innovative techniques, we can recover valuable nutrients such as nitrogen and phosphorus from wastewater. This not only improves sustainable agricultural practices, but also redefines our waste management strategy. In the past decade, the spotlight has shifted dramatically. No longer do we merely focus on pollution control. Instead, resource recovery from wastewater is now essential. As Logan and Rabaey in 2012, this evolution is vital for environmental health.

Natural treasures such as ammonia and phosphate are indispensable for our food supply. Ammonia is typically synthesized using the energy-guzzling Haber-Bosch process, consuming a staggering 1% of the world's total energy (Cherkasov, Ibhadon, & Fitzpatrick, 2015). Phosphorus, while plentiful in nature, faces limitations in accessibility and quality. Over the last decade, phosphorus prices have skyrocketed by two to three times, with projections for continued rises within the next 20 to 70 years (Jacobs, Cordell, Chin, & Rowe, 2017).

Alarmingly, nearly all nitrogen and phosphorus consumed by humans re-enters the ecosystem through waste—either feces or urine Spångberg, Tidåker, and Jönsson 2014). Wastewater treatment plants strive to eliminate these nutrients, curbing the dreaded phenomenon of algal blooms and eutrophication in our waterways. The most frequently employed techniques include nitrification/denitrification and metal precipitation, effectively scrubbing wastewater of these nutrients (Coats, Watkins, & Kranenburg, 2011). However, the nitrification process can be energy-intensive, consuming 60% of operational costs (Nancharaiah, Venkata Mohan, & Lens, 2016).

A more sustainable strategy revolves around closed nutrient loops, capturing and reusing resources instead of discarding them as waste (Chojnacka, Moustakas, & Witek-Krowiak, 2020). According to the U.S. EPA, over 100,000 miles of rivers and streams, approximately 2.5 million acres of lakes and ponds, and over 800 square miles of bays and estuaries suffer from nitrogen and phosphorus pollution.

In excess, these nutrients can incite harmful algal blooms, a scourge that costs the tourism industry around $1 billion annually. The report outlines an "aspirational goal," a 25-year challenge to develop a Nutrient Roadmap. This roadmap aims to facilitate smarter nutrient removal and recovery at water resource recovery facilities (WRRFs). The wastewater utility of tomorrow focuses on recovering valuable resources, transforming how we view wastewater from mere problem to opportunity.

8. Advanced Oxidation Processes (AOPs)

Advanced Oxidation Processes (AOPs) generate highly reactive species to purify wastewater. These powerful oxidizers, primarily hydroxyl radicals, break down persistent pollutants and pathogens. AOPs excel where traditional methods falter, tackling difficult-to-degrade compounds effectively. By neutralizing a diverse array of contaminants, this cornerstone technology significantly reduces environmental impact. Wastewater streams benefit from AOPs' ability to address complex pollution profiles Figure 7). The process renders effluents safer, overcoming challenges in modern water treatment. As a result, AOPs have become indispensable in contemporary wastewater management strategies. Their versatility and efficiency in eliminating organic compounds and harmful microorganisms position AOPs as a crucial advancement in water purification technology merhaba (Hübner et al. 2024; Pandis et al. 2022).

Figure 7. AOPs process and applications

Ozone-Based AOPs

Ozone (O3) stands tall as a fierce oxidant, exhibiting a strong oxidation potential of 2.07 V against SCE. Yet, this reaction isn't a free-for-all; it's selective. With typical reaction rate constants between 1.0 × 100–103 M–1 s–1, O3 prefers to engage with the ionized and dissociated forms of organic compounds, shunning their neutral versions. Under certain conditions, O3 can also generate OH·, launching a wave of indiscriminate oxidation through indirect mechanisms(Hübner et al. 2024).

UV-Based AOPs

Wastewater treatment faces a persistent challenge: recalcitrant organic pollutants. Conventional biological methods often fall short in degrading these stubborn compounds. Enter Advanced Oxidation Processes (AOPs), a versatile solution to this problem. AOPs harness the power of hydroxyl radicals, initiated by photons interacting with catalysts or oxidants. Titanium dioxide (TiO2), a key player, excites to produce oxidative valence band holes and reductive conduction band electrons. This mechanism drives the breakdown of resistant pollutants. AOPs offer flexibility, combining with other treatments to enhance efficiency and water quality. Techniques like ozonation, photocatalysis, and Fenton's reaction each bring unique strengths to the table. For stringent discharge standards or water reuse, AOPs prove indispensable (Hübner et al. 2024).

Fenton-Related

Among these metals that are able to activate H_2O_2 and produce hydroxyl radicals in water, iron is the most frequently used. In the so-called Fenton process, H_2O_2 reacts with Fe^{2+} to generate strong reactive species. The reactive species produced are traditionally recognized as hydroxyl radicals, though other substances such as ferryl ions are proposed (Oturan and Aaron 2014).

Sulfate Radical-Based AOPs

Sulfate radical-based advanced oxidation processes begin with S2O8 2−, a strong oxidant. Its standard oxidation potential reaches 2.01 V. However, activation unlocks even greater power. Heat, UV irradiation, transitional metals, or high pH transform S2O8 2− into sulfate radicals (SO4 ·−). These radicals pack a mighty 2.6 V punch, surpassing their precursor. This potent conversion drives advanced oxidation, unleashing a cascade of powerful chemical reactions (Deng and Zhao 2015; Hübner et al. 2024; Oturan and Aaron 2014).

Other AOPs

Wastewater treatment faces a critical challenge: removing stubborn pollutants. Advanced oxidation processes (AOPs) offer a solution. Ultrasound irradiation, operating at 16 kHz–100 MHz, creates powerful cavitation effects. Sound waves generate microbubbles that nucleate, grow, and implode. This implosion produces extreme conditions: 4200–5000 K temperatures and 200–500 atm pressures. Under these forces, water molecules fragment into hydroxyl radicals. Electronic-beam irradiation achieves similar results. These innovative AOPs, alongside other methods, provide effective tools for breaking down resistant contaminants in water (Deng and Zhao 2015; Oturan and Aaron 2014; Wang et al. 2019).

Multiple Mechanisms Occurring During AOPs for Wastewater Treatment

AOPs remove pollutants through multiple mechanisms. OH· and SO4·– oxidation play key roles, but non-radical processes can also contribute. The significance of these alternative pathways varies widely, influenced by the specific AOP and reaction environment. Some scenarios see non-radical mechanisms dominating, while in others their impact is negligible. Understanding these complex interactions is crucial for optimizing wastewater treatment efficiency(Deng & Zhao, 2015; Mata-Álvarez, Mata-Alvarez, Mac, & Llabr, 2000).

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