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Assessment of agroforestry potential and applications in the Southeastern Anatolia Region of Türkiye

Türkiye'nin Güneydoğu Anadolu Bölgesi'nde tarımsal ormancılık potansiyeli ve uygulamalarının değerlendirilmesi

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Abstract

In this study, the potential of agroforestry systems in the Southeastern Anatolia Region of Türkiye was evaluated considering the region's ecological and socio-economic characteristics. Agroforestry integrates agriculture, forestry, and livestock production within the same land unit and represents a sustainable land-use approach. The region faces environmental constraints such as low precipitation, high temperatures, erosion, salinity, and land degradation. However, irrigation expansion through the Southeastern Anatolia Project (GAP) has created favorable conditions for multifunctional land-use systems. This study reviewed national and international literature published between 2000 and 2024, focusing on windbreaks, shelterbelts, poplar–willow-based agrosilvicultural systems, and silvopastoral practices. The results indicate that the region has significant potential for agroforestry development. Systems including species such as *Populus* spp., *Salix* spp., *Robinia pseudoacacia*, *Cupressus sempervirens*, and *Pistacia* spp. can improve agricultural productivity and ecological resilience. Agroforestry practices enhance soil organic matter, reduce erosion, regulate microclimatic conditions, support carbon sequestration, and provide economic benefits through diversified products and increased rural income.

Keywords: Agroforestry, Climate change adaptation, Carbon sequestration, Multifunctional land use

Özet

Bu çalışmada, Türkiye'nin Güneydoğu Anadolu Bölgesi'nde agroforestry (tarımsal ormancılık) sistemlerinin potansiyeli, bölgenin ekolojik ve sosyo-ekonomik özellikleri dikkate alınarak değerlendirilmiştir. Agroforestry, tarım, ormancılık ve hayvancılık faaliyetlerinin aynı arazi biriminde birlikte yürütülmesini sağlayan sürdürülebilir bir arazi kullanım yaklaşımıdır. Bölge; düşük yağış, yüksek sıcaklık, erozyon, tuzluluk ve arazi bozulumu gibi çevresel sorunlarla karşı karşıyadır. Bununla birlikte, Güneydoğu Anadolu Projesi (GAP) kapsamında sulama olanaklarının genişlemesi, çok işlevli arazi kullanım sistemlerinin geliştirilmesi için uygun koşullar oluşturmuştur. Bu çalışmada 2000–2024 yılları arasında yayımlanan ulusal ve uluslararası literatür incelenmiş; rüzgâr perdeleri, koruyucu ağaç kuşakları, kavak–söğüt temelli agrosilvikültürel sistemler ve silvopastoral uygulamalar ele alınmıştır. Bulgular, bölgenin agroforestry uygulamaları açısından önemli bir potansiyele sahip olduğunu göstermektedir. Özellikle *Populus* spp., *Salix* spp., *Robinia pseudoacacia*, *Cupressus sempervirens* ve *Pistacia* spp. gibi türleri içeren sistemlerin tarımsal verimliliği ve ekolojik dayanıklılığı artırabileceği belirlenmiştir. Agroforestry uygulamaları toprak organik maddesini artırmakta, erozyonu azaltmakta, mikroiklim koşullarını düzenlemekte ve karbon tutulmasına katkı sağlamaktadır. Ayrıca ürün çeşitliliği ve kırsal gelir artışı yoluyla ekonomik faydalar da sunmaktadır.

Anahtar Kelimeler: Tarımsal ormancılık, İklim Değişikliğine Uyum, Karbon tutumu, Çok amaçlı arazi kullanımı

1. Introduction

Agroforestry is a land-use system aimed at sustainable production, formed through the integration of agricultural, forestry, and livestock activities on the same land unit. This approach is widely implemented worldwide due to its multiple benefits, including enhancing soil fertility, preventing erosion, improving water-use efficiency, conserving biodiversity, and contributing to rural development (Nair, 1993; Jose, 2009). In arid and semi-arid regions, agroforestry holds strategic importance for reducing land degradation, facilitating adaptation to climate change, and strengthening food security. In this context, models developed in India, the African Sahel region, and Latin America represent prominent examples (Garrity, 2004; Leakey, 2012).

Türkiye, with its diverse climatic zones and ecological variability, possesses significant potential for agroforestry development. Traditionally, olive-cereal and vineyard-fruit tree combinations and the use of multipurpose plant species in the Aegean and Mediterranean regions (Turna, 2013); rural home garden systems in hazelnut and tea-growing areas of the Black Sea region (Turna and Acar, 2002; Turna et al., 2025a), including linden (*Tilia* spp.) (Turna, 2001); and windbreaks and willow–poplar-based practices integrated into wheat, sunflower, and other agricultural activities in Central Anatolia represent examples of agroforestry systems in the country (Karatay and Okur, 2018). However, Southeastern Anatolia- one of the driest regions of Türkiye and characterized by limited forest resources- presents both significant challenges and important opportunities for the development of agroforestry systems.

The region draws attention not only because of its ecological constraints- such as low precipitation, high temperatures, intense evaporation during the summer months, and the dominance of steppe vegetation- but also due to the intensity of agricultural production and the fact that rural livelihoods largely depend on agriculture. The expansion of irrigation opportunities through the Southeastern Anatolia Project (GAP) has significantly increased agricultural diversity and productivity, leading to the widespread cultivation of cotton, wheat, maize, lentils, and vegetables (Bozkurt and Ayberk, 2016). This situation has created new opportunities for the development of agroforestry systems through the integration of agricultural activities with forestry practices.

The intensity of agricultural production in the region, the limited extent of forest areas, and the need for the sustainable use of existing resources make agroforestry not only an ecological necessity but also a socio-economic imperative. Practices such as windbreaks, shelterbelts, poplar cultivation, silvopastoral systems, and traditional pistachio–grape integrations offer substantial potential for both rural development and sustainable land use.

This review was prepared to reveal the agroforestry potential of the Southeastern Anatolia Region, taking into account its general characteristics, and is based on articles, reports, and theses published between 2000 and 2024. A literature search was conducted in Web of Science, Scopus, Google Scholar, and national databases using the keywords "agroforestry," "GAP," "windbreaks," "silvopastoral," and "arid lands." Studies not directly related to the region were excluded; the selected sources were classified and analyzed according to themes such as windbreaks, poplar- and willow-based agrosilvicultural models, and silvopastoral practices. In addition, direct observations and field assessments conducted by the authors during field studies in the region were incorporated into the evaluation; the photographs used in the article and indicated without specific references were taken by the corresponding author during these field studies.

2. General characteristics of The Southeastern Anatolia Region

The area covering nine (Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa, and Şırnak) provinces in the southeastern Türkiye is referred to as the GAP Region and, with a surface area of 75,193 km², constitutes 9.7% of the country's total territory (STB, 2022). Among Türkiye's seven geographical regions, it stands out in terms of its potential vulnerability to drought and desertification.

Drylands possess distinct characteristics, constraints, and potentials compared to other ecosystems in terms of climate, soil, water resources, biodiversity, and economic conditions (Wale and Dejenie, 2013). In these areas, climatic features such as low average precipitation, irregular rainfall patterns, sparse vegetation cover, and recurrent drought conditions are prominent (Wale and Dejenie, 2013; Gaur and Squires, 2018; Yoram, 2022). Addressing desertification, land degradation, and poverty in an integrated manner necessitates approaches that combine environmental protection, poverty alleviation, and sustainable development (Kassahun et al., 2008; El-Beltagy and Madkour, 2012). Desertification and land degradation are complex environmental processes that generate profound socio-economic impacts, particularly in arid regions (Imeson, 2012; Baartman et al., 2007).

Therefore, holistic strategies aimed at simultaneously mitigating environmental degradation and reducing poverty are required in dryland areas.

Considering global climate change trends, the GAP Region is also confronted with the risks of drought and desertification. Nevertheless, the region's abundant water resources provide significant advantages in addressing drought, desertification, land degradation, and food security challenges.

One of the most significant characteristics of the region is the profound transformation brought about by the dams constructed within the scope of the GAP Project in the Euphrates-Tigris basins and the canal systems based on irrigation networks aimed at improving water and soil resources. Afforestation and vegetation efforts of DG Forestry (ogm.gov.tr) carried out along the dam reservoirs and irrigation canals not only extend the operational lifespan of the dams but also contribute to multiple benefits, including agriculture, transportation, recreation, public health, and rural and urban infrastructure services (Figure 1).

In brief, ensuring the sustainability of the new ecosystems emerging with irrigation requires the development of multipurpose projects based on a holistic approach tailored to the region's ecological, economic, and socio-cultural conditions. Through the proper management of water resources and the optimal utilization of natural assets, regional development can be further supported. Indeed, the primary objective of the GAP initiatives is to increase the income levels and improve the living standards of the local population.

With the expansion of irrigation, the cropping pattern in the region has diversified. Prior to 1995, dry farming predominated; however, the transition to irrigated agriculture led to the cultivation of secondary crops requiring irrigation- particularly cotton, as well as sunflower, soybean, and maize- and lands that previously produced a single crop per season began yielding at least two crops annually (STB, 2022).

The region possesses a substantial natural resource potential, with the average annual discharge of the Euphrates and Tigris rivers amounting to approximately 53 billion m³. Of this total, 30 billion m³ originates from the Euphrates and 16.7 billion m³ from the main tributaries of the Tigris. The region's main river flow potential, estimated at 46.7 billion m³ annually, accounts for 28.5% of Türkiye's total river water potential. Within cultivable agricultural lands, the total area of Class I, II, and III lands amounts to 2,467.5 thousand hectares (ha), corresponding to 33% of the total land area. When Class IV lands suitable for limited cultivation (649.3 thousand hectares) are included, it is evident that 42.2% of the region's soils are suitable for agricultural use. Of the region's total land area of 7.5 million hectares, 43.6% (3,290,575 ha) is allocated to crop production, 29.4% (2,214,473 ha) to meadows and pastures, and 19.2% (1,451,185 ha) to forests and shrublands (STB, 2022).

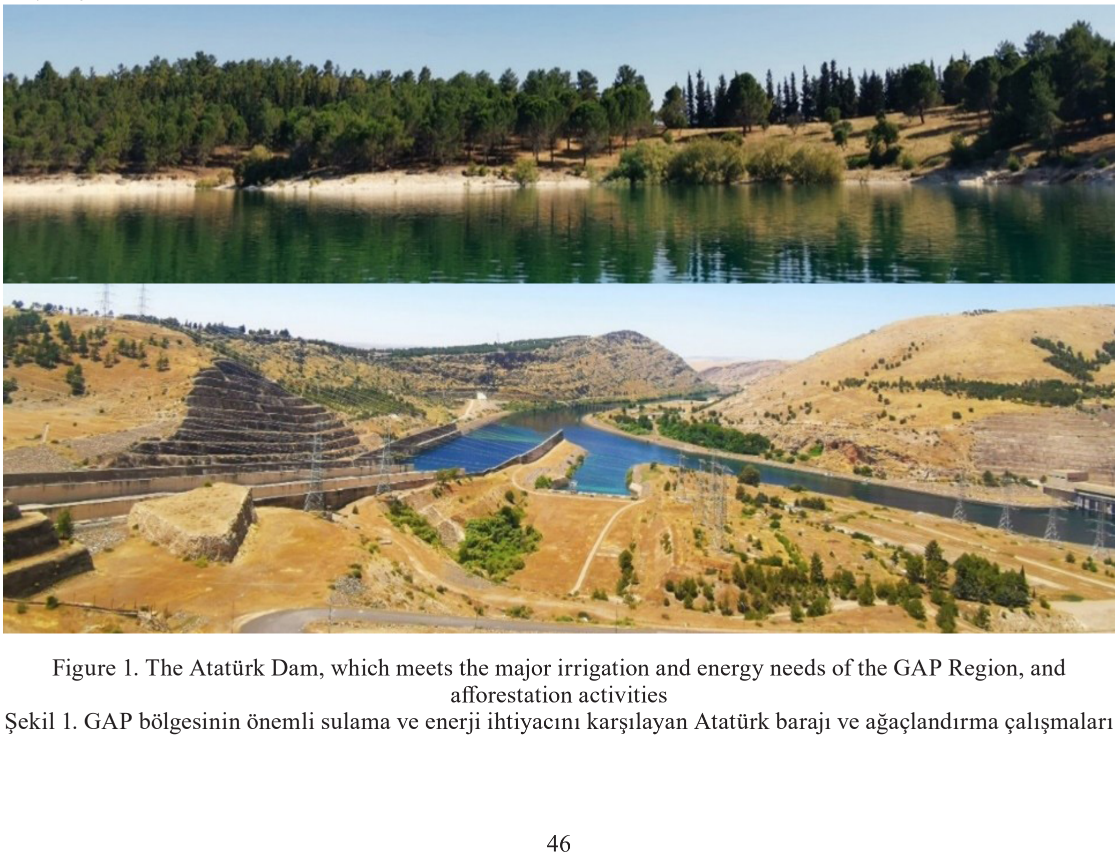

Figure 1. The Atatürk Dam, which meets the major irrigation and energy needs of the GAP Region, and afforestation activities
Şekil 1. GAP bölgesinin önemli sulama ve enerji ihtiyacını karşılayan Atatürk barajı ve ağaçlandırma çalışmaları

2.1. Geographical location, and the subregions

The Southeastern Anatolia Region is the lowest-altitude region of Türkiye and is also characterized by relatively uniform aspect conditions. From a geographical perspective, it is divided into two subregions: the Tigris (Dicle) to the east of the Karacadağ volcanic cone, and the Middle Euphrates subregion to the west. Özçağlar (1986) evaluated the geographical distribution of agricultural lands in the region across six distinct subregions: the Diyarbakır Basin, Karacadağ, the Mardin Threshold, and the Urfa, Gaziantep, and Adıyaman plateaus.

In terms of landforms, the Tigris subregion is characterized by relatively simple topography, comprising extensive plateaus and plains. Located at elevations between 500 m and 1,000 m, this area receives an average annual precipitation of approximately 500 mm. Due to high temperatures, intense evaporation results in pronounced summer drought conditions. The elevations of the plateaus shaped by the Euphrates River and its tributaries range between 500 m and 1,000 m (Turna, 2023). In both subregions, drought constitutes the primary limiting factor for agricultural activities; however, with the provision of irrigation water through the GAP, agricultural diversification has increased, and the potential for energy production has expanded.

2.2. Land use and agricultural structure

The Region is one of Türkiye’s most important agricultural centers. According to data from TÜİK (2023), agricultural lands account for more than 55% of the total regional area. A significant proportion of these lands, depending on irrigation availability, is devoted to the cultivation of various crops, primarily cotton, wheat, lentils, barley, and maize. The Diyarbakır Basin is prominent for cereal production, watermelon, pistachio, and cotton cultivation; livestock production is dominant in Karacadağ; cereals, legumes, almonds, and figs are characteristic of the Mardin; cotton, maize, and wheat are widely cultivated in the Şanlıurfa; cereals, pulses, cotton, pistachio, and olive groves stand out in Gaziantep; and field crops, vineyards, and orchards are common in Adıyaman.

Livestock production constitutes a significant economic activity in the region, with small ruminant breeding (sheep and goats) being particularly widespread. In addition, stall-fed livestock production has shown recent growth. Sericulture is traditionally practiced in Kilis and its surrounding areas. However, overgrazing of rangelands, insufficient forage crop production, and climatic constraints negatively affect the livestock sector.

2.3. Forestry and vegetation

The region is generally characterized by a continental climate, with hot and dry summers and cold and rainy winters. The dominant natural vegetation is steppe. Forest areas are limited and are typically found as clusters or scattered individuals along the foothills of the Southeastern Taurus Mountains, consisting mainly of oak species along with some other broadleaved species in degraded or sparsely distributed forest formations. In the western part of the region, forests composed of Turkish red pine (*Pinus brutia*), Eldar pine (*P. eldarica*), and stone pine (*P. pinea*), together with maquis communities, are present. A large proportion of the forests exhibit degraded coppice characteristics and have been further deteriorated due to the use of leaves as animal fodder and the extraction of fuelwood. Nevertheless, the region is relatively rich in terms of biodiversity and holds considerable potential for non-timber forest products and ecosystem services.

Although forestry activities provide limited economic contributions, there exists significant potential for agroforestry practices both within forested areas and in lands used for agricultural production. In particular, windbreaks established within and around agricultural fields, as well as poplar- and willow-based plantations along wetlands and irrigation canals, stand out as key elements that could facilitate the integration of forestry with agriculture in the region.

3. Agroforestry potential and the Region

In light of the general characteristics of the region, a clear understanding of certain concepts is necessary to determine its agroforestry potential. According to Turna (2023), the main agroforestry systems include:

- *Within agrosilvicultural systems*: Fallow practices, multipurpose gardens, multipurpose woody species, woody plants integrated into other cropping systems, mixed plantations, shade trees for agricultural crops, agroforestry for timber and energy production, windbreaks, and living hedges;

- *Within silvopastoral systems*: Protein banks (multipurpose forage-tree components established within and along field margins), hedgerows composed of fodder species, trees, shrubs, and bushes in rangelands, and the integrated cultivation of livestock and plant species;
- *Agrosilvopastoral systems*: The combined production of livestock and woody plants, the establishment of multipurpose woody hedgerows, the development of mixed production systems (livestock +

crops) around settlements, and forestry-based practices related to apiculture and aquaculture.

From a functional perspective, agroforestry models aim to fulfill production functions such as food, fodder, bioenergy, and timber production; biodiversity-based habitat functions; ecological functions related to soil and water conservation through windbreaks; and cultural functions associated with recreation and landscape values.

The principal agroforestry practices applied in tropical regions are summarized as an example in Table 1 (Nair, 2012).

Table 1. Agroforestry practices in some tropical countries
Tablo 1. Bazı tropikal ülkelerdeki agroforestry uygulamaları

Agroforestry Practices	Descriptions
Alley Cropping	Cultivation of fast-growing species- preferably legumes- within crop fields (trees are pruned to below 1.0 m to prevent shading of agricultural crops; pruning residues are used as animal fodder or for mulching).
Home Gardens	Multi-layered combinations of various trees and crops around farmhouses (livestock may also be included).
Improved Fallow	Fast-growing, preferably leguminous woody species are planted and left fallow for short periods (2-3 years) between cropping cycles to enhance soil fertility; woody species may also provide economic products.
Multipurpose Trees and Shrubs in Cropland and Pastures	Fruit trees and other multipurpose forest species scattered randomly or planted in systematic arrangements within crop or livestock production areas (trees provide fruits, fuelwood, fodder, and timber).
Silvopasture (Grazing and Protein Banks)	Integration of trees into livestock production systems: grazing cattle (*Bos taurus*) beneath widely spaced or scattered trees; stall feeding of livestock with high-quality fodder obtained from trees grown in blocks on farms.
Shade Cropping	Cultivation of shade-tolerant species under or among timber or other commercial tree crops.
Windbreaks	Use of trees to protect fields from wind damage, sea intrusion, flooding, etc.
Taungya	Cultivation of agricultural crops during the initial stages of plantation establishment.

3.1. The relationship between GAP Region and agroforestry

The GAP is a multi-sectoral project encompassing irrigation, energy, agriculture, and rural development within the framework of regional development. Therefore, considering its general characteristics, the region possesses significant potential to enable the integration of agricultural activities with forestry practices as a form of multifunctional land use.

In particular, in a region where agricultural activities predominate due to site conditions, irrigation plays a crucial role. With the expansion of irrigation opportunities through the GAP, crop diversity has increased, and in addition to cotton and wheat, the potential for cultivating maize, vegetables, and forage crops has also expanded.

Examining the crop pattern of the region in 2022, 60.89% of Türkiye's cotton production, 95.37% of red lentils, 80.97% of field pea production, 38.94% of durum wheat, 75.07% of snake cucumber (acur in Turkish), 72.84% of mint, 11.43% of tomato paste pepper, 14.42% of watermelon, 12.70% of eggplant, 95.40% of pistachio, 84.39% of unprocessed spice pepper, 50.14% of dried seeded grapes, 18.03% of wine grapes, and 29.50% of almonds were supplied from the region. With the expansion of irrigation, significant increases have occurred particularly in the production of fresh vegetables, fruits, and industrial crops, leading to a more diversified cropping pattern (STB, 2022; TÜİK, 2023).

Indeed, Bozkurt and Ayberk (2016) report that in the post-GAP period, the average farm size in the Harran Plain of Şanlıurfa was 32.08 ha. Of the agricultural activities, 86.3% are conducted under irrigated conditions, while 13.7% are carried out as dry farming. Cotton accounts for 69.7% of the cultivated crops, followed by wheat, maize, lentils, and barley. In recent years, with the expansion of irrigated lands, at least two crops (e.g., wheat+ cotton, wheat + silage maize, barley+ cotton) have begun to be cultivated within a single year.

In arid and semi-arid areas such as Southeastern Anatolia, as well as in semi-humid zones associated with reservoirs and water resources, varying ecological conditions allow for the implementation of diverse agroforestry models. For example, silvopastoral systems based on species such as mulberry (*Morus*), oak (*Quercus*), and juniper (*Juniperus*) may be suitable for cold arid environments, where-as agrosilvicultural systems centered on pistachio (*Pistacia*) can be applied in hot arid regions. Considering the general characteristics of the region, basin-based agroforestry models aimed at the multifunctional use of lands rich in water resources are presented schematically (USDA, 2008).

As illustrated in Figure 2, the basin-based map demonstrates the spatial integration of subsystems such as windbreaks (A), silvopastoral systems (B), and riparian vegetation (C), thereby providing guidance for potential land-use strategies.

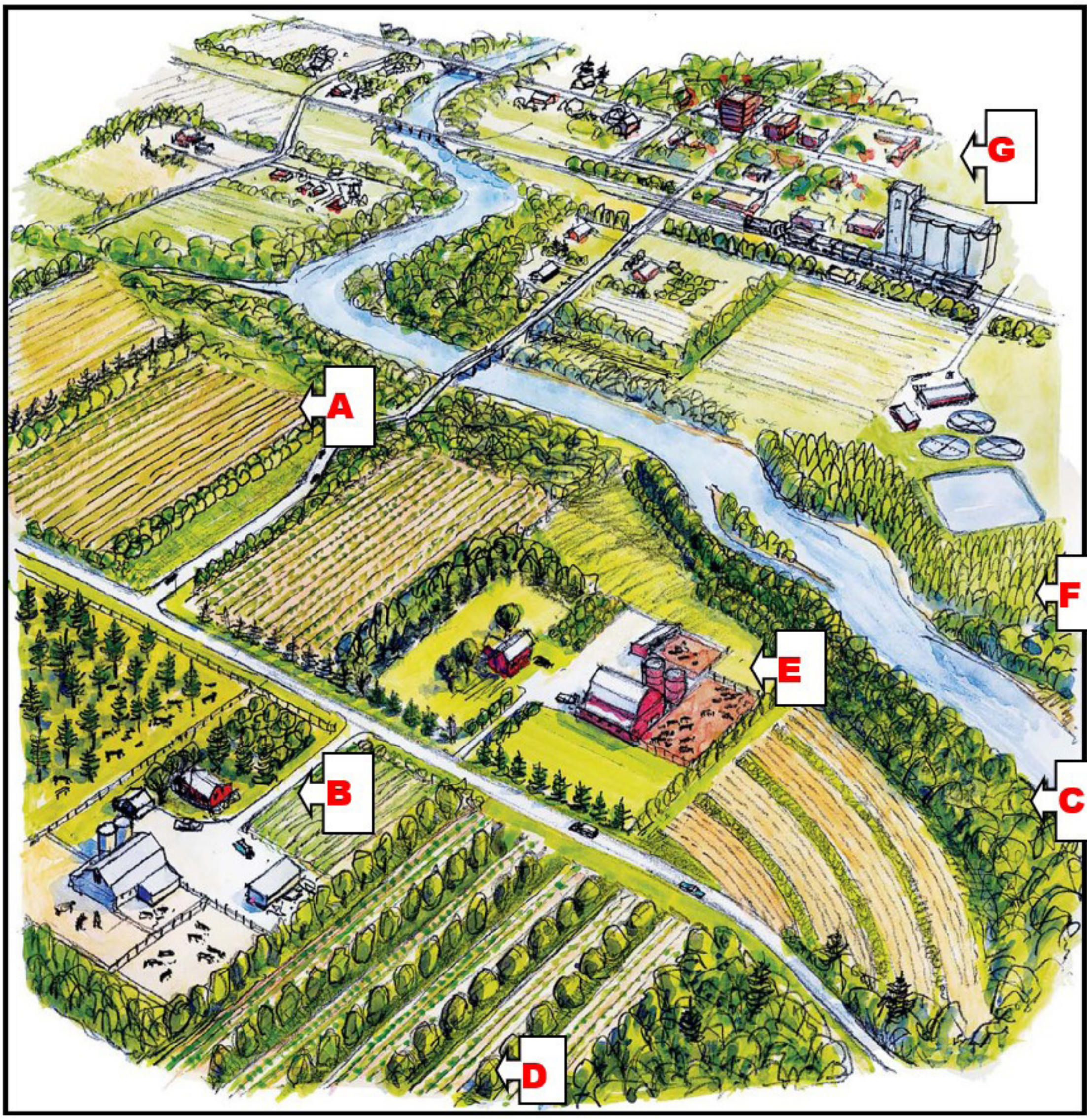

Figure 2. Spatial representation of agroforestry systems: A) Windbreak, B) Silvopastoral system, C) Riparian vegetation, D) Trees and shrubs planted among agricultural crops, E) Farm forestry, F) Special applications, G) Settlement area

Şekil 2. Agroforestry sistemlerinin alansal gösterimi: A) Rüzgâr perdesi, B) Silvipastoral sistem, C) Su kenarı bitkileri, D) Zirai ürünler arasında ağaç/ ağaççık dikimi, E) Çiftlik ormancılığı, F) Özellikli uygulamalar, G) Yerleşim alanı

3.2. Windbreaks and shelterbelts

In a region where agricultural activities are conducted over extensive plains, there is a clear need for agroforestry models- particularly windbreaks- within large-scale farming systems. Especially in areas lacking or containing very few forest tree species, soils and agricultural crops are exposed to the full range of adverse wind effects due to open-field conditions (Figure 3).

In addition to the negative impacts of wind and storms, improper irrigation practices are likely to lead to salinization and land degradation. In recent years, experts have increasingly emphasized the need for careful irrigation management. Through farmer training and technical support from specialists, the establishment of trees, shrubs, and bushes along irrigation canals, as well as the implementation of properly designed agroforestry models at regular intervals within large fields (such as windbreaks and gallery poplar or willow plantations), can help prevent salinization and land degradation while simultaneously enhancing crop diversity and productivity.

Figure 3. Agricultural activities and irrigation in the Harran Plain, Şanlıurfa (URL-1)
Şekil 3. Şanlıurfa-Harran ovasında tarım ve sulama

The most important agroforestry practice that can be implemented in these areas is the establishment of windbreaks, shelterbelts, and protective forest zones designed to protect agricultural lands from cold winter conditions and hot, desiccating winds during the summer. In flat areas such as the Harran Plain, wind erosion, dust transport, and sandstorms pose serious threats to agricultural production. Despite this, windbreak systems are not sufficiently implemented in the region. However, scientific studies have demonstrated that windbreaks conserve soil moisture, reduce dust and sand movement, prevent the dispersal of sown seeds by wind, and increase crop yields (FAO, 2015; Jose, 2009; Turna et al., 2024). Nevertheless, farmers often avoid such practices due to concerns that windbreaks may fragment agricultural lands and reduce usable field areas. In contrast, research findings indicate that windbreaks enhance crop productivity, contribute to biodiversity conservation, strengthen ecosystem services, and provide additional recreational value (Turna et al., 2024).

The use of windbreaks in agricultural lands is illustrated in Figure 4. These practices were first implemented in the mid-19th century in the state of Nebraska, USA. According to Kafer and Straight (2022), the net increase in total crop yield ranges between 10-20%, depending on the crop type. In the establishment of windbreaks and shelterbelts, regional ecological characteristics are taken into consideration when determining belt permeability, row spacing, row orientation, and particularly the selection of plant material. In species selection, poplars (*Populus nigra* and *P. euphratica*), eucalyptus (*Eucalyptus camaldulensis*), Mediterranean

Figure 4. Usage of windbreaks in agricultural areas (Nebraska, USA; URL-2)
Şekil 4. Tarımsal alanlarda rüzgâr perdelerinin kullanımı (Nebraska, ABD)

cypress (*Cupressus sempervirens*), and black locust (*Robinia pseudoacacia*) are prominent.

Along irrigation and drainage canals, cypress and black poplar species are established perpendicular to the prevailing wind direction, while *Populus euphratica* is preferred in saline areas. Along wide field margins, cypress is planted in the direction facing the wind, eucalyptus and/or poplar are used in the middle rows, and black locust is planted closer to the fields due to its nitrogen-fixing capacity. On the outermost edge of the windbreaks, shrub and small tree taxa suitable for medicinal and aromatic use in the region are preferred.

3.3. Integration of riparian woody taxa

An important field of activity within agroforestry practices is the presence of potential areas in the region for species such as poplar, willow, and Russian olive (*Elaeagnus angustifolia*), which can tolerate both arid and saline soil conditions. This also contributes to increasing agricultural crop yields to a certain extent. With the implementation of the GAP, agroforestry models in irrigable agricultural lands, particularly those based on poplar cultivation, are expected to enhance multipurpose production, including industrial crops, forage crops, vegetable cultivation, and fruit production (Kaya and Güney, 2014).

Özkahraman (1987) reports that in the Savur Valley of Mardin, approximately 7,000 ha are under black poplar (*Populus nigra*) cultivation, producing around 120,000 m³ of wood annually, of which approximately 50,000 m³ is exported to Middle Eastern countries. This is also significant in meeting the increasing demand for poplar wood driven by the expansion of agricultural production, thereby supplying demand from local resources.

Afforestation efforts along rivers and streams create protective and rehabilitative zones for both agricultural and residential areas. Such practices fulfill multiple functions, including the utilization of leafy branches, production of timber and fuelwood, enhancement of landscape quality, and conservation of biodiversity for flora and fauna. These applications not only prevent soil erosion in agricultural lands but also reduce the direct transfer of agricultural chemicals into streams, creeks, and rivers through runoff, thereby preventing water pollution (Turna, 2023).

When established in intercropping systems or in alternating rows integrated with agricultural crops, these models increase economic returns and diversify land use. For example, cultivating poplar rows in combination with watermelon, vegetables, or forage crops can achieve yields comparable to conventional agriculture; moreover, regular annual poplar harvesting provides a continuous income stream. Similarly, planting coniferous species such as cypress in strip arrangements among agricultural crops contributes significantly to mitigating potential climate change impacts through their windbreak function (Figure 5).

Such traditional practices represent successful examples of agrosilvicultural systems and are widely observed both in the region and throughout Türkiye (Turna, 2023).

Agroforestry practices based on forest tree species such as poplar and willow in the region will contribute to the production of timber and fuelwood, diversification of income through the cultivation of primary and secondary agricultural crops, the creation of favorable microclimatic conditions, improvements in soil health, and increases in rural employment and income levels.

There are also traditional agrosilvicultural systems that have long been practiced by local communities in Southeastern Anatolia. Examples include the integration of vineyards (grapes), pistachio, and dryland crops within gaps in forested areas- both on public (state-owned) and private lands- in provinces such as Adıyaman and Gaziantep, as well as the cultivation of grapes and tobacco within *Pistacia* species growing in sparsely distributed oak and juniper forest areas (Figures 6 and 7).

Figure 5. Cultivation of forest and fruit trees in rows among (right) and around (left) agricultural crops
Şekil 5. Tarımsal ürünler arasında (sağ)/etrafında (sol) sıralar halinde orman ve meyve ağaçlarının yetiştirilmesi

Figure 6. Agrosilvicultural practices in the Adıyaman province
Şekil 6. Adıyaman ilindeki agrosilvikültürel uygulamalar

Figure 7. Agroforestry practices in the Gaziantep province
Şekil 7. Gaziantep ilindeki tarımsal ormancılık uygulamaları

In Şanlıurfa, the establishment of windbreaks using black locust, Turkish red pine, and cypress around *Pistacia* species and vineyards may serve as a representative example. Within state-owned lands, combined production systems can be implemented between plantations of Turkish red pine (*Pinus brutia*) and Eldar pine (*P. eldarica*), incorporating grafted pistachio and olive trees, with crops such as cotton, wheat, field pea, lentils, and vegetables (onion, pepper, tomato, etc.) cultivated in the understory. These practices demonstrate that traditional methods can be integrated with scientifically supported modern agroforestry models (Turna, 2023).

A representative example of agrosilvicultural practice is presented in Figure 8. As observed, olive and pistachio trees are planted at wide (6×6 m or 5×5 m) spacings on privately owned land, with vineyards established between them and forest tree species

Figure 8. Multifunctional land use in the Diyarbakır and Siverek (Şanlıurfa) region
Şekil 8. Diyarbakır ve Siverek (Şanlıurfa) yöresinde çok amaçlı arazi kullanımı

such as Turkish red pine and pyramidal cypress planted along the margins. Naturally occurring oak species are preserved as scattered individuals throughout the site. In this way, the land is utilized multifunctionally, ensuring maximum productivity from all soil layers.

3.4. Silvopastoral systems

When examined in terms of livestock production, the region has gained significant potential in parallel with the diversity and productivity of agricultural crops. According to the GAP 2022 Progress Report (STB, 2022), although the livestock population in the region declined significantly during the 1995-2005 period, as observed nationwide, it began to recover after 2010. Data for the 2000-2022 period indicate increases in livestock numbers across the region, except for Angora goats (*Capra aegagrus hircus*). Compared to the year 2000, between 2000 and 2022 the cattle population increased by 129.68%, hair goats (*Capra*) by 127.15%, and sheep (*Ovis aries*) by 109.11%, while the Angora goat population increased by 64.72%.

In order to further enhance and diversify these developments in livestock production, the implementation of agroforestry models is of considerable importance. Through silvopastoral systems, livestock production can be supported by providing fodder resources and enabling controlled grazing in both natural and plantation areas. By planting regionally suitable tree, shrub (forest/fruit), and herbaceous taxa within rangelands, multifunctional use of the same land unit can be achieved (*horti-agri-silvicultural* activities and shade-based production). Taking into account the eco-silvicultural characteristics of the species in afforestation efforts increases the overall success rate of such systems.

The establishment of greenbelt afforestation along water bodies such as streams and rivers, combined with forage crops, enables the implementation of agrosilvopastoral systems. Such practices also provide opportunities for rural development through apiculture and aquaforestry, which represent important components of agroforestry.

Within the scope of non-timber forest products and ecosystem services, extensive work has been conducted on medicinal and aromatic plants, the cosmetics industry, bulbous ornamental plants, dye plants, and mushroom cultivation; however, it is emphasized that these activities should be further expanded.

Experimental trials conducted in Akçakale (Şanlıurfa) have successfully implemented the integration of Eldar pine, Mediterranean cypress (*Cupressus sempervirens*), black locust (*Robinia pseudoacacia*), and black poplar (*Populus nigra*) with forage crops such as alfalfa, clover, and couch grasses (Fidan and Güldaş, 2006).

Combinations of alfalfa in the initial years, followed by bromus and clover species in later years, yielded productive results. The establishment of black locust, Russian olive, poplars, and willow taxa along streambeds and floodplains contributes significantly to stream rehabilitation as well as to flora and fauna diversity. Such systems reduce fodder deficits, alleviate pressure on oak forests resulting from leaf harvesting for animal feed, increase soil organic matter, and contribute to livestock income.

3.5. Applicable agroforestry models for the Region

Agroforestry models applicable to the region are presented in Table 2. When the system-species relationships outlined in the Table are integrated with regional land capability classes and water resources, they visually and comparatively demonstrate the economic and ecological benefits of multilayered land use. Thus, the Table functions as a roadmap for decision-makers. Identifying the most suitable species combinations (e.g., pistachio-grape-cereal systems) for different agro-ecological conditions (of subregions) within the region, along with their associated ecological and economic benefits, is of critical importance.

Through agroforestry practices in the region, ecological benefits such as reducing soil erosion, combating salinity, and creating microclimatic conditions (wind, temperature, humidity, evaporation, and evapotranspiration); economic benefits such as income diversification, timber production, and export potential; social benefits such as increasing farmer income, reducing rural outmigration, and generating rural employment; and cultural benefits through the integration of traditional knowledge with modern practices can be achieved.

In agricultural lands lacking irrigation facilities, the crops and other species to be selected must be drought-tolerant (xerophytic). For example, existing or artificially established woody taxa (such as oak, juniper, mastic, mulberry, pine, and cedar) scattered individually or in small clusters within wheat-growing areas contribute to soil conservation, provide shade and resting areas for workers, and serve as shelter and nesting habitats for animals.

Table 2. Applicable agroforestry systems and suitable plant taxa for the Region
Tablo 2. Bölgede uygulanabilir agroforestry sistemleri ve uygun bitkiler

System type	Tree taxa	Agricultural crops	Livestock / Forage crops	Purpose
Agrosilvicultural	Poplar (*Populus*), willow (*Salix*), pistachio (*Pistacia*), and olive (*Olea europaea*)	Cotton, maize, vegetables	—	Integration of timber and agricultural crops
Silvopastoral	Eldar pine (*P. eldarica*), Cypress (*Cupressus*), Black locust (*Robinia pseudoacacia*), poplar (*Populus*)	—	Alfalfa, clover, brome, couch grass	Fodder support, reducing pressure on forests
Agrosilvopastoral	Oak (*Quercus*), pistachio, grapevine	Cereals, legumes	Small ruminant livestock	Multifunctional land use
Windbreaks	Cypress (*Cupressus*), Black locust (*Robinia pseudoacacia*), poplar (*Populus*), eucalyptus (*Eucalyptus*), casuarina (*Casuarina*)	Cotton, wheat, vegetables	—	Erosion control, microclimate regulation

In agrosilvicultural practices with broad implementation potential across the region, agroforestry applications can be employed in drought-exposed and degraded areas to promote soil conservation and enhance water retention capacity. In addition to the use of windbreaks in the cultivation of industrial crops, greater caution and more intensive management practices are required in areas with partially sloping and more sensitive soil structures (Figure 9).

As in Figure 9, in sparsely vegetated areas where agricultural activities are carried out in fragmented parcels, the introduction of irrigation water enables the cultivation of vineyards among fruit trees such as olive, almond, pistachio, and apricot, along with nitrogen-fixing forage crops planted between them. Considering the region's extensive implementation potential, the exemplary land-use models applied in the İrem Vineyards located on the foothills of Mount Ağrı can be regarded as a successful example for agroforestry practices. Spring and autumn views of these applications are presented in Figure 10 (Turna, 2023; URL-3). Such land-use models not only enhance the landscape value of the area but also attract numerous tourists to the region.

Figure 9. Traditional agricultural practices in the Diyarbakır and Siverek (Şanlıurfa) region
Şekil. 9. Diyarbakır ve Siverek (Şanlıurfa) yöresinde geleneksel tarım faaliyetleri

 

Figure 10. Summer (left) and autumn (right) views of the agroforestry model integrating poplar and vineyards (Ağrı-İrem Vineyards)
Şekil 10. Kavak+ üzüm bağlarının birlikte uygulandığı tarımsal ormancılık modelinin yaz (sol) ve sonbahar (sağ) görünümleri (Ağrı-İrem Bağları)

Along the boundaries, poplar, willow, and Russian olive trees are planted, while a wide range of fruit and vegetable crops- primarily apricot, apple, peach, grape, cherry, and maize- are cultivated. Moreover, the unique autumn landscapes characterized by shades of yellow, brown, green, and red contribute to ecotourism, while also providing habitat for numerous fauna species. As illustrated in Figure 11, the land-use pattern shown in Figure 10 and widely observed in the region clearly demonstrates the seasonal dynamics and the contribution of agroforestry to recreation and ecotourism potential.

Water erosion on sloping and relatively steep lands should be minimized through measures that reduce surface runoff rates and velocity, such as strip cropping, contour planting, crop rotation, mixed cropping (intercropping systems), agroforestry practices, contour-based slope barriers (e.g., grass strips, terraced soil and stone bunds), terracing and its maintenance, as well as grassed waterways or vegetated buffer (protective) strips (Turna, 2023).

Indeed, a study entitled “Rehabilitation and Silvopastoral Utilization Opportunities of Degraded Oak Coppice Forests in Eastern Anatolia” (Fidan et al., 2007) suggests that, in degraded oak stands, instead of afforestation, it is more appropriate to utilize the gaps between stools by establishing high-quality forage species such as smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), bird’s-foot trefoil (*Lotus corniculatus*), and salad burnet (*Sanguisorba minor*).

The example presented in Figure 10 is particularly significant in terms of proper land evaluation. Through intensive agroforestry practices aligned with land capability classes, ecosystem services can be maximized while simultaneously contributing to rural development- especially food production- and implementing soil and water conservation measures (Turna, 2023).

Figure 11. Comparison of land-use patterns ((Ağrı-İrem Vineyards)
Şekil 11. Arazi kullanımlarının kıyaslanması ((Ağrı-İrem Bağları)

In summary, the implementation of agroforestry systems in the region could:
- Increase resilience to climate change processes; agroforestry models make significant contributions to land conservation, particularly against irregularities in temperature and precipitation. Windbreaks are of critical importance in mitigating the adverse effects of wind and storms on agricultural crops and soils, as well as on public health and safety.

- Regulate soil and atmospheric humidity; under open-field conditions, wind in particular accelerates soil drying, promotes topsoil loss through wind erosion, and increases evaporation. Tree taxa provide a shelter effect that mitigates these negative impacts.

- Facilitate the utilization of deeper soil layers; agricultural crops generally exploit only the upper 20-30 cm of soil, which may lead to surface crusting and salinization while limiting soil aeration. In contrast, forest trees develop root systems extending to depths of 80-100 cm (even shallow-rooted species reach 30-40 cm) and in some cases up to 150 cm, thereby enabling the use of deeper soil horizons.

Through agroforestry models, multiple benefits can be achieved, including contributions to soil organic matter accumulation, enhancement of the region's aesthetic and recreational value, provision of support structures for fruit and vegetable cultivation, supply of fuelwood and, to some extent, timber for rural communities, support for animal feed production, opportunities for poplar-based intercropping systems, and enhancement of biodiversity.

Another area type with considerable agroforestry implementation potential in the region is urban areas and their surroundings. Turna et al. (2025b) emphasize that the design and implementation of landscape projects in urban and peri-urban green spaces are of great importance, particularly for city planners and other specialists. In a rapidly developing and changing world, lands located within and around cities must be evaluated in a multifunctional and efficient manner. As in developed countries, urban green areas of Türkiye can be structured according to agroforestry models, enabling the maximization of potential productivity either simultaneously or in sequential phases. This issue is especially significant in greater municipalities such as Diyarbakır, Şanlıurfa, and Gaziantep. The initial and advanced stages of an agroforestry model with high implementation potential in the region are presented in Figure 12.

Figure 12. Agroforestry models applicable in the region
Şekil. 12. Bölgede uygulanabilecek agroforestry modelleri

4. Discussion and Conclusion

4.1. Discussion

The Southeastern Anatolia Region holds strategic importance for the implementation of agroforestry systems due to the intensity of agricultural production, the limited extent of forest resources, and the fact that rural livelihoods largely depend on agriculture. However, existing practices are predominantly based on traditional knowledge, and scientifically grounded modern agroforestry applications have not yet been sufficiently developed.

In arid and semi-arid regions of the countries, agroforestry has long been utilized due to its benefits in addressing growing food challenges, preventing erosion, conserving soil moisture, increasing crop diversity, and contributing to rural development. When climate change scenarios are taken into account, the steadily increasing food demand accelerates soil degradation and environmental problems, posing serious threats to long-term agricultural productivity.

Soil, which is of critical importance for food production, is a non-renewable and limited resource that is increasingly being depleted due to unsustainable land-use practices. Healthy soils play a fundamental role in poverty reduction and food security by enhancing crop productivity and strengthening resistance to pests and diseases (FAO, 2017; Hou et al., 2020).

In windbreak systems supported by *Albizia* and *Acacia* species implemented on India's Deccan Plateau, cotton and wheat yields increased by 15-20% per hectare, generating an additional annual income of approximately 120-150 USD/ha (Garrity, 2004; Nair, 2012). Similarly, *Faidherbia albida*-based silvopastoral systems in the African Sahel have increased soil organic carbon stocks by up to 25%, directly contributing to food security (Place et al., 2012).

Agrosilvicultural models proposed for the Southeastern Anatolia Region- such as oak-pistachio-grape or poplar-vegetable integrations- have the potential to provide comparable advantages in terms of carbon sequestration capacity and long-term income generation.

In Latin America (Brazil and Colombia), shade trees integrated into coffee and cocoa plantations have been shown to enhance carbon sequestration capacity over a 30-year period and increase annual income by an average of 18% (Leakey, 2012). Similar potential applications in the GAP Region could be realized through strip planting of tree species such as poplar and willow and their integration with fruit and vegetable production within agrosilvicultural systems. Such practices would not only increase farmers' income at the local level but also contribute to the conservation of biodiversity.

According to the climate projection report of the Turkish State Meteorological Service (mgm.gov.tr), under the RCP4.5 scenario, annual average temperatures across Türkiye are expected to increase by 1.5-2.6 °C by the 2050s, while under the RCP8.5 scenario, increases of 2.5-3.5°C are projected. Regional assessments for the Southeastern Anatolia Region, encompassing the Tigris-Euphrates Basin, indicate that summer temperatures may rise by 2.5-3 °C and total annual precipitation may decrease by 5-10% (MGM, 2023; Demircan et al., 2015).

These climatic conditions suggest that windbreak systems with high water retention capacity, together with deep-rooted poplar and willow-based systems, will play a critical role in supporting regional agriculture. Moreover, poplar-based agroforestry applications are estimated to yield an average annual wood production of 8-10 m³ per hectare and, under current market conditions, provide an internal rate of return of approximately 10-12%. These findings demonstrate that agroforestry systems offer not only ecological benefits but also a strategic solution for sustainable economic development.

Islam et al. (2013) emphasize that agroforestry systems present a promising and sustainable alternative through the integration of trees with crops and/or livestock on the same land unit, thereby contributing to improved livelihoods, enhanced climate resilience, and strengthened food and nutrition security. Studies by Allen et al. (2004) and Mukhlis et al. (2022) further indicate that agroforestry practices can rehabilitate degraded lands and enhance ecosystem services by improving soil properties through leaf litter inputs and root activity.

These examples suggest that the windbreak systems, poplar-based applications, and silvopastoral models proposed for the Region could yield similar outcomes if developed in accordance with the region's ecological conditions.

4.2. Conclusion

The Southeastern Anatolia Region has become one of Türkiye's most important agricultural centers through the opportunities provided by the GAP Project, despite its ecological constraints. However, the intensity of agricultural production and the limited extent of forest resources make the development of agroforestry practices a necessity. The region:

- The expansion of irrigation opportunities through the GAP has created favorable conditions for the implementation of agroforestry systems.
- The integration of forestry components of D.G. Forestry into the agricultural pattern dominated by cotton, wheat, lentils, and vegetable production will provide both ecological and economic benefits. Agroforestry practices can reduce rural outmigration by increasing rural employment. Crop-timber-livestock combinations will diversify farmers' income sources and strengthen economic resilience.
- Poplar and willow cultivation represent priority areas for the expansion of region-specific agrosilvicultural systems. Poplar and willow production should be promoted through private sector initiatives and cooperatives.

- Windbreaks will play a critical role in addressing erosion, salinity, and land degradation problems. Farmers should be provided with seedlings and technical support for establishing windbreaks and shelterbelts. It should be clearly communicated through scientific evidence that windbreaks do not result in land loss but rather contribute to long-term yield increases. Farmers should also be trained in irrigation techniques, especially by the Ministry of Agriculture and Forestry, to prevent salinization and land degradation. Owing to both its climatic constraints and the irrigation advantages provided by the GAP Project, the Southeastern Anatolia Region occupies a distinctive position. In particular, the need for windbreaks and shelterbelts is more urgent in this region compared to others.

- Silvopastoral systems can enhance rural incomes by providing fodder support for livestock while simultaneously reducing pressure on forest resources. Long-term experimental plots should be established to identify tree and shrub species suitable for the region. Optimal combinations of trees, forage crops, and livestock should be investigated for silvopastoral systems.

- Agrosilvicultural practices (such as pistachio-grape-cereal combinations) in degraded oak areas should be supported. Buffer zones with fast-growing species should be established along irrigation and drainage canals. In this way, sustainable land management can be achieved.

In summary, the Region, with its high agricultural production capacity and the advantages provided by the GAP Project, constitutes one of the most critical areas in Türkiye for the implementation of agroforestry systems. In this region, agroforestry is not merely an alternative land-use option but also a strategic instrument for sustainable development, ecosystem restoration, and the enhancement of rural welfare.

The rapid increase in land degradation associated with land-use practices in Türkiye necessitates the development of multidimensional, urgent, and long-term strategic interventions. In this context, it is recommended to expand sustainable land management approaches based on ecological integration, such as the use of organic fertilizers, biofertilizers, crop rotation, and intensive agroforestry applications.

These practices can make significant contributions to restoring soil fertility and improving soil structure, thereby reducing dependence on synthetic inputs. Furthermore, the development of educational programs aimed at increasing farmers' knowledge and awareness, together with institutional and policy-level support for these processes, is considered a critical requirement for safeguarding soil health and strengthening agricultural sustainability in the long term.

Authors' contributions

Main idea/Planning: İ. Turna - Data collection and analysis: İ. Turna, D. Güney, F. Atar - Literature review: İ. Turna, H. Turna- Review and correction: İ. Turna, F. Atar, H. Turna, E. Atar

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