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# Afforestation of arid and semiarid ecosystems in Turkey

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**Abstract:** Sustainable management of arid and semiarid forests requires careful planning and implementation. Afforestation by planting and seeding is a fundamental tool for the establishment of new forests on barren landscapes and restoration of degraded forests in arid and semiarid ecosystems. In afforestation efforts, the consideration of site preparation, selection of species, seed source, and planting methods pose a number of ecological and economic challenges. Possessing one of the world's richest floras, Turkey suffered from heavy degradation during the last millennia. Some studies suggested that forests and steppes once covered 60%–70% and 10%–15% of the Anatolian landscape, respectively. Growing population, overgrazing, clearance for agriculture, fires, excessive timber harvesting, and misuse of lands led to a 26% reduction in the forest area. The Turkish Forest Service completed 2.3 million ha of afforestation and 1.2 ha of erosion control works, mostly in semiarid landscapes. This article presents an assessment of afforestation activities in the semiarid and arid regions of Turkey and is a review of the efforts exerted during the period 1945 to 2014.

**Key words:** Afforestation, desertification, ecosystem management, restoration, site preparation

## 1. Introduction

Human settlement within the current boundaries of Turkey dates back to almost 10,000–11,000 YBP (Zohary, 1969; Aschmann, 1973; Boydak et al., 2006). Deforestation in the arid and semiarid regions was followed by the formation of anthropogenic forests to anthropogenic steppes. Where degradation continues, steppes can turn into "anthropogenic deserts" across a wide range of landform features: plains, plateaus, or rugged mountains and hills (Boydak, 1997; Boydak and Çalışkan, 2015). Soils in most of these barren lands were compacted by over 50 years of intensive grazing accompanied by topsoil loss caused by water and wind erosion. Despite centuries of human activity, ninety percent of the forests in Turkey are 'native' (not planted) in origin and contain over 450 tree and shrub species (Mayer and Aksoy, 1998; Çolak and Rotherham, 2006).

The Anatolian landscape was composed of 60%–70% forest and 10%–15% steppe 4000 years ago (Davis, 1965–1988). The OGM (2014) stated that overgrazing, overcutting, fires, agriculture clearing, wars, and other misuse of the land have decreased the forest area to 26% while increasing the steppe area to 24% (Mayer and Aksoy, 1998; Çolak and Rotherham, 2006), but Uslu (1959) claimed that about half of the steppes in Central Anatolia are "anthropogenic." Despite these differences, it is probable that up to half of the steppes in the Central Anatolia region possess "anthropogenic" characteristics (Boydak and Çalışkan, 2014, 2015).

Forestlands in Turkey are thought to have declined from 50 million ha (Ürgenç, 1998) prior to human settlement to 21.7 million ha by 2012 (Boydak and Çalışkan, 2014). The Turkish Forest Service has afforested 3.5 million ha of land since 1945 mainly in the arid and semiarid regions, thereby enlarging the country's forest area. According to the 2014 report by the Turkish Ministry of Forest and Water Affairs, Turkey's forest area increased by about 1.5 million ha from 1972 to 2012. On the other hand, the current annual raw wood material consumption was about 40.7 million $m^3$ in 2014 (Boydak and Çalışkan, 2014).

Turkey is one of the major floral regions in the world, with more than 12,000 taxa of herbaceous and woody species, of which 3500 species are endemic (Ekim et al., 2000). Turkey contains three important main vegetation zones and intersections of these zones: Euro-Siberian, Irano-Turanian, and Mediterranean vegetation zones (Figure 1). The rich vegetation in Turkey is because of its geographic location and the different climate and subclimate types. Turkey is located in the transition of temperate and tropical climates, containing the Asian continental and Eastern Mediterranean zones (Oliver, 1983; Boydak et al., 1995). The many climate and

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subclimate types, marine, continental, and Mediterranean climates, and their transition zones are caused by the morphological features.

In arid and semiarid regions, many ecological, biological, technical, and socioeconomic constraints affect afforestation. Ecological conditions in arid and semiarid regions are usually extreme, with unsuitable climatic and soil conditions. Technical practices must be carefully and patiently done to ensure success. In addition, socioeconomic and political constraints may have more severe impacts on afforestation and natural revegetation than the ecological processes do.

The United Nations Convention to Combat Desertification defined drought as "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" (UNCCD, 1994). The United Nations Food and Agriculture Organization (FAO) provided a more specific description and defined arid regions as areas with precipitation less than 300 mm and semiarid regions as regions receiving precipitation between 300 and 600 mm (Goor, 1963; Ürgenç, 1998; Boydak and Çalışkan, 2015).

In Turkey, arid areas are most commonly delimited using the formulation of Erinç (1965) based on precipitation and temperature. Index values, climate types, and vegetation cover are shown in Table 1. According to Erinç's "Drought Indices Average Annual Area Map" (Figure 1), arid and semiarid areas cover about 35% of Turkey. Sixty percent of the country's total land area is covered by a combination of the above-described areas combined with areas dominated by dry-subhumid conditions (Türkeş, 1990; Boydak and Çalışkan, 2015). Table 1 and Figure 1 show desert steppe vegetation in a small area in the very south of Turkey but most of the country is covered by steppe vegetation, dry forests, and humid forests according to Erinc's classification. Perhumid forests are also seen in the northeastern part of the country. There were also shifts in aridity index classifications in Turkey from humid conditions in the 1960s to dry subhumid climatic conditions in the early 1990s (Türkeş, 1999). Similarly, semidry areas increased and very humid areas decreased from 1991 to 2006 (Deniz et al., 2011).

The United Nations FAO defined afforestation as turning an area that has not been covered by a forest for at least 50 years into forest land through planting (FAO, 1967; Savill et al., 1997; Mansourian, 2005). In addition to planting for wood production, this term also covers planting trees for aesthetics or soil protection on nonforested lands outside the forest production areas. Such plantings include agricultural areas or other lands that belong to the treasury, municipality, or other public and legal entities and are located around towns and cities, and other settlement areas that are distant from forests.

This study presents an assessment of afforestation activities carried out in the semiarid and arid regions of Turkey. First, past decisions on natural vegetation and land use in the semiarid and arid regions of Turkey are explored. Then ecological, biological, technical, and socioeconomic constraints of afforestation in these areas are discussed. Then silvicultural principles of afforestation in semiarid and arid regions are evaluated based on the goals of afforestation projects. Specific steps of selection of species, preparation of sites, spacing of plants, and tending of plantations are discussed.

## 2. Afforestation practices in Turkey

The first sand dune afforestation with stone pine (*Pinus pinea*) was implemented by the Romans on the coastline of Antalya-Belek-Serik (Köprüçay) within the scope of a large-scale afforestation project to prevent dune expansion. Roman efforts led to currently self-sustaining forests where successful sand dune fixation was achieved while the farmlands were protected. There are still 129-year old stone pine trees that remain undamaged and that are side by side with young trees (Boydak and Çalışkan, 2014). The Ottoman Empire undertook only minor afforestation

**Table 1.** Climate types according to Erinç's precipitation efficiency formula (Erinç, 1965).

| Indices values and climate types | Vegetation cover |
|---|---|
| <8 Hyperarid | Desert |
| 8–15 Arid | Desert steppes |
| 15–23 Semiarid | Steppe |
| 23–40 Subhumid | Park looking dry forest |
| 40–55 Humid | Humid forest |
| >55 Perhumid | Perhumid forest |

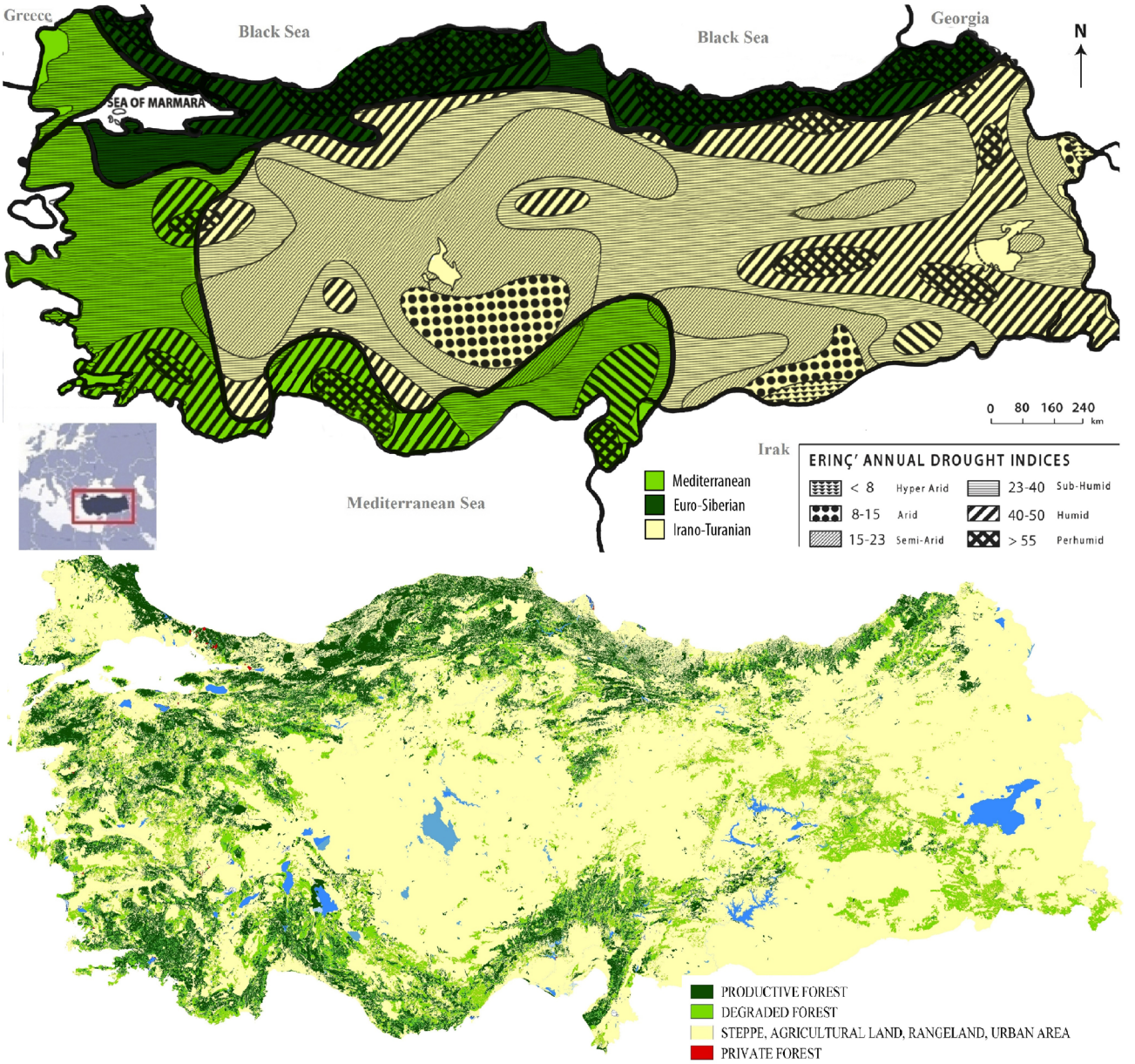


**Figure 1.** Above: Phytogeographical regions of Turkey: Euro-Siberian, Mediterranean, and Irano-Turanian (modified from Davis et al., 1971 and Çolak and Rotherham, 2006) and Erinç's Drought Indices Annual Average Area Map of Turkey (Türkeş 1990). Below: Productive and degraded forests together with other land use types (courtesy of General Directorate of Turkish Forestry).

measures until the enactment of the Forestry Regulation in 1870. However, the comprehensive Ottoman archives reveal that some small-scale activities were carried out during or prior to that period (Diker and İnal, 1945; Bingöl, 1990a; Bingöl, 1990b; Ürgenç, 1998; Günay, 2003). After World War II, afforestation was performed in a well-organized, planned, and comprehensive scope; 4924 ha of afforestation was performed using 4.9 million seedlings by 1955 (Ürgenç, 1998). The year 1955 was a milestone for Turkey when extensive afforestation activities were commenced (Figure 2).

Full-range broadcast seeding of Lebanon cedar (*Cedrus libani*), which was initiated in karstic areas of Mersin-Anamur-Armutkırı in the Taurus Mountains, resulted in the re-establishment of 206,000 ha of these forests from 1984 to 2015. These relatively localized efforts were important because they extended forests in the subhumid, partially arid, and semiarid climate regimes that were

A B

**Figure 2.** A: Planting 1-year-old bare-rooted seedlings of *Pinus brutia* using planting bars on terraces prepared by man power, Keşan 1967) (photo: courtesy of Keşan Forestry Enterprise). B: Thinning application in a *Pinus brutia* plantation at the age of 12 (Keşan) (photo: M. Boydak).

common across large areas of Turkey (Boydak, 1986; Boydak and Ayhan, 1990; Boydak and Çalıkoğlu, 2008; Boydak and Çalışkan, 2014). The Turkish Forrest Service had afforested 2.3 million ha and carried out erosion control works on an area of 1.2 million ha (rehabilitation and restoration) mostly in the semiarid regions by late 2014. Afforestation areas have been steadily increasing (OGM, 2014).

Table 2 shows the success of afforestation efforts mostly in the semiarid areas from 2002 to 2012. The success of afforestation was determined by the survival rate of plants in every 10th row throughout the plantation area. The areas where planting survival was below 40% (12% of the area) were completely replanted, while interplanting to replace dead trees was applied where the survival rate was between 40% and 60% (23%).

**3. Ecological, biological, technical, and socioeconomic constraints of afforestation in the semiarid and arid areas of Turkey**

Ecosystems in arid and semiarid regions are fragile. Ecological conditions are usually extreme, with low precipitation, high temperatures and evaporation rates, shallow and stony soils, low organic matter, erosion hazard, and soil compaction often caused by excessive grazing. Much of the soils across the semiarid and arid forested regions of Turkey commonly have high lime content. High $CaCO_3$ can lead to seedling chlorosis and excessive high pH reduces plant-available iron and manganese (Boydak and Çalışkan, 2014, 2015). Atmospheric moisture is lower in the most arid systems, with relative humidity typically in the Southeast Anatolian region ranging from 20% to 25% and possibly lower in some years (Ürgenç,

**Table 2.** Success of afforestation primarily in semiarid areas of Turkey from 2002 to 2012*.

| | | | Success of afforestation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of projects | Total area (ha) | 0–10 % | 11–20 % | 21–40 % | 41–60 % | 61–70 % | 71–80 % | 81–100 % | Success of afforestation < 60% | Success of afforestation > 60% |
| Area | 1763 | 867,538 | 9309 | 30,957 | 61,525 | 202,658 | 141,827 | 186,405 | 234,857 | 304,448 | 563,090 |
| Percentage within the total area | | | 1 | 4 | 7 | 23 | 16 | 22 | 27 | 35 | 65 |

*Statistic Data of General Directorate of Turkish Forestry

1998). In addition to these environmental challenges, there are difficulties in providing adequate seed quality and quantity from suitable provenances for afforestation, especially when selecting species originating from the anthropogenically maintained steppe areas (Boydak and Çalışkan, 2015).

Afforestation practices in arid and semiarid regions are expensive investments requiring knowledge, patience, and continuity. At the same time, they are praiseworthy due to their high returns and benefits to the nature and society. The highest cost item in the afforestation of arid and semiarid regions in Turkey is weeding and soil cultivation by labor or mechanization; therefore, more economical approaches are adapted taking into account the research findings.

Deforestation of arid and semiarid regions is closely associated with low income and poor educational background of the local population. Forest villagers are in the lowest income category. Therefore, afforestation efforts that do not involve rural people are perceived by local people as a problem (like elimination of their grazing land) rather than a solution. Such socioeconomic and political constraints may have more severe impacts on afforestation and natural revegetation than do ecological processes (Sene, 1996; Boydak, 1997; Boydak and Çalışkan, 2015).

Despite these challenges, the Forest Organization Eastern Anatolian Watershed Rehabilitation Effort recently supported 3610 projects in 88 catchment areas encompassing 350 villages and 11 provinces that simultaneously addressed agricultural, forestry, and related land-use issues. The result was the implementation of integrated watershed management practices across 3.7 million ha by 2007 (Boydak and Çalışkan, 2015).

## 4. Silvicultural principles of afforestation in semi-arid and arid regions

The silvicultural practices explained below are the direct result of research into the ecological, technical, and socioeconomic conditions of the arid and semiarid deforested areas of Turkey. Afforestation in Turkey is usually implemented in anthropogenic steppes with severe ecological conditions or in more suitable lands within the anthropogenic steppes. Although afforestation was done in the past in these limited rangelands, afforestation activities are currently forbidden in rangelands. In the arid and semiarid regions of the country, the objectives of afforestation are soil conservation, erosion control, regulation of water regimes, and improvement of wild life. However, there are also certain areas with deep soils and precipitation of 400–600 mm where the goal of afforestation is wood production.

The primary purpose of afforestation in arid and semiarid regions is to conserve soil and water, which can be described as "afforestation for erosion control." There are, however, also second and third site class areas suitable for classical afforestation where reasonable amounts of wood can be harvested. Moreover, some areas require special attention. Either plantation or seeding can be used for afforestation of arid regions depending on the ecological and biological conditions (Boydak and Çalışkan, 2014, 2015).

### 4.1. Afforestation by planting in semiarid and arid regions

Afforestation of arid and semiarid regions involves the selection of species, preparation of the sites, spacing, planting or seeding, and tending of the plantations.

#### 4.1.1. Selection of species

Because of the restricted water conditions, careful attention is paid to the selection of species and provenances. This selection is also important for wildlife and grazing. Some tree and shrub species in Table 3 serve the wildlife and grazing aim as well.

Tree, shrub, and bush species to be planted in arid and semiarid regions should be capable of developing a taproot rapidly. Drought-resistant exotic species could be used provided their suitability has been proven through appropriate adaptation trials (Gezer and Aslan, 1980; Aslan, 1984; Işık et al., 2002). Exotic species are used in limited areas. Today the modern approach is to respect the native flora of Turkey, which is in practice. Tree and shrub species that are resistant to arid and semiarid conditions and capable of fixing nitrogen should considered by regional authorities since they may contribute significantly to organic matter content and soil fertility. For example, nitrogen-fixing species such as Russian olive can significantly contribute to the N pool (Yildiz et al., 2017). Multipurpose species that also provide nonwood products have several advantages.

Using native species from the local provenance, if available, increases the success of restoration significantly; however, if relict forest stand seed sources are not present in the nearby area, seed performances of the desired species originating from sites that have similar climate and soil conditions can be used after they are positively assessed in controlled plot experiments before widespread use. In particular, collection of the seeds from native species in suitable sites (bordering anthropogenic and natural steppes, with similar exposures and altitude (±50–100 m)) contributes significantly to the success of afforestation (Boydak and Çalıkoğlu, 2008).

Results of seed origin trials are also taken into account. The Forest Research Institutes performed seed origin experiments with native *Pinus brutia*, *Pinus nigra*, *Cedrus libani*, *Pinus sylvestris*, and *Cupressus sempervirens* both inside and outside of their natural ranges and obtained

**Table 3.** Species that can be suggested for the afforestation of the arid and semiarid regions in Turkey (Uslu, 1970; Odabaşı and Boydak, 1984; Yaltırık, 1984; Boydak, 1986; Ürgenç, 1998; Yildiz et al., 2017).

| Central Anatolia | North of Southeastern Anatolia, south of Eastern Anatolia | Southern parts of Southeastern Anatolia |
|---|---|---|
| *Acer monspessulanum* | *Ailanthus glandulosa*[2] | *Acacia melanoxylon*[2] |
| *Ailanthus glandulosa*[2] | *Cedrus libani* | *Acer monspessulanum*[4] |
| *Berberis vulgaris*, *B. crataegina* | *Celtis tournefortii* | *Acer negundo*[2,3], *A. syriaca*[3] |
| *Calligonum polygonoides* | *Crataegus aronia*, *C. monogyna* | *Amygdalus arabica*[2] |
| *Celtis tournefortii* | *Haloxylon persicum*[2] | *Anagyris foetida*[4] |
| *Crataegus aronia*, *C. monogyna* | *Juniperus* spp. | *Capparis ovata* var. *palaestina*[4] |
| *Elaeagnus angustifolia* | *Pinus nigra* subsp. *pallasiana* | *Celtis tournefortii* |
| *Haloxylon persicum*[2] | *Pinus sylvestris* | *Cerasus microcarpa*[4] |
| *Juglans regia* | *Pistacia terebinthus* | *Cercis siliquastrum* |
| *Juniperus* spp. | *Prunus amygdalus*, *P. mahaleb* | *Ceratonia siliqua* |
| *Malus communis* | *Pyrus elaeagnifolia* | *Cornus sanguinea* subsp. *sanguinea*[4] |
| *Morus alba*, *M. nigra* | *Robinia pseudoacacia*[2] | *Elaeagnus angustifolia* |
| *Paliurus spina-christi* | *Quercus* spp. | *Fraxinus oxyphylla*[3] |
| *Pinus nigra* subsp. *pallasiana* | | *Fraxinus angustifolia* subsp. *syriaca*[3] |
| *Pistacia terebinthus* | | *Haloxylon persicum*[2], *H. aphyllum*[2] |
| *Platanus orientalis*[1] | | *Juglans regia* |
| *Populus* spp.[1] | | *Juniperus* spp. |
| *Prunus* spp. | | *Pinus brutia*, *P. eldarica*, |
| *Pyrus elaeagnifolia* | | *Pinus halepensis*, *Pinus pinea* |
| *Robinia pseudoacica*[2] | | *Pistacia khinjuk*[4] |
| *Quercus* spp. | | *Pistacia terebinthus* |
| *Tamarix* spp. | | *Platanus orientalis*[1] |
| *Thuja orientalis*[2] | | *Populus* spp.[1] |
| | | *Rhamnus punctatus*[4] |
| | | *Rhus coriaria*[4] |
| | | *Prunus amygdalus*, *P. mahaleb* |
| | | *Pyrus elaeagnifolia* |
| | | *Salix* spp.[1] |
| | | *Ulmus pumila*[3] |
| | | *Quercus* spp. |

[1] On lands along rivers and streams; [2] Exotic species; [3] Recommended by Ürgenç (1998), [4] Recommended by Yılmaz et al. (2013)

preliminary assessment results (Dağdaş, 1998; Işık et al., 2002; Çalıkoğlu et al., 2010). Turkey faces some challenges in finding appropriate seed sources for the afforestation of arid and semiarid areas, especially the anthropogenic steppes. In this case, seeds are transferred from areas that are ecologically similar. Priority is given to the native tree and bush species while some drought-resistant exotic species are also used. Similarity between the ecological conditions and examples of successfully planted species are taken into account as the main criteria for the selection of exotic species (Boydak et al., 1995).

Many different species have been successfully used in Eastern, Southeastern, and Central Anatolia. As a result of research, tree and bush species used or recommended for use in three regions covering the arid and semiarid areas of Turkey are presented in Table 3 (Uslu, 1970; Odabaşı and Boydak, 1984; Yaltırık, 1984; Boydak, 1986; Ürgenç, 1998; Yildiz et al., 2017).

Climate change may affect the seed sources of provenances in the long term. On the other hand, afforestation in arid and semiarid areas increases carbon sequestration and mitigates climate change.

**4.1.2. Preparation of afforestation sites**

Grazing in the barren areas (areas where woody plants such as tree and bush species are rare or absent) and degraded forestlands, especially within the semiarid regions in Turkey, leads to partial soil erosion. Grazing causes soil compaction, which reduces soil aeration and water infiltration, decreases biological activity, and increases surface runoff. However, in such compacted soils, circulation is very slow; therefore, the seedlings will not be able to grow adequately unless appropriate soil tillage is performed.

Three-year results of research carried out with *Pinus nigra* at a site in Eskisehir-Musaözü reveal that the highest water retention was achieved where the clearing of ground vegetation by rake on the whole area was followed by deep soil cultivation with a ripper (Figure 3) or ripper plough and then treated with a disc harrow (Zoralioğlu, 1990). This study's results are similar to results obtained from a second experimental site established in the Eskişehir-Karasakal area (Boydak and Zoralioğlu, 1992). In both experimental sites, survival rates and average height growth of containerized seedlings were significantly greater than those of bare-root seedlings. Furthermore, average survival rates of both containerized and bare-root seedlings were significantly greater at the Eskişehir-Musaözü site where weeding operations were implemented compared to the Eskişehir-Karasakal site where no weeding was applied (Zoralioğlu, 1990; Boydak and Zoralioğlu, 1992).

Results from a research study on semiarid lands around Lake Eymir in Ankara showed that cultivation of soil on terraces to a minimum depth of 45 cm had a great impact on seedling survival rates (Büyükduman, 1977). The main purposes of soil cultivation in semiarid regions are to increase soil aeration and to store rainwater inside the soil as much as possible through full-range, mid-depth, or deep soil cultivation (45–80 cm) before planting. After planting, shallow soil cultivation (10–15 cm) increases soil infiltration and reduces soil water loss, increasing the time and amount of water available to seedlings (Zoralioğlu, 1990; Boydak and Zoralioğlu, 1992; Ürgenç, 1998). Since capillaries in the surface soil are broken, water does not move to the surface and evaporate. Water moves through capillary action only at the root level and thus can be consumed by plants for a longer time (Çepel, 1982). These cultivation treatments are important for seedling survival and growth in semiarid areas prone to prolonged dry and hot summer conditions. *Pinus halepensis*, *Pinus brutia*, *Pinus pinea*, *Pinus elderica*, *Pinus nigra*, and *Cupressus sempervirens* were planted on the Şanlıurfa-Gölpınar and Gaziantep-Dülükbaba experimental sites. Survival rates were higher and height growth was 3–4 times higher on deep cultivated soils compared to shallow native soils (Aslan, 1984). Twenty to twenty-five-cm-high container seedlings had a positive contribution to the success of afforestation in arid and semiarid regions, as was also supported by other research (Zengin and Karakaş, 2006). Seven-year results of *Cedrus libani* seedlings established in semiarid areas of Antalya-Korkuteli-Yelten (annual precipitation: 382 mm) and Burdur-Bucak-Ürkütlü (annual precipitation: 673 mm, slightly more than the semiarid region's average precipitation) suggest that polyethylene-tubed cedar seedlings (10 × 25 cm) are more suitable for afforestation sites in semiarid and arid regions compared to other bare rooted and Enso-type seedlings (Erkan and Aydın, 2010).

In principle, existing living vegetation in arid and semiarid afforestation sites should be preserved because it is very difficult to establish plantation forests that could adapt to arid and semiarid sites as well as natural vegetation. In Turkey, deep soil cultivation is performed on the whole area before planting and shallow soil cultivation is performed at the beginning of the dry season after planting. Moreover, absorption terraces are constructed on sloped lands by machinery where slopes permit (Figures 3 and 4). On the other hand, planting of mycorrhizal inoculated containerized seedlings with well-developed root-to-stem ratios increases plant survival (Boydak and Çalışkan, 2014, 2015).

**4.1.3. Spacing**

The planting spacing used for afforestation in Turkey is shown in Table 4. The table presents general spacing values determined from both spacing studies conducted in Turkey and observations in afforestation practices (Pamay, 1969; Boydak, 1982, 1992). Spacing can be adjusted depending on the ecological conditions and species. The spacing should be adjusted according to the following principles for arid and semiarid regions.

In arid and semiarid regions, the main factor that affects spacing is the first intermediate objective. In conventional afforestation, commercial evaluation of the first thinning yield or establishment of canopy closure under certain circumstances constitutes the first intermediate objective (Boydak, 1982). The canopy closure criterion is also very important in arid and semiarid regions. Furthermore, the narrowest limit for spacing is determined by economic conditions and the widest limit by tree quality (Evert, 1971, 1973; Boydak, 1982, 1992). Since precipitation is usually a limiting factor in semiarid and arid regions, wider spacing is considered than in less arid areas.

In Turkey, different combinations of trees and shrubs have been used for the afforestation of arid and semiarid regions, mainly for soil and water conservation (erosion control) purposes or for rehabilitation of degraded forest areas (Figure 5). Such species combinations are expected to provide tree cover over most land after a while (e.g., in 10–15 years). Thus, the direct impact of rainfall on soil surface


**Figure 3.** A: Complete ripping with a three tine ripper. B: Gradoni (terrace) construction with a two furrow ripper plow (Nevşehir-Avanos). C and D: Terrace construction with a tine mounted on an excavator (Mersin-Mut). E: Construction of terraces on steep slope with a spider. F: Construction of terraces (100–180 cm width and 50–80 cm depth) in steep slope with a mini excavator (photos: courtesy of the General Directorate of Combating Desertification and Erosion-ÇEM).

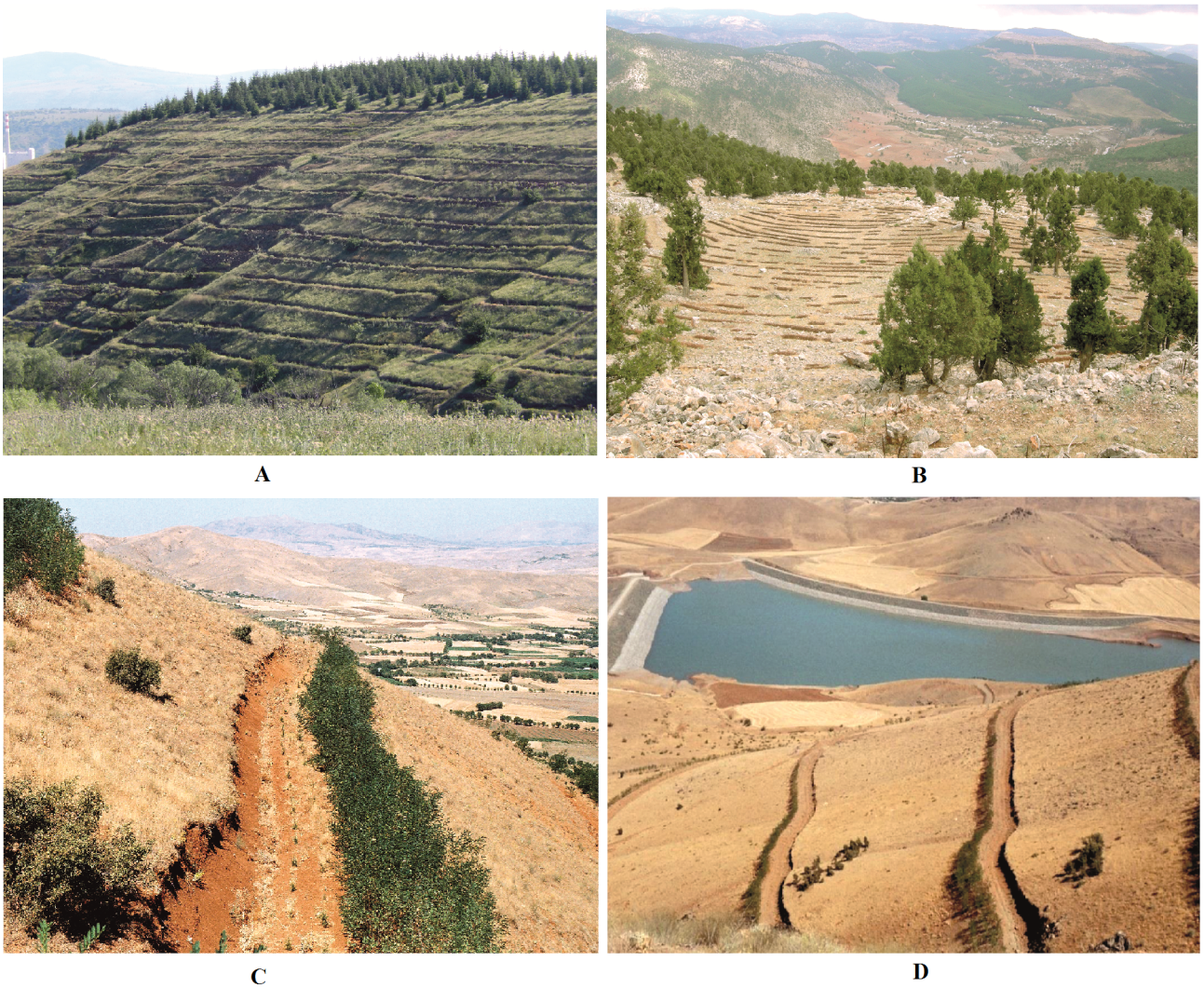


**Figure 4.** A: View of terraces constructed by mini excavator (Eskişehir-İnönü) (photo: S. Çalışkan). B: Discontinuous terraces (Mersin-Tarsus) (photo: courtesy of the General Directorate of Combating Desertification and Erosion-ÇEM). C and D: Wide terraces. These terraces are suitable for erosion control but not for afforestation (Elazığ-Sivrice) (photo: M. Boydak).

**Table 4.** Tree spacing that can be applied in the classical type of plantations established on sites with higher precipitation and deeper soils than semiarid areas in Turkey (Boydak and Çalışkan, 2014, 2015).

| Species | Spacing |
|---|---|
| Black pine (*Pinus nigra*) | 3 × 1.5 m or maximum 3 × 2 m |
| Scots pine (*Pinus sylvestris*) | 3 × 1.5 m or maximum 3 × 2 m |
| Lebanon cedar (*Cedrus libani*) | 3 × 1.5 m or maximum 3 × 2 m |
| Turkish red pine (*Pinus brutia*) | 3 × 2 m, maximum 3 × 3 m |
| Aleppo pine (*Pinus halepensis*) | 3 × 2 m, maximum 3 × 3 m |
| Oak species (*Quercus* spp.) | 2 × 1.5 m, 3 × 1 m maximum 2 × 2 m, 3 × 1.25 m |
| Other broadleaved species | 3 × 3 m, maximum 3 × 4 m |

A B

**Figure 5.** A: Turkish red pine (*Pinus brutia*) afforestation in the Southeastern Anatolia Region. This afforestation site was irrigated during the first two years (Urfa-Ceylanpınarı) (photo: M. Boydak). B: A plantation established with *Pinus nigra* on partially fertile soils in a semiarid area. Elazığ-Pincirik (photo: M. Boydak).

and the carriage of soil particles by runoff can be reduced. Studies have revealed that planting different combinations of plants contributes not only to the effectiveness of erosion control but also to the generation of multipurpose products and other benefits from such plantations (Acar et al., 2006).

In semiarid regions, different approaches can be applied for spacing depending on precipitation and ecological conditions (Boydak and Çalıkoğlu, 2008; Boydak and Çalışkan, 2014). Two appropriate approaches are as follows:

First approach: Specific locations in arid and semiarid regions may have favorable conditions such as higher annual precipitation and positive physiographic and edaphic conditions (e.g., shaded exposures, moist air flows, flat or slightly sloped landscapes, deep soils, and others), which compensate for the negative effects of aridity to a certain extent. The existing spacing on such areas (classical afforestation sites in the semiarid zones) in Turkey is not made wider because of the high mortality rates of seedlings on such areas. On slopes where terrace construction is necessary, the horizontal distance between terraces can be expanded up to 3.5 m.

Second approach: Usually for soil conservation and water regulation purposes in semiarid region plantations to be established on poor soils or near the anthropogenic steppe border, terrace distances can be arranged around 4–5 m and distance between the plants can be increased depending on the conditions. Where erosion is a concern, tree and bush combinations can be created and the spacings are narrowed to diminish erosion. These and similar approaches are applied taking into consideration the site-specific conditions.

**4.2. Afforestation by seeding in arid and semiarid regions**

Afforestation by sowing seeds is commonly and successfully realized with *Quercus* spp. and *Cedrus libani* in the arid–semiarid and arid–semihumid regions of Turkey (Figures 6 and 7). Findings (Aslan, 1988; Uğurlu and Çevik, 1991; Taşdemir and Karatay, 2007) recommend that deep soil cultivation be performed during rehabilitation and restoration with oak species in Eastern, Central, and Southeastern Anatolia regions by sowing at a depth of 5–10 cm, depending on the species. Afforestation by sowing with oak species is more successful than planting. Sowing is commonly performed on large areas by complete ripping, especially in the Eastern and Southeastern Anatolia regions (Figure 6).

In 1984, afforestation through full-range broadcast seeding with seeds enclosed in carpels was successfully performed in barren karstic sites within the semiarid and arid–semihumid areas in the Taurus mountain range. The sites had been formed by the degradation of *Cedrus libani* forests and the intent was to reforest the area with *Cedrus libani* (Boydak, 1986, 1996; Boydak and Ayhan, 1990; Boydak and Çalıkoğlu, 2008). The results of accompanying studies showed that shallow, middepth, and deep soil cultivation could increase the survival rate significantly in karstic areas whose soils were suitable for cultivation. Moreover, the target tree survival could be achieved using fewer seeds per unit area (Çelik et al., 2005; Boydak and Çalıkoğlu, 2008).

**Figure 6.** Seedlings emerged by sowing acorns (Elazığ-Sivrice). A: Spot seeding on terraces (photo: C. Orhan). B: Spot seeding on strips (photo: M. Boydak).

Barren karstic sites in the Taurus Mountains were also successfully revegetated with broadcast seeding of carpel-enclosed seeds of Lebanon cedar (*Cedrus libani*). This cheap and effective technique resulted in forest re-establishment of about 206,000 ha across a wide range of climate conditions and represented the collaborative efforts of academic researchers and land-use managers.

### 4.3. Tending of the plantations

An important difference between the afforestation of arid (<300 mm MAP) and semiarid regions (300–600 mm MAP) is the great need to irrigate through the first two years in the former, while such irrigation is not often needed to establish forests in the latter. In both cases, essential biological and technical measures need to be taken (Ürgenç, 1998; Boydak and Çalışkan, 2014). In afforestation areas where site tending is carried out by machines for 3 to 5 years after planting, the soil should be cultivated at a depth of 10–15 cm by disc harrowing between the planting lines, competing shoots and weeds should be cleared, and the capillary system of the soil should be broken. Manual weeding operations by hoeing should be performed on the planting lines and on strips extending 25–40 cm on both sides of the planted seedlings. Such applications decrease evapotranspiration. In the first year, hoeing and piling soil around the root collar of the seedlings increase the survival rates. During the first and second growing seasons, tending young seedlings can be reported twice a year. Weeding is needed at least during the first 3 to 5 years on sites prepared (terrace and gradoni construction) manually. It is appropriate to apply weeding operations on the whole terrace surface. Tending is applied as a rule in all afforestation activities in semiarid and arid regions as well as classical and industrial plantations in Turkey.

## 5. Conclusion

The aims of afforestation in arid and semiarid regions of Turkey are soil conservation, erosion control, and regulation of water regimes. Wood production can also be a goal in certain areas with deep soils and MAP of 400–600 mm. On the other hand, agroforestry or agrosilvopastoral systems should be applied instead of afforestation in arid regions because of the severe ecological conditions.

Socioeconomic constraints also have severe impacts on afforestation and natural revegetation. Deforestation of arid and semiarid regions is closely associated with low income and poor educational background, and forest villagers are in the lowest income category.

Although arid and semiarid regions are fragile ecosystems, anthropogenic steppe areas that are formed as a result of forest destruction can be reforested. If not afforested/reforested, degraded arid and semiarid ecosystems can further deteriorate and ultimately result in desertification caused by continuing human impacts. As degradation processes unfold, local communities can become increasingly impoverished to the point that people may be forced to leave the area.

The goal of afforestation in arid and semiarid areas must be clearly defined taking in the ecological condition, since the goal will determine the choice of species. Spacing should be decided by considering land fertility; precipitation; expected mortality rates of planted seedling, combinations


**Figure 7.** A: Seeding on strips established by tine mounted on an excavator (Mersin-Mut) (photo: Courtesy of the General Directorate of Combating Desertification and Erosion-ÇEM). B: Area prepared by complete ripping by ripper for broadcast seeding on bare karstic land (Mersin-Erdemli) (photo: courtesy of the General Directorate of Combating Desertification and Erosion-ÇEM). C: Application of broadcast seeding in *Cedrus libani* on snow (Mersin-Fındıkpınarı) (photo: M. Gözükara). D-Application of broadcast seeding in *Cedrus libani* on bare karstic land before the first snow fall in autumn on deep cultivated soil (Mersin-Fındıkpınarı) (photo: M. Gözükara).

of tree, shrub and perennial pasture plant species to plant; and thinning options and their timing. Proper selection of native species and provenances is essential. The use of high quality seeds and high quality seedlings with well-developed root and stem ratio, and planting of preferably mycorrhizal inoculated containerized seedlings increase plant survival. Appropriate site preparation through deep cultivation of soil by machinery, wider planting distances, timely planting operations, shallow soil cultivation for 3 years after planting, and implementation of replacement and other silvicultural treatments when necessary are the key factors for success. Furthermore, timely application of tending operations is also important. Failure in some of the very dry years should not discourage foresters of semiarid and arid regions.

Human impact that results in deforestation of arid and semiarid regions in Turkey is closely associated with low income and poor educational background. The know-how acquired through the studies conducted in arid and semiarid regions and experienced foresters contribute significantly to the restoration and reforestation of especially anthropogenic steppe areas. From the socioeconomic perspective, afforestation efforts in the arid and semiarid regions of Turkey are successful and reduce the erosion problems. These benefits will increase in the future.

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