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# Tree Growth, Plant Diversity, and Soil Properties as Affected by Floodwater Spreading in an Arid Region of Iran

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**ABSTRACT**

**Aims:** So far, no specific study has been conducted on the selection of suitable species in the floodwater spreading projects of the country. This research aims to achieve this goal for ecosystem restoration in a floodwater-spreading area in western Iran. In this regard, soil characteristics, plant biodiversity, growth status, and tree survival will be considered.
**Materials & Methods:** In the floodwater spreading area, three pure tree stands and a mixed tree stand, as well as a non-afforested area, were chosen; outside the floodwater spreading area, a non-afforested area (control) was considered. The afforested stands were 15 years old and included *Eucalyptus camaldulensis*, *Prosopis juliflora*, and *Ziziphus spina-christi*. At each location, tree growth, plant diversity, and soil properties (0–25 cm) were measured.
**Findings:** Fifteen years after planting, in the flood-spreading area, all pure and mixed stands improved organic matter (2-4 times), nitrogen (3-6 times), and phosphorus (1.5-2 times) compared to the control area. The biggest tree height was related to *E. camaldulensis* (5.8 m), and the highest standing volume was also observed for *E. camaldulensis* (16.5 $m^3.ha^{-1}$), followed by *P. juliflora* (3.2 $m^3.ha^{-1}$). The crown cover of *E. camaldulensis* and *P. juliflora* was 3-3.3 times larger than that of *Z. spina-christi*. The survival rate of *P. juliflora* (77%) was higher than *that of E. camaldulensis* (63%) and *Z. spina-christi* (69%). The seedling mortality could be due to inadequate soil moisture in some years. In pure tree stands under floodwater, the Diversity (0.25 times) and Richness indices (0.24 times) were higher than those in the control area. These two variables in the non-afforested area were greater (0.15 and 0.34 times, respectively) than in the control area. In the *E. camaldulensis* stand (0.88) and *the P. juliflora* stand (0.87), the evenness index did not significantly differ from that in the control area (0.84).
**Conclusion:** All three tree species were relatively successful in terms of survival and growth in the floodwater spreading area. Thus, for the restoration and development of afforestation, improvement of soil fertility, and vegetation cover in such dry, low-rainfall regions, the use of these three species, either pure or mixed, is recommended in floodwater-spreading areas.

**Keywords:** Basal Area; Plant Diversity; *Prosopis juliflora*; Survival Rate; *Ziziphus spina-christi.*

**CITATION LINKS**

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## Introduction

The construction of flood distribution networks on alluvial fans, plains, and sandy lands is one of the methods recommended for utilizing floods, especially for afforestation in arid and semi-arid regions. In general, the entry of a large volume of floodwater containing salts and abundant suspended loads by depositing abundant sediments over time causes significant changes in the physical-chemical properties of the primary soil and its fertility [1, 2, 3, 4]. Also, it leads to quantitative and qualitative changes in vegetation cover, increases biodiversity and species richness, and promotes the growth of afforested species [5, 6, 7, 8]. On the other hand, by controlling seasonal floods and using them effectively, it is possible to reduce the risks posed by flood flows, land destruction, and erosion, while also providing the water needed for agriculture. Of course, although it is not possible to control all floods, damage can be minimized through proper management [9].

The importance of flood spreading in relation to soil resources is that the deposition of suspended matter on young soils of eroded lands fertilizes the soil of those areas [1]. Another fact is that trees primarily affect the soil, and the effects of different species on the soil differ [10]. In addition, tree species affect vegetation cover, and this effect depends on the age and type of the tree species present [8, 11]. In arid regions where potential evaporation is several times greater than precipitation, spreading floodwater and soil infiltration can significantly reduce water loss. The term flood spreading in aquifers has been chosen because floods spread water across alluvial fans and alluvial plains (consisting of coarse-grained sediments). Its goals are the creation of wooded pastures, afforestation, restoration of environmental resources, improvement of coarse-grained soils, and, finally, the artificial recharge of groundwater in large volumes to increase the ability to exploit these resources for the prosperity and development of agriculture in arid and semi-arid regions [3]. In other words, spreading floodwater into an aquifer is a simple way to exploit sediment-laden floods that would otherwise be inaccessible. Since floods are thought to be rich in nutrients, they can effectively fertilize alluvial cones and floodplains composed of coarse-grained sediments, enabling their economic exploitation. For example, floods can be used to irrigate annual and perennial crops, rangeland plants, shrubs, and trees, as well as to store water in aquifers and subsurface reservoirs. In addition, by controlling and exploiting rapids and floods, human and financial losses caused by them in agricultural lands, urban, and rural areas can be prevented [5].

Given the importance of floodwater spreading in arid regions and the need to select appropriate species to restore these areas, research into its impact on arid-region watersheds is essential. This is why, to date, no specific study has been reported in the literature on selecting suitable species for the country's floodwater spreading projects. For this reason, for the first time, the present study in the Mousian floodplain area (located in the arid region of western Iran) is aimed to find more suitable tree species for the restoration of this area by planting the trees *Ziziphus spina-christi, Prosopis juliflora*, and *Eucalyptus camaldulensis*, while determining the physical and chemical characteristics of the soil, plant biodiversity, and the growth and survival status of the trees. We hypothesized that *Eucalyptus camaldulensis* would grow faster than the other two tree species in the flood-spreading area and would be better able to restore the area in the short term.

## Materials & Methods

The research site is located in the floodplain of Mousian (Dehloran city, Ilam province, western Iran) (Figure 1). The site study is situated in an arid zone, with a latitude of 32˚30' to 32˚32' and a longitude of 47˚30' to 47˚32', between the Doviraj and Chikhav rivers. The altitude is 180 m above sea level. The flood-mitigation project covered 3,500 hectares and was implemented in 2005. In this year, in a part of it, afforestation was carried out with *E. camaldulensis, P. juliflora,* and *Z. spina-christi,* both pure and mixed (mixture of three species), with a planting distance of 7 m × 7 m (Figure 2).

The region is influenced by a moderate-to-severe hot desert climate, with an mean annual rainfall of 235.2 mm and an mean annual temperature of 26.4°C. The critical dry period lasts approximately 8 months, from early April to November [12]. (Figure 3). The soil texture is sandy and loamy-sandy. The most important geological formations of the basin, from ancient to modern, include the Aghajari formations, the Bakhtiari conglomerates, and the Quaternary alluvial deposits [12]. It is worth noting that after the implementation of the floodwater spreading, a total of 40 floods occurred.

For this investigation, floodwater-spreading areas were selected, with 10 ha of afforestation and an area without afforestation. Additionally, a non-afforested area was chosen outside the floodwater-spreading basin (as a control). Afforestation involved 15-year stands of

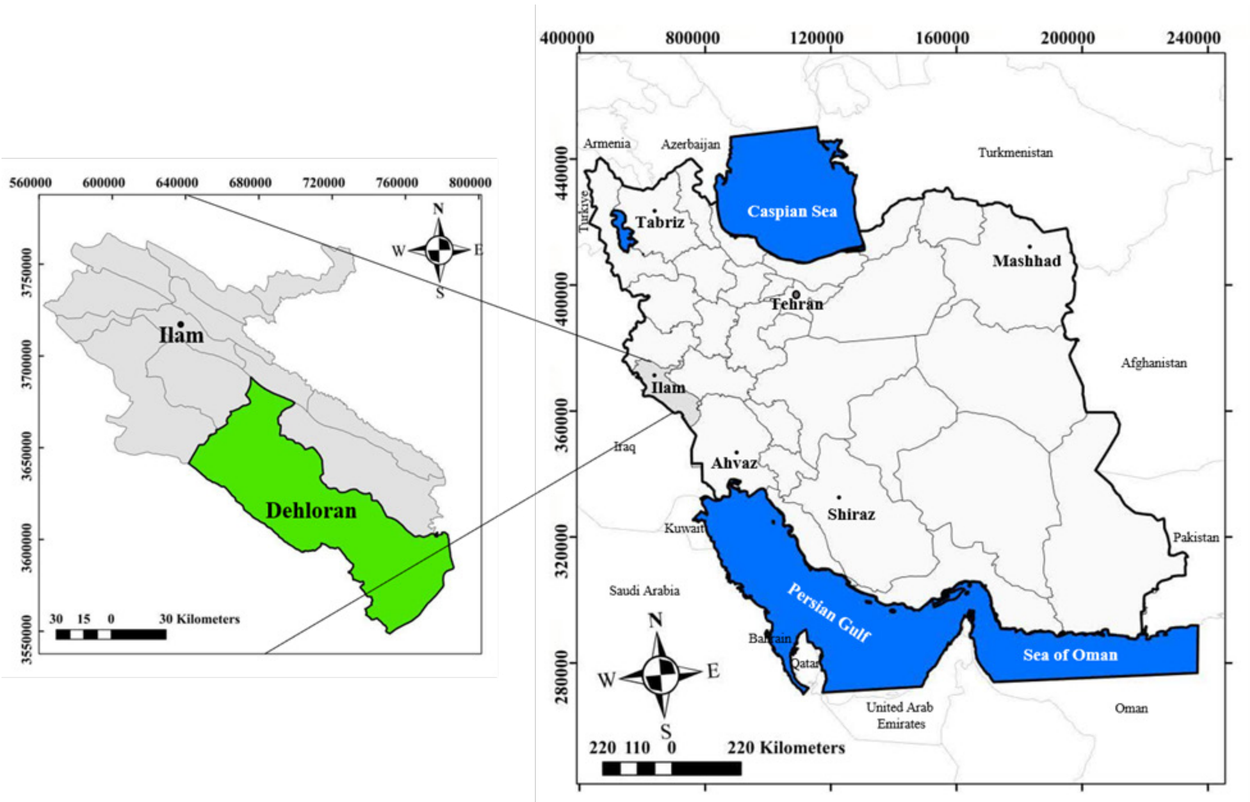


**Figure 1)** The situation of the studied region (green) in the map of Iran.

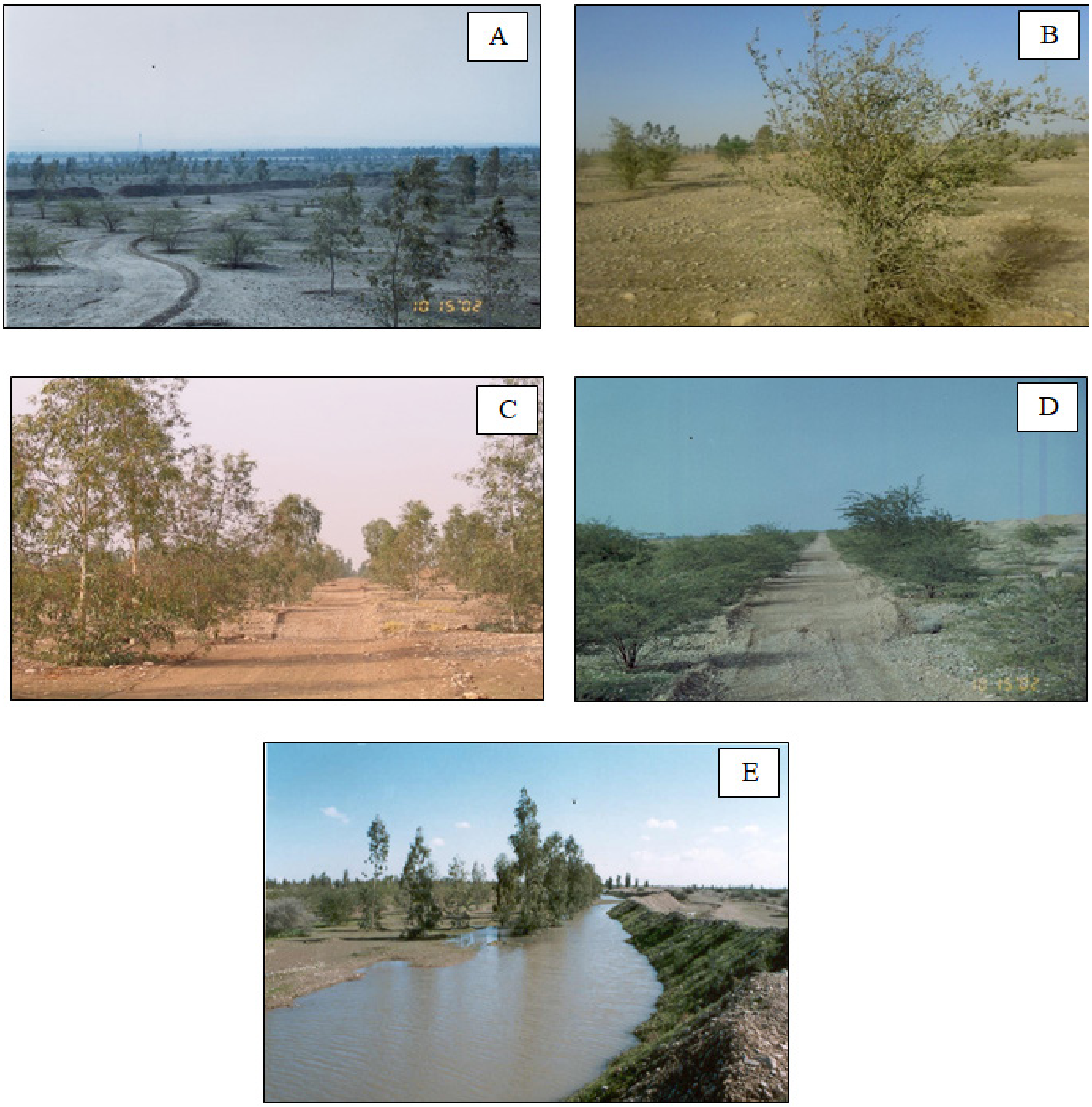


**Figure 2)** The trees grown in the floodwater spreading area of the study site.

*Eucalyptus camaldulensis*, *Prosopis juliflora*, and *Ziziphus spina-christi*. Using a systematic-random method within each stand, eight 30 m × 30 m sample plots were selected for measuring tree height, diameter at breast height, crown diameter, and canopy cover. The survival rate of each species was calculated by counting the number of trees that survived at the end of the period (15 years), dividing by the number of trees planted at the beginning of the period, and multiplying by 100.

Within the sample plots of 30 m × 30 m, 10 sub-plots of 1 $m^2$ were selected to determine the percentage of herbaceous cover. Tree species names and densities of each tree species were recorded in each subplot to determine the Indices of Shannon-Wiener diversity, Margalef richness, and Pielou evenness [13]. Additionally, four soil samples from the 0-25 cm depth were collected at the corners of each plot (30 m × 30 m) to obtain a mixed sample. Soil samples for N, P, C, Ca, K, EC, C/N, percent lime, and soil texture were collected in each plot [14].

In the soil laboratory (Faculty of Natural

Resources and Marin Science, Tarbiat Modares University), soil reaction (pH) was measured using the distilled water method (water to soil ratio 1:2.5), electrical conductivity with an electrical conductivity meter, calcium with a Flame Photometer, organic carbon with the Walkley-Black method, total nitrogen with the Kjeldahl method, soil absorbable phosphorus using a spectrophotometer, and soil exchangeable potassium using a Flame Photometer.

**Statistical Analysis**

After collecting the data, it was stored in EXCEL software as a database. Data analysis was performed using SPSS 11.5 software. For this purpose, data normality was assessed using the Kolmogorov-Smirnov test, and homogeneity of variance was assessed using the Levene test. Then, one-way analysis of variance (ANOVA) and Tukey's mean comparison test were used. Plant diversity indices were calculated using Past. 4.12 software.

A view of the reforested floodplain (A), *Ziziphus spina-christi* stand (B), *Eucalyptus camaldulensis* stand (C), *Prosopis juliflora* stand (D), water stored behind the dam, and the growth of reforested trees (E).

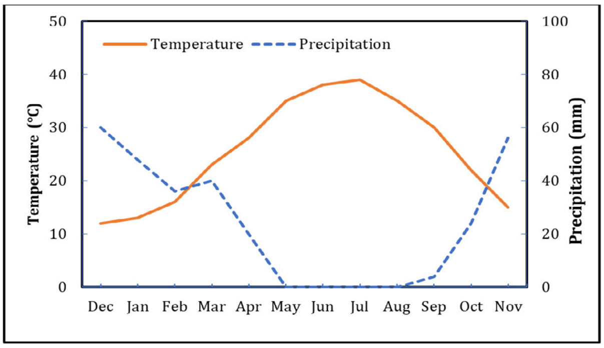


**Figure 3)** Ombrothermique curve of the study area.

## Findings

Fifteen years after planting, in the flood-spreading area, all pure and mixed stands improved organic matter (2-4 times), nitrogen (3-6 times), and phosphorus (1.5-2 times) compared to the control area. The percent of clay and silt aggregation in the flooded and control areas did not differ significantly (Table 1).

In flooded areas, survival of *P. juliflora* (77%) was higher than *E. camaldulensis* (63%) and *Z. spina-christi* (69%) (Figure 4-A). The crown cover of *E. camaldulensis* and *P. juliflora* was higher than *that of Z. spina-christi* (Figure 4-B). Diameter at breast height (Figure 4-C), height (Figure 4-D), basal area (Figure 4-E), and volume (Figure 4-G) of *E. camaldulensis* were higher than those of *P. juliflora and Z. spina-christi*. In fact, the volume of *E. camaldulensis* was approximately 16 times greater than that of *Z. spina-christi* and 5 times greater than that of *P. juliflora* (Figure 4-H).

In pure tree stands under floodwater, the Diversity (0.25 times) and Richness indices (0.24 times) were higher than those in the control area (Figure 5-A and 5-B). These two variables in the non-afforested area were greater (0.15 and 0.34 times, respectively) than in the control area (Figure 5-A and 5-B). Richness index in non-afforested flood spreading areas was higher than that in afforested flood spreading areas (Figure 5-B). In *the E. camaldulensis* stand (0.88) and *the P. juliflora* stand (0.87), the evenness index did not significantly differ from that in the control area (0.84) (Figure 5-C).

In pure tree stands under floodwater, the Diversity (0.25 times) and Richness indices (0.24 times) were higher than those in the control area. These two variables in the non-afforested area were greater (0.15 and 0.34, respectively) than in the control area. In the *E. camaldulensis* stand (0.88) and *the P. juliflora* stand (0.87), the evenness index did not significantly differ from that in the control area (0.84).

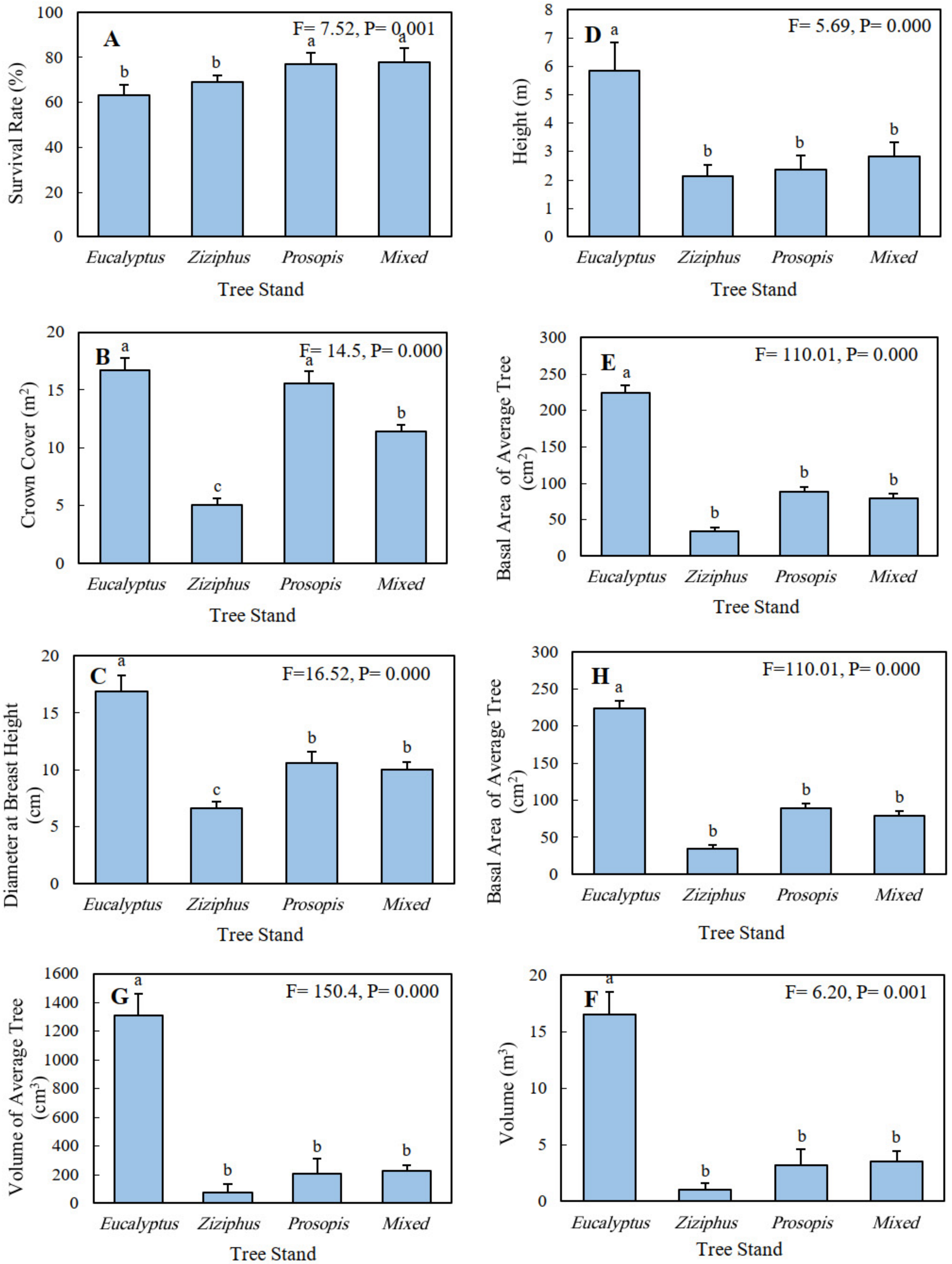


**Figure 4)** Comparison of means (± standard deviation) of growth variables among the flooded tree stands.

**Table 1)** One-way Anova (F and P values) and comparison of means (Tukey test) of soil properties among the flooded tree stands, flooded non-afforested area, and control area (out of the flood spreading area).

| Variable | Flood Spreading Area | | | | | Control Area | F-Value | P-value |
|---|---|---|---|---|---|---|---|---|
| | *Eucalyptus* | *Ziziphus* | *Prosopis* | Mixed Stand | Non-Afforested Area | | | |
| pH | 7.7$^{a}$ | 7.7$^{a}$ | 7.5 $^{bc}$ | 7.4$^{c}$ | 7.6$^{b}$ | 7.8$^{a}$ | 10.71 | 0.000 |
| EC (ds.m$^{-1}$) | 0.15$^{a}$ | 0.10$^{c}$ | 0.15$^{a}$ | 0.14$^{ab}$ | 0.12$^{bc}$ | 0.11$^{c}$ | 6.82 | 0.000 |
| Organic Matter (%) | 2.16$^{a}$ | 1.10$^{b}$ | 1.77$^{a}$ | 1.80$^{a}$ | 1.73$^{a}$ | 0.55$^{c}$ | 9.49 | 0.000 |
| N (%) | 0.06$^{ab}$ | 0.04$^{b}$ | 0.08$^{a}$ | 0.073$^{a}$ | 0.03$^{b}$ | 0.01$^{c}$ | 11.6 | 0.000 |
| C/N | 21$^{b}$ | 14.42$^{b}$ | 12.83$^{b}$ | 16.08$^{b}$ | 34.49$^{ab}$ | 55.79$^{a}$ | 3.11 | 0.000 |
| P (mg.g$^{-1}$) | 15.54$^{a}$ | 5.75$^{bc}$ | 7.17$^{b}$ | 15.01$^{a}$ | 4.90$^{c}$ | 4.32$^{c}$ | 68.93 | 0.000 |
| K (mg.g$^{-1}$) | 22.68$^{bc}$ | 21.18$^{bc}$ | 30.37$^{ab}$ | 33.75$^{a}$ | 24.31$^{bc}$ | 15.12$^{c}$ | 4.78 | 0.020 |
| Ca (mg.g$^{-1}$) | 123.37$^{a}$ | 48.02$^{c}$ | 126.21$^{a}$ | 115.03$^{a}$ | 83.86$^{b}$ | 93$^{b}$ | 51.47 | 0.000 |
| Mg (mg.g$^{-1}$) | 18.52$^{a}$ | 13.75$^{b}$ | 18.86$^{a}$ | 18.74$^{a}$ | 17.45$^{a}$ | 15.10$^{b}$ | 9.80 | 0.000 |
| Lime (%) | 29.47$^{a}$ | 17.70$^{d}$ | 21.66$^{c}$ | 25.62$^{b}$ | 14.68$^{e}$ | 21.35$^{c}$ | 41.82 | 0.000 |
| Clay (%) | 10.37$^{ab}$ | 11.62$^{a}$ | 9.50$^{ab}$ | 11$^{ab}$ | 10.37$^{ab}$ | 7.87$^{b}$ | 4.35 | 0.003 |
| Silt (%) | 30.25 | 29.25 | 27.87 | 27 | 29.37 | 26.87 | 0.395 | 0.850$^{ns}$ |
| Sand (%) | 59.37 | 59.12 | 62.62 | 62 | 60.25 | 65.50 | 1.01 | 0.420$^{ns}$ |

ns: Nonsignificant

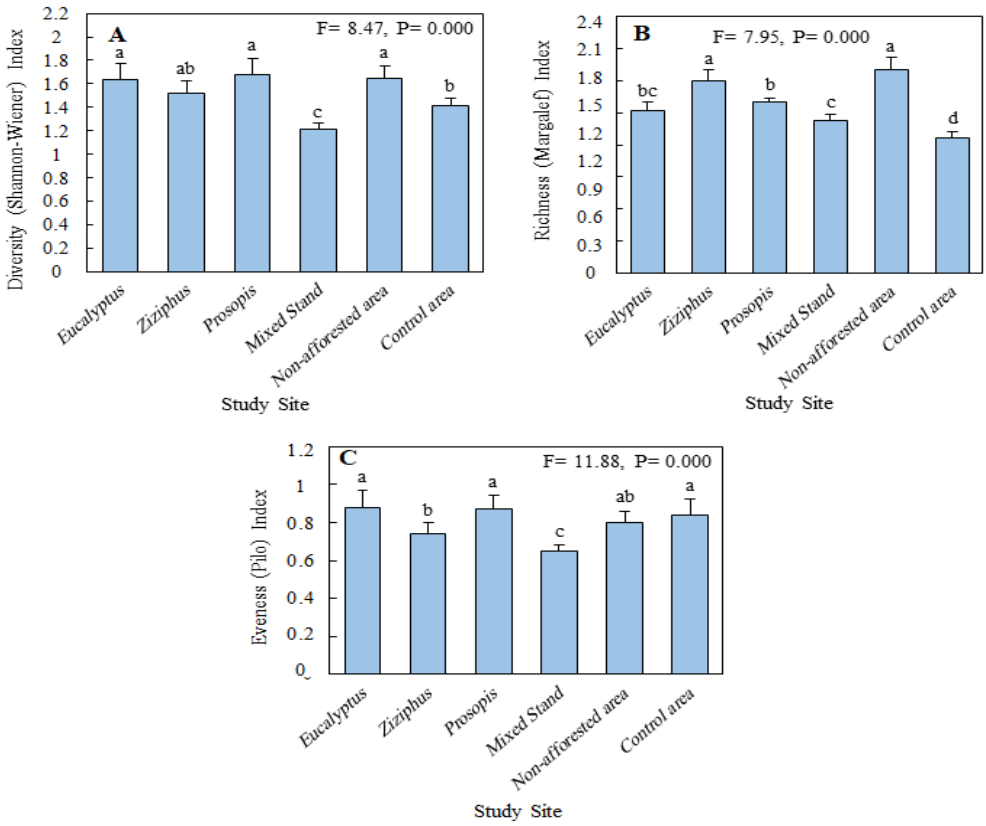


**Figure 5)** Comparison of means (± standard deviation) of vegetation diversity indexes among the flooded tree stands, flooded non-afforested area, and control area (out of the flood spreading area).

## Discussion

In the present study, in the non-forest floodplain area, compared to the control area, soil organic matter and nitrogen increased by 3 times, potassium by 1.5 times, and magnesium by 1.2 times, while soil acidity decreased slightly. In this regard, studies by other researchers [15,16] indicated increases in organic matter and nitrogen, and decreases in soil acidity, in the flood-spreading area. Similarly, an increase in calcium and magnesium in the floodplain of Gareh Bygon of Fars province [1], and after 10 years in this station, there was an increase in nitrogen, calcium, and phosphorus [4]. This is why, in the floodplain of Ab Barik in Bam (Kerman Province), no change in nitrogen levels was detected, but potassium and phosphorus increased [3]. The findings of other reports also indicated improved soil fertility due to flood spreading area [1, 2, 3, 17, 18].

In our study, no significant difference was observed in the percentage of silt and sand particles between flood-spreading areas with and without afforestation (and the control). However, similar to the findings in other investigations [4, 19], in our investigation, in the flood-spreading area, soil texture (due to sedimentation of fine-grained suspended particles, especially clay) improved compared to the control area. In parallel research [2], an increase was reported in the amounts of silt and clay in the flood-spreading area (2.3 and 1.9 times, respectively) and a decrease in the amount of sand (2 times) compared to the control area. In general, flood spreading can improve the soil's nutrient absorption by increasing the percentage of fine particles.

In the current study, afforestation with *P. juliflora* was more favorable for electrical conductivity, organic matter, nitrogen, phosphorus, calcium, magnesium, and lime than in the flood spreading area without afforestation. This indeed confirms the vital role of tree species in improving soil characteristics [20]. On the contrary, the soil of the control area (outside the flood spreading area) had more salinity and lower organic matter, nitrogen, phosphorus, potassium, and clay percentage than the soil of the afforested areas in the flood spreading area [21]. Although each of the planted species acted differently in terms of soil richness, the pure stands of *P. juliflora* and *E. camaldulensis*, and the mixed stand formed more fertile soil in terms of nutrients than the pure *Z. spina-chrisi* stand.

In our research, afforested species in flooded areas increased soil nutrient levels, so that *E. camaldulensis* and *P. juliflora* stands had better soil fertility than the Z. *spina-chrisi* stand. Some studies have shown that *Eucalyptus* trees perform better than other tree species. For example, in an investigation, a twofold increase in phosphorus was detected in *Eucalyptus* stands compared to *Albizia* stands [20]. Conversely, in other reports, *Eucalyptus* species are blamed for degrading soil and inhibiting the growth of other plants [21, 22].

In general, in the flood spreading area, the soil under the *Z. spina-chrisi* trees had a lower content of organic matter, nitrogen, phosphorus, calcium, and magnesium than the soil under the *E. camaldulensis* and *P. juliflora* trees. In other words, in the flood-spreading area, these two tree stands can add more organic matter and nutrients than the *Z. spina-chrisi* tree stand within 15 years after afforestation. This is because the soil in the three afforestation stands did not differ in the percentages of clay, silt, and sand particles, confirming that the tree species cannot be expected to change soil texture in the short term [23].

*E. camaldulensis* trees grown in the flood spreading area had larger diameter, height, basal area, and standing volume than the *Z. spina-chrisi* and *P. juliflora* trees. Like *P. juliflora* trees, *Eucalyptus* trees provided greater canopy cover than *Z. spinachrisi* trees (and mixed stands). *P. juliflora* had a better condition than the *E. camaldulensis* and *Z. spina-chrisi* with a higher survival rate.

In the flood-prone area, species richness was higher in the non-forested area than in the forested area. This implies that afforestation has limited species richness, possibly due to competition among trees. Evenness was higher in the control area than in the flood spreading area. This is because plant diversity and species richness were higher in the flood spreading area than in the control area. In the literature, following flood events, improvements in plant diversity have often been noted [4, 8]. Likewise, in some studies, increasing vegetation cover has led to changes in species composition and even the dominance of high-quality species, resulting from flood spreading [13, 24, 25]. Studies conducted in dryland rangelands also showed that flood spreading is a method for maintaining soil moisture, improving forage quality [26, 27], and enhancing the condition of wildlife ecosystems [8].

## Conclusion

Given the importance of tree stands in increasing soil fertility and, on the other hand, the need to monitor research findings, it is necessary to choose species with higher survival and superior growth parameters, and to use them for afforestation. According to our hypothesis, *E. camaldulensis* shows the best growth among the three studied species. This is why *P. juliflora*, as a non-native species, has the highest survival rate. *Z. spina-chiristi*, which is a native species, is in an intermediate state in terms of growth and survival; therefore, considering its environmental values and adaptability in the region, it deserves to be prioritized for afforestation development. In general, for the restoration and development of afforestation, improvement of soil fertility, and also the increase of fauna and flora in flood spreading areas of such dry and low-rainfall regions, it is better to use all three species either in pure form or in mixed form.


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