

# Linking Site Constraints to Plant Traits: Multi-Criteria Prioritization of Native Perennials in a Semi-Arid Industrial Landscape

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## Research Article

**Keywords:** Industrial revegetation, Native perennials, Multi-criteria decision-making, Semi-arid landscapes, Site-adapted screening

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# Linking Site Constraints to Plant Traits: Multi-Criteria Prioritization of Native Perennials in a Semi-Arid Industrial Landscape

## Abstract:

Background and Aims: Revegetation of semi-arid industrial landscapes faces compound edaphic and climatic constraints that challenge plant establishment. This study develops a transparent, site-informed decision framework for prioritizing native perennial plants, using the Şanlıurfa Organized Industrial Zone (Türkiye) as a case study.

Methods: The framework integrates measured soil properties (25 sampling points), long-term climate data, regional floristic records, and expert judgments. The Analytic Hierarchy Process (AHP) derived criterion weights, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) ranked 36 eligible native perennials within functional groups.

Results: Soil analysis revealed severe organic matter deficiency (96% of samples <2%), high calcareous content (88% >15%), and macronutrient variability, coinciding with extreme summer drought and thermal stress. AHP weights prioritized drought/heat tolerance (32.3%) and calcareous-soil adaptation (23.6%). *Pistacia terebinthus*, *Elaeagnus angustifolia*, and *Rhus coriaria* ranked highest, with sensitivity analysis confirming ranking stability.

Conclusion: The framework offers a reproducible, transferable screening protocol for pre-implementation candidate selection, maintaining clear separation between measured site evidence, botanical knowledge, and management preferences in water-limited industrial settings.

**Keywords:** Industrial revegetation; Native perennials; Multi-criteria decision-making; Semi-arid landscapes; Site-adapted screening

## Introduction:

Industrial zones concentrate production, infrastructure, and employment, but their construction and operation can also create sealed, excavated, or sparsely vegetated surfaces and may alter local soil functions (Keddari et al., 2025). The magnitude and form of these effects vary with the natural soil environment, construction history, traffic, material storage, and subsequent land management (Zhao et al., 2023). Accordingly, soil degradation cannot be assumed solely from proximity to industrial facilities; compaction, structural deterioration, loss of organic matter, or reduced water-holding capacity require direct measurements, suitable reference conditions, or temporal evidence (Liu et al., 2025). This distinction is particularly important in semi-arid regions, where high summer temperatures and limited and irregular precipitation already constrain plant establishment. Greening industrial landscapes is therefore not merely a matter of visual improvement. It is a sustainable land-management challenge involving water efficiency, persistent vegetation cover, biodiversity support, and feasible long-term maintenance (Wang et al., 2023).

Native perennial plants provide a relevant starting point for low-input revegetation because regional adaptation may reduce water and maintenance requirements while supporting locally appropriate habitat (Russo et al., 2025). Nevertheless, inclusion in a regional flora does not demonstrate that a taxon currently occurs within an industrial zone or that it will establish successfully after planting. A regional literature-based candidate pool can identify potentially suitable taxa beyond the restricted assemblage remaining in an intensively modified site, but the taxonomic identity, native status, life history, and relevant functional traits of each candidate must be verified from traceable sources (Antunes et al., 2022). Long-lived vegetation objectives also require a clear distinction between perennial and annual or biennial species. Trees, shrubs or subshrubs, and herbaceous perennials provide different forms of structure, cover, soil-surface protection, and habitat; they should therefore be evaluated within their respective functional groups rather than treated as operationally interchangeable alternatives. Relevant screening attributes include drought and heat tolerance, compatibility with alkaline, calcareous, saline, or low-fertility conditions, water and maintenance demand, and biodiversity and landscape value (Munson et al., 2015).

Research on industrial land has commonly emphasized contamination assessment and the spatial distribution of soil properties, whereas plant recommendations are often presented as descriptive lists without an explicit procedure for balancing ecological suitability and management requirements (Joimel et al., 2017; Wu et al., 2022; Wang et al., 2024; Qi et al., 2025). A defensible screening process should distinguish four types of evidence: conditions measured at the sampled locations, regional floristic records used to identify potential candidates, published evidence used to describe plant traits, and expert judgments used to express management priorities. Multi-criteria decision-making methods can organize these evidence types and make trade-offs transparent, but they do not establish soil degradation, local species occurrence, or restoration success. Within this limited role, the Analytic Hierarchy Process (AHP) can be used to derive the relative weights of predefined criteria, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can rank candidates from a documented performance matrix. Sensitivity analysis is then required to determine whether the resulting priorities depend excessively on a particular set of criterion weights (Sharma and Miyazaki, 2019).

Against this background, this study develops a site-informed decision framework for prioritizing regionally documented native perennial plants for low-input revegetation in a semi-arid industrial landscape, using the Şanlıurfa Organized Industrial Zone in southeastern Türkiye as a case study. The framework links the chemical and fertility-related soil conditions measured at 25 sampling locations with long-term regional climate information, documented plant traits, and criterion weights elicited from a nine-member expert panel. Annual and biennial taxa are excluded, and the eligible perennial candidates are evaluated within their respective functional groups. AHP is used only to weight the selection criteria, TOPSIS is used to prioritize the plant alternatives, and sensitivity analysis is used to assess ranking stability. The study does not claim that industrial activity caused the measured soil conditions, that the candidate taxa currently occur within the OIZ, or that the prioritized taxa have already produced restoration outcomes. Instead, it offers a transparent pre-implementation screening approach for identifying candidates that should proceed to propagation, establishment trials, and subsequent performance monitoring. The framework is intended to support comparable revegetation decisions in water-limited industrial landscapes while maintaining a clear separation between measured site evidence, regional botanical knowledge, and management preferences.

## Material and Methods:

### *Study Area and Research Design:*

The Şanlıurfa Organized Industrial Zone (OIZ) in southeastern Türkiye was selected as the case study area to operationalize the proposed framework within a semi-arid industrial landscape (Çalışkan, 2019)(Figure 1). The research design integrated four distinct streams of evidence: chemical and fertility-related soil constraints measured at 25 sampling locations, long-term regional climate data, documented native floristic records, and multidisciplinary expert judgments comprising landscape architecture, plant ecology, botany, soil science, and geography.



**Fig. 1.** Study area - Şanlıurfa Organized Industrial Zone (Modified from Google Earth Pro, 2026)

Methodologically, the study followed a systematic sequential procedure:

1. Characterizing the specific edaphic and climatic constraints of the site,
2. Screening a literature-derived regional plant pool to isolate eligible native perennials,
3. Establishing site-informed selection criteria,
4. Deriving criterion weights via the Analytic Hierarchy Process (AHP),
5. Prioritizing the candidate taxa within their respective functional groups using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS),
6. Validating the robustness of the final rankings through sensitivity analysis.

### *Soil Sampling, Laboratory Analyses, and Data Treatment:*

Soil sampling was conducted in June 2026. A total of 25 composite soil samples were collected from accessible unsealed locations within the OIZ. To capture the actual variability of potential planting sites, sampling locations

were selected purposively to include the immediate surroundings of industrial parcels, roadsides, and vacant land. At each location, one composite sample was prepared by combining four to five subsamples collected from different micro-positions at a depth of 0-20 cm (Chen et al., 2024). The geographic coordinates of every sampling location were recorded and plotted (Figure 2). The map explicitly displays the exact sampled points rather than implying a uniform sampling grid across the entire OIZ boundary, as the objective was to characterize available unsealed surfaces rather than to spatially interpolate the entire industrial zone.



**Fig. 2.** The sample area, which is the Organized Industrial Zone, and the points where soil samples were taken (modified from Google Earth Pro, 2026)

The samples were air-dried, gently disaggregated, and passed through a 2 mm sieve before analysis. Soil pH was measured in a saturated soil paste (Yaraş and Daşgan, 2012), while electrical conductivity (ECe) was determined in the corresponding saturation extract and reported exclusively in standard units ( $\text{dS m}^{-1}$ ) (Ratshiedana et al., 2023). Calcium carbonate ( $\text{CaCO}_3$ ) content was determined using the calcimeter method (Elfaki et al., 2016). Available phosphorus was extracted using the Olsen method (Recena et al. 2022), and soil organic matter was determined using the Walkley-Black wet-oxidation method (Gogoi et al, 2026). Exchangeable potassium was extracted with ammonium acetate (Uludağ and Ağca, 2019). In accordance with clear data presentation standards, all intermediate instrument readings (e.g., absorbance values, raw calcimeter readings) were excluded, and only final analytical concentrations were retained for evaluation.

Data treatment and descriptive statistics (mean, standard deviation, minimum, maximum, and coefficient of variation) were conducted using IBM SPSS 27 software to describe point-to-point variation among the 25 samples. Because the locations were selected purposively without an undisturbed reference area, the results were treated strictly as current edaphic constraints limiting plant establishment, not as proof of industry-induced soil degradation (Vural & Erdoğan, 2014).

#### ***Climate Data:***

Long-term monthly temperature, sunshine duration, and precipitation data for Şanlıurfa covering the period 1929-2025 were obtained from the Turkish State Meteorological Service. These data were used to characterize the long-term semi-arid climatic setting specifically high summer temperatures, prolonged sunshine, and severe precipitation deficits which strongly inform the drought- and heat-tolerance requirements for perennial plant establishment.

#### ***Regional Candidate Pool, Eligibility Screening, and Functional Grouping:***

A critical limitation in many revegetation projects is the reliance on unverified or ecologically incompatible plant lists. To address this, an initial candidate pool of 36 native plant taxa was derived from regional floristic records for Şanlıurfa Province. The purpose of this literature-based pool was to serve as a pre-implementation screening

tool to identify regionally adapted taxa, rather than to claim that these taxa currently inhabit the highly modified OIZ site.

To ensure the selection met the objective of persistent, long-lived vegetation cover, a strict eligibility screening was applied: all annual and biennial taxa were entirely excluded from the evaluation due to their transient ground cover and limited long-term restoration impact. The remaining eligible native perennials were then strictly categorized into three distinct functional groups:

- Trees
- Shrubs and Bushes
- Herbaceous Perennials

These groups provide fundamentally different forms of spatial structure, root reinforcement, and maintenance needs. Therefore, they were evaluated exclusively within their respective categories to prevent methodologically flawed comparisons between distinct life forms.

### ***Derivation and Operationalization of the Decision Criteria***

Criterion development logically followed the edaphic and climatic characterization of the study area and preceded all pairwise comparisons and alternative scoring. To ensure context-sensitive prioritization, three complementary evidence streams were considered:

- The measured edaphic constraints, specifically highlighting high calcareous content, organic matter deficiency, and macronutrient variability,
- Long-term meteorological data indicating severe summer thermal stress and precipitation deficits,
- The functional and management objectives for persistent, low-input industrial revegetation.

A nine-member expert panel reviewed these evidence streams and finalized six specific decision criteria (C1-C6). The criteria were firmly established prior to the mathematical evaluations.

### ***Expert Panel and AHP Weighting Procedure:***

To strictly limit subjective bias, the Analytic Hierarchy Process (AHP) was utilized exclusively as a pre-weighting tool to determine the relative importance of the predefined criteria, rather than to generate the criteria or evaluate the plant alternatives. The expert panel performed pairwise comparisons of the six criteria using Saaty's 1-9 fundamental scale (Saaty, 2008).

A reciprocal  $n \times n$  pairwise comparison matrix  $A$  was constructed, where  $a_{ij}$  represents the relative importance of criterion  $i$  over criterion  $j$ :

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

The values in the pairwise comparison matrix were normalized to create a standard matrix using the following equation:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (2)$$

Subsequently, the final criterion weights ( $w_i$ ) were calculated by averaging the row sums of the normalized matrix:

$$w_i = \frac{\sum_{j=1}^n b_{ij}}{n} \quad (3)$$

Finally, a consistency check was performed. A Consistency Ratio (CR) of less than 0.10 was required to confirm that the experts' pairwise comparisons were logically coherent and mathematically acceptable for use in the subsequent TOPSIS stage (Razdan et al., 2024).

### ***TOPSIS Prioritization Method:***

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was employed to rank the 36 eligible perennial candidates based on their performance against the weighted criteria. The method operationalizes the principle that the optimal alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Han et al., 2025).

- First, the expert panel scored the 36 native perennials against each criterion on a scale of 1 to 10 to construct the initial decision matrix ( $x_{ij}$ ). This matrix was then normalized to ensure comparability across criteria:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (4)$$

- The normalized matrix was converted into a weighted standard decision matrix ( $v_{ij}$ ) by multiplying it with the criteria weights ( $w_j$ ) derived from the AHP:

$$v_{ij} = w_j \times r_{ij} \quad (5)$$

- The positive ideal solution ( $A^*$ ) and negative ideal solution ( $A^-$ ) were determined by extracting the maximum and minimum values for each criterion column:

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} \quad (6)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \quad (7)$$

- The Euclidean distances of each plant alternative from the positive ideal ( $S_i^*$ ) and negative ideal ( $S_i^-$ ) solutions were calculated:

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \quad (8)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (9)$$

- Finally, the relative closeness coefficient ( $C_i^*$ ) to the ideal solution was computed for each plant species, determining the final ranking where a higher coefficient indicates greater suitability (Ogonowski, 2022):

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (10)$$

#### **Sensitivity Analysis:**

To validate the reliability of the TOPSIS rankings and determine whether the priorities depended excessively on the initial AHP weights, a sensitivity analysis was conducted. The baseline weight of each criterion was systematically increased and decreased by 10%. During these variations, the weights of the remaining criteria were proportionally adjusted to ensure the total sum remained exactly 1.0. The TOPSIS calculations were repeated for all generated scenarios. The overall stability of the decision model was evaluated by calculating Spearman's rank correlation coefficient ( $\rho$ ) between each scenario's ranking and the baseline ranking, thereby confirming the methodological robustness of the proposed framework (Gaona et al., 2025).

#### **Results:**

##### **Edaphic Constraints and Soil Characterization:**

According to the first stage of the study methodology, 25 composite soil samples were taken from different purposively selected points of the Şanlıurfa Organized Industrial Zone to represent available unsealed surfaces for potential planting.

The saturation percentage, pH values, and electrical conductivity of the saturation extract (ECe) results are given in Table 1. To ensure analytical clarity and eliminate redundancy, ECe is reported exclusively in standard units (dS m<sup>-1</sup>). Descriptive statistics for these baseline parameters are presented in Table 2.

**Table 1.** Saturation, pH, and electrical conductivity results of soil samples.

| Sample No. | Saturation (%) | pH   | ECe (dS/m <sup>-1</sup> ) |
|------------|----------------|------|---------------------------|
| 1          | 66             | 7.65 | 0.735                     |
| 2          | 68             | 7.54 | 0.794                     |
| 3          | 61             | 7.63 | 1.043                     |
| 4          | 56             | 7.74 | 0.730                     |
| 5          | 67             | 7.72 | 0.870                     |
| 6          | 59             | 7.65 | 0.847                     |
| 7          | 60             | 7.70 | 0.699                     |
| 8          | 72             | 7.66 | 0.851                     |
| 9          | 57             | 7.81 | 0.707                     |
| 10         | 55             | 7.88 | 0.601                     |
| 11         | 65             | 7.73 | 0.597                     |
| 12         | 56             | 7.82 | 0.780                     |
| 13         | 66             | 7.74 | 0.805                     |
| 14         | 62             | 7.71 | 0.675                     |
| 15         | 57             | 7.83 | 0.587                     |
| 16         | 59             | 7.79 | 0.684                     |
| 17         | 58             | 7.76 | 0.736                     |
| 18         | 56             | 7.66 | 0.844                     |
| 19         | 41             | 8.03 | 0.320                     |
| 20         | 54             | 7.80 | 0.832                     |

|    |    |      |       |
|----|----|------|-------|
| 21 | 42 | 7.75 | 0.535 |
| 22 | 43 | 7.87 | 0.385 |
| 23 | 44 | 7.89 | 0.408 |
| 24 | 55 | 7.86 | 0.722 |
| 25 | 57 | 7.84 | 0.686 |

**Table 2.** Descriptive statistics for saturation, pH, and ECe values.

| Parameter      | Minimum | Maximum | Average | Standard deviation | Coefficient of variation (%) |
|----------------|---------|---------|---------|--------------------|------------------------------|
| Saturation (%) | 41.00   | 72.00   | 57.44   | 8.14               | 14.18                        |
| pH             | 7.54    | 8.03    | 7.76    | 0.11               | 1.35                         |
| ECe (dS/m)     | 0.320   | 1.043   | 0.699   | 0.165              | 23.54                        |

The saturation values of the soil samples ranged between 41% and 72%, with a mean saturation value of 57.44%. The pH values of the soils ranged between 7.54 and 8.03, with a mean pH value of 7.76. The rather low pH variability among samples (CV=1.35%) indicates that slightly alkaline reaction conditions uniformly prevail in the research area. Although this slightly alkaline soil reaction does not indicate an extreme level of alkalinity that directly inhibits plant survival, it constitutes an environmental constraint that may limit the availability of phosphorus and some micronutrients for plant uptake. The electrical conductivity values ranged between 0.320 and 1.043 dS m<sup>-1</sup>. The fact that the ECe value remained well below 2.0 dS m<sup>-1</sup> in all samples indicates that there is no significant salinity constraint in the studied soils under current conditions.

To evaluate macronutrient constraints and structural limitations, calcium carbonate (CaCO<sub>3</sub>), available phosphorus, organic matter, and available potassium levels were analysed. In accordance with standard reporting practices, intermediate instrument readings were explicitly excluded. The comprehensive analytical concentrations and classifications for each sampling point are detailed in Table 3, and the corresponding descriptive statistics for these edaphic parameters are summarized in Table 4.

**Table 3.** Macronutrient and structural parameter concentrations of the soil samples.

| Sample No | CaCO <sub>3</sub> (%) | Phosphorus (ppm) | Organic Matter (%) | Potassium (ppm) |
|-----------|-----------------------|------------------|--------------------|-----------------|
| 1         | 18.2                  | 3.79             | 0.76               | 113.7           |
| 2         | 6.00                  | 15.99            | 1.16               | 194.4           |
| 3         | 10.2                  | 8.41             | 0.94               | 133.2           |
| 4         | 22.4                  | 3.88             | 0.36               | 117.0           |
| 5         | 8.30                  | 5.11             | 0.75               | 129.6           |
| 6         | 22.0                  | 11.95            | 1.54               | 189.9           |
| 7         | 22.4                  | 19.45            | 1.82               | 265.2           |
| 8         | 19.7                  | 31.56            | 2.63               | 300.0           |
| 9         | 31.9                  | 6.10             | 0.39               | 63.60           |
| 10        | 28.5                  | 6.68             | 0.57               | 129.9           |
| 11        | 20.5                  | 9.07             | 0.96               | 165.6           |
| 12        | 25.0                  | 15.00            | 0.60               | 209.7           |
| 13        | 18.6                  | 19.12            | 0.74               | 293.1           |
| 14        | 15.5                  | 8.57             | 0.44               | 176.4           |
| 15        | 23.9                  | 9.40             | 0.70               | 108.0           |
| 16        | 23.5                  | 9.73             | 0.32               | 130.8           |
| 17        | 28.1                  | 22.09            | 1.11               | 149.1           |
| 18        | 22.8                  | 3.22             | 1.20               | 244.2           |
| 19        | 31.1                  | 5.52             | 0.58               | 17.40           |
| 20        | 27.7                  | 7.42             | 0.34               | 122.1           |
| 21        | 26.6                  | 3.05             | 0.81               | 141.9           |
| 22        | 31.5                  | 10.72            | 0.63               | 41.70           |
| 23        | 30.7                  | 5.61             | 0.78               | 74.40           |
| 24        | 27.7                  | 7.58             | 0.36               | 120.3           |
| 25        | 30.7                  | 8.00             | 0.32               | 85.80           |

**Table 4.** Descriptive statistics for the edaphic parameters.

| Parameter             | Minimum | Maximum | Average | Standard deviation | Coefficient of variation (%) |
|-----------------------|---------|---------|---------|--------------------|------------------------------|
| CaCO <sub>3</sub> (%) | 6.00    | 31.90   | 22.94   | 7.19               | 31.34                        |
| Phosphorus (ppm)      | 3.05    | 31.56   | 10.28   | 6.86               | 66.71                        |
| Organic matter (%)    | 0.32    | 2.63    | 0.83    | 0.54               | 64.36                        |
| Potassium (ppm)       | 17.40   | 300.00  | 148.68  | 72.78              | 48.95                        |

When the analytical results were evaluated cumulatively, it was determined that the primary edaphic constraints for revegetation in the research area arise not from salinity, but from a combination of severe organic matter deficiency, high calcareous content, and macronutrient variability. Specifically, 88% of the samples were highly

or very highly calcareous ( $\text{CaCO}_3 > 15\%$ ), while 96% exhibited severe organic matter contents below 2%. Furthermore, 44% of the samples had low phosphorus levels ( $< 8$  ppm), and 56% were deficient in available potassium ( $< 140$  ppm).

These findings indicate that high lime content and severe organic matter deficiency coexist across the vast majority of the research area. This structural limitation, accompanied by a slightly alkaline reaction, creates a challenging environment for nutrient availability, microbial activity, and water-holding capacity. Based on these combined edaphic constraints, the priority restoration requirements and targeted intervention strategies for the sampling points were categorized (Table 5).

**Table 5.** Prioritized restoration requirements based on combined edaphic constraints.

| Restoration priority | Sample points     | Determining edaphic constraints                                                 | Priority restoration approach                                                                                  |
|----------------------|-------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Very high            | 19                | Very high lime, very low organic matter, low phosphorus, and very low potassium | Combined application of organic matter improvement with targeted phosphorus and potassium management           |
| Very high            | 9, 10, 20, 23, 24 | Very high lime, very low organic matter, low phosphorus, and low potassium      | Organic improvement, phosphorus and potassium supplementation, and use of species tolerant to calcareous soils |
| Very high            | 1, 4              | High lime, very low organic matter, low phosphorus, and low potassium           | Simultaneous remediation of phosphorus and potassium deficiencies through organic improvement                  |
| Very high            | 22                | Very high lime, very low organic matter, and very low potassium                 | Organic matter and potassium-focused improvement                                                               |
| High                 | 5                 | Very low organic matter with low phosphorus and potassium                       | Organic matter, phosphorus, and potassium supplementation                                                      |
| High                 | 21                | Very high lime, very low organic matter, and low phosphorus                     | Organic improvement and phosphorus management                                                                  |
| High                 | 25                | Very high lime, very low organic matter, and low potassium                      | Organic improvement and potassium management                                                                   |
| High                 | 15, 16            | High lime, very low organic matter, and low potassium                           | Organic matter and potassium-focused improvement                                                               |
| High                 | 3                 | Moderate lime, very low organic matter, and low potassium                       | Organic improvement and potassium supplementation                                                              |
| High                 | 18                | High lime, low organic matter, and low phosphorus                               | Organic improvement and phosphorus supplementation                                                             |
| Medium               | 11, 12, 13, 14    | High lime and very low organic matter                                           | Organic matter enhancement and planting with species adapted to calcareous conditions                          |
| Medium               | 17                | Very high lime and low organic matter                                           | Organic improvement and use of species tolerant to high lime                                                   |
| Medium               | 6, 7              | High lime and low organic matter                                                | Organic matter enhancement and improvement of soil structure                                                   |
| Medium               | 2                 | Moderate lime and low organic matter                                            | Organic matter supplementation and protective soil management                                                  |
| Medium               | 8                 | High lime; other indicators relatively suitable                                 | Selection of species adapted to calcareous conditions and preservation of existing soil quality                |

### *Climatic Pressures on Revegetation:*

When the long-term climatic data of Şanlıurfa and the current evaporation and precipitation anomaly findings were evaluated together, it was observed that the research area experiences a severe dry period characterized by extreme high summer temperatures, long sunshine duration, extremely limited summer precipitation, and high evaporation (Table 6).

**Table 6.** Long-term monthly climate characteristics of Şanlıurfa (MGM, 2026a).

| Month  | Average temperature (°C) | Average highest temperature (°C) | Average lowest temperature (°C) | Sunshine duration (hours) | Number of rainy days | Monthly total rainfall (mm) |
|--------|--------------------------|----------------------------------|---------------------------------|---------------------------|----------------------|-----------------------------|
| Jan.   | 5.7                      | 10.0                             | 2.2                             | 4.1                       | 11.84                | 85.4                        |
| Feb.   | 7.1                      | 12.0                             | 3.0                             | 5.1                       | 10.37                | 68.2                        |
| March  | 11.0                     | 16.5                             | 5.9                             | 6.3                       | 10.43                | 64.9                        |
| April  | 16.4                     | 22.4                             | 10.4                            | 7.8                       | 8.71                 | 48.5                        |
| May    | 22.3                     | 28.8                             | 15.4                            | 10.0                      | 6.01                 | 26.8                        |
| June   | 28.2                     | 34.8                             | 20.7                            | 12.1                      | 1.31                 | 4.2                         |
| July   | 32.1                     | 38.8                             | 24.4                            | 12.3                      | 0.26                 | 2.0                         |
| August | 31.6                     | 38.4                             | 24.1                            | 11.2                      | 0.23                 | 3.0                         |

|        |      |      |      |      |       |       |
|--------|------|------|------|------|-------|-------|
| Sep.   | 27.2 | 34.0 | 20.1 | 10.0 | 0.80  | 4.6   |
| Oct.   | 20.6 | 27.1 | 14.7 | 7.9  | 4.64  | 25.3  |
| Nov.   | 13.2 | 18.8 | 8.6  | 5.8  | 7.42  | 44.6  |
| Dec.   | 7.7  | 12.1 | 4.1  | 4.0  | 10.68 | 78.7  |
| Annual | 18.6 | 24.5 | 12.8 | 8.1  | 72.70 | 456.2 |

According to the long-term data, the annual mean temperature in Şanlıurfa is 18.6 °C. During the critical June-September period, monthly mean temperatures range between 27.2 and 32.1 °C, while mean maximum temperatures peak between 34.0 and 38.8 °C. The mean maximum temperature reaching 38.8 °C in July and 38.4 °C in August indicates that plants are exposed to severe thermal stress during daytime hours. Additionally, sunshine duration reaches up to 12.3 hours daily in July. This combination creates a climatic structure that drastically increases atmospheric water demand and moisture loss from the soil surface.

Although the annual average total precipitation is 456.2 mm, its distribution is highly irregular, with approximately 51% occurring in winter and only 2% in summer. The total precipitation during the June-September period is limited to 13.8 mm, perfectly coinciding with the period of highest temperatures. This creates a pronounced seasonal drought that severely limits natural soil moisture replenishment during the warm period (Figure 3).

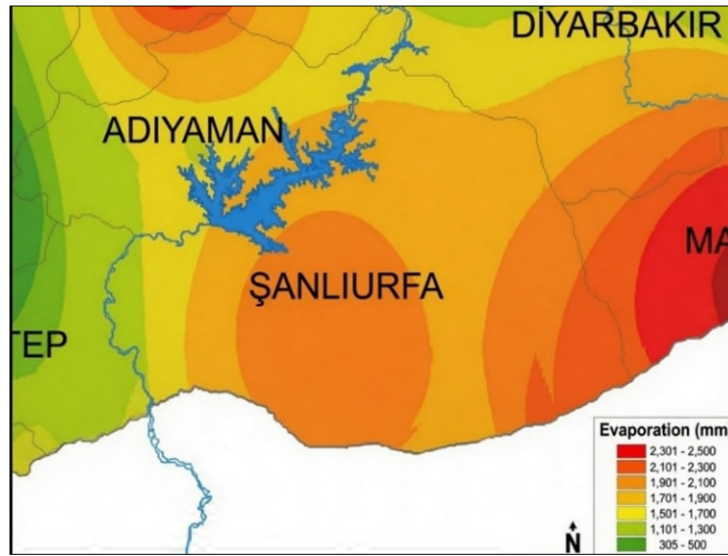


**Fig. 3.** Spatial distribution of open surface evaporation in Şanlıurfa during the May-October 2025 period and location of Şanlıurfa (MGM, 2026b)

The open surface evaporation map (Figure 3) demonstrates that high evaporation occurs during the May-October period, indicating that the soils in the research area are susceptible to rapid moisture loss. Particularly, the severe organic matter deficiency identified in the majority of the samples is a structural constraint that further complicates the soil's ability to compensate for climate-induced moisture loss.

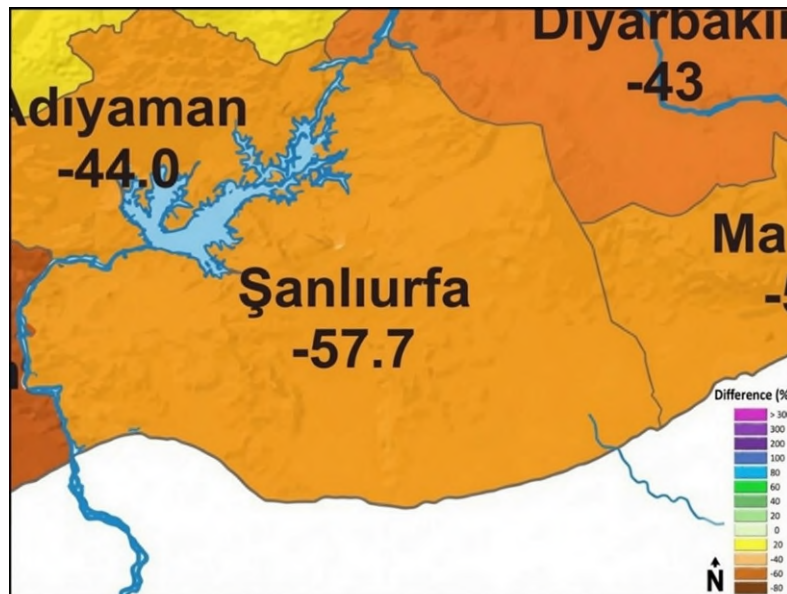


**Fig. 4.** Change in rainfall in Şanlıurfa in 2025 compared to normal levels (MGM, 2026c)

Furthermore, the precipitation anomaly map (Figure 4) reveals that recent precipitation was 57.7% below long-term normals, demonstrating that current conditions heavily reinforce the long-term drought pressure.

When climatic findings are considered alongside the edaphic constraints, a pronounced limitation matrix emerges for perennial plant establishment. Although the soils lack significant salinity, the combination of high calcareous content, severe organic matter deficiency, prolonged thermal stress, and high atmospheric water demand severely constrains the structural resilience of the soil and its capacity to retain plant-available water.

#### **Expert Elicitation and AHP Criterion Weights:**

Following the establishment of edaphic and climatic constraints, a nine-member expert panel determined the specific criteria for prioritizing native perennial plants. The finalized criteria and their scopes are presented in Table 7.

**Table 7.** AHP criteria set used in the evaluation of native plant species.

| Code | Criterion                                   | Scope of the criterion                                                                                                                                                                 |
|------|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C1   | Resistance to drought and high temperature  | The ability of the species to survive under prolonged summer drought, high temperature, long sunshine duration, and high evaporation conditions                                        |
| C2   | Adaptation to calcareous and alkaline soils | The capacity of the species to adapt to high CaCO <sub>3</sub> content and slightly alkaline soil reaction                                                                             |
| C3   | Tolerance to low soil fertility             | The ability of the species to grow in low organic matter conditions and in soils that are insufficient or variable in terms of phosphorus and potassium                                |
| C4   | Soil stabilization and restoration capacity | The capacity of the species to reduce erosion, stabilize the soil, and contribute to organic matter accumulation through its root system, ground cover ability, and biomass production |
| C5   | Low water and maintenance requirement       | The ability of the species to sustain itself after establishment with limited irrigation, fertilization, pruning, and general maintenance inputs                                       |
| C6   | Landscape and ecological use value          | The potential of the species in terms of visual quality, seasonal effect, contribution to local identity, habitat creation, and supporting biodiversity                                |

The AHP method was utilized to derive the relative importance of these predefined criteria based on the experts' pairwise comparisons. The individual evaluations of the nine experts were aggregated into a group decision using the geometric mean method. The final pairwise comparison matrix obtained from this process is presented in Table 8.

**Table 8.** Pairwise comparison matrix.

| Criterion | C1   | C2   | C3   | C4   | C5   | C6   |
|-----------|------|------|------|------|------|------|
| C1        | 1.00 | 2.00 | 2.00 | 3.00 | 3.00 | 4.00 |
| C2        | 0.50 | 1.00 | 2.00 | 2.00 | 3.00 | 4.00 |
| C3        | 0.50 | 0.50 | 1.00 | 0.50 | 2.00 | 3.00 |
| C4        | 0.33 | 0.50 | 2.00 | 1.00 | 2.00 | 3.00 |
| C5        | 0.33 | 0.33 | 0.50 | 0.50 | 1.00 | 2.00 |
| C6        | 0.25 | 0.25 | 0.33 | 0.33 | 0.50 | 1.00 |

Following the construction of the pairwise comparison matrix, the values were normalized. The resulting normalized pairwise comparison matrix is presented in Table 9.

**Table 9.** Normalized pairwise comparison matrix.

| Criterion     | C1      | C2      | C3      | C4      | C5      | C6      |
|---------------|---------|---------|---------|---------|---------|---------|
| C1            | 0.34286 | 0.43636 | 0.25532 | 0.40909 | 0.26087 | 0.23529 |
| C2            | 0.17143 | 0.21818 | 0.25532 | 0.27273 | 0.26087 | 0.23529 |
| C3            | 0.17143 | 0.10909 | 0.12766 | 0.06818 | 0.17391 | 0.17647 |
| C4            | 0.11429 | 0.10909 | 0.25532 | 0.13636 | 0.17391 | 0.17647 |
| C5            | 0.11429 | 0.07273 | 0.06383 | 0.06818 | 0.08696 | 0.11765 |
| C6            | 0.08571 | 0.05455 | 0.04255 | 0.04545 | 0.04348 | 0.05882 |
| Column total: | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |

In the final stage of the AHP method, the weights of the selection criteria were calculated (Table 10). By taking the arithmetic mean of the consistency vector, the maximum eigenvalue was calculated as  $\lambda_{\max} = 6.18524$ . For the six criteria, the consistency index was found to be  $CI = 0.03705$ , and the consistency ratio was calculated as  $CR = 0.02988$ . The fact that the obtained consistency ratio is well below the threshold value of 0.10 indicates that the pairwise comparisons based on expert evaluations are highly consistent, ensuring that the determined criterion weights can be used reliably in the subsequent TOPSIS stage.

**Table 10.** AHP criterion weights and ranking of importance.

| Rank | Code | Criterion                                  | Criterion weight | Importance ratio (%) |
|------|------|--------------------------------------------|------------------|----------------------|
| 1    | C1   | Resistance to drought and high temperature | 0.32330          | 32.33                |

|   |    |                                             |         |       |
|---|----|---------------------------------------------|---------|-------|
| 2 | C2 | Adaptation to calcareous and alkaline soils | 0.23564 | 23.56 |
| 3 | C4 | Soil stabilization and restoration capacity | 0.16091 | 16.09 |
| 4 | C3 | Tolerance to low soil fertility             | 0.13779 | 13.78 |
| 5 | C5 | Low water and maintenance requirement       | 0.08727 | 8.73  |
| 6 | C6 | Landscape and ecological use value          | 0.05509 | 5.51  |

According to the AHP results, "Resistance to drought and high temperature" (C1) emerged as the most critical parameter with a weight of 32.33%, directly reflecting the severe atmospheric water demand and thermal stress characteristic of the region. This was closely followed by "Adaptation to calcareous and alkaline soils" (C2) at 23.56%, which perfectly corresponds to the widespread high-lime constraint identified in the soil samples. "Landscape and ecological use value" (C6) received the lowest weight (5.51%), indicating a consensus among the experts that in severely constrained semi-arid industrial sites, plant survival, adaptation, and soil stabilization strictly take precedence over purely aesthetic or ornamental considerations.

#### Identification of Eligible Native Plant Candidates

Before conducting the multi-criteria evaluation, an inventory of 36 eligible native perennial plant species was established based on comprehensive literature reviews and regional botanical studies. According to prior literature, these specific taxa are reported to possess significant potential for landscape restoration, ecological revegetation, and ornamental use in the region (Kaya, 2002; Akan et al., 2005; Aydoğdu and Akan, 2005; Balos and Akan, 2008; Abak and Akan, 2014).

By focusing strictly on perennial taxa comprising trees, shrubs, and perennial herbaceous plants as indicated by preceding botanical records, the selection aligns with the functional requirements for persistent, year-round soil stabilization and long-term structural restoration in degraded industrial environments. These 36 literature-backed perennial species served as the definitive alternatives for the subsequent TOPSIS evaluation (Table 11).

**Table 11.** The 36 eligible native perennial plant species identified for the evaluation.

| Plant Species                      | Family                 | Functional Group          |
|------------------------------------|------------------------|---------------------------|
| <i>Achillea aleppica</i>           | <i>Asteraceae</i>      | Herbaceous Perennial      |
| <i>Achillea wilhelmsii</i>         | <i>Asteraceae</i>      | Herbaceous Perennial      |
| <i>Alhagi pseudalhagi</i>          | <i>Fabaceae</i>        | Shrub / Bush              |
| <i>Amygdalus arabica</i>           | <i>Rosaceae</i>        | Shrub / Bush              |
| <i>Andrachne telephioides</i>      | <i>Phyllanthaceae</i>  | Herbaceous Perennial      |
| <i>Argyrolobium crotalarioides</i> | <i>Fabaceae</i>        | Shrub / Bush              |
| <i>Bongardia chrysogonum</i>       | <i>Berberidaceae</i>   | Herbaceous Perennial      |
| <i>Celtis tournefortii</i>         | <i>Cannabaceae</i>     | Tree                      |
| <i>Cichorium intybus</i>           | <i>Asteraceae</i>      | Herbaceous Perennial      |
| <i>Cruciata taurica</i>            | <i>Rubiaceae</i>       | Herbaceous Perennial      |
| <i>Dianthus strictus</i>           | <i>Caryophyllaceae</i> | Herbaceous Perennial      |
| <i>Elaeagnus angustifolia</i>      | <i>Elaeagnaceae</i>    | Tree                      |
| <i>Ephedra campylopoda</i>         | <i>Ephedraceae</i>     | Shrub / Bush              |
| <i>Equisetum arvense</i>           | <i>Equisetaceae</i>    | Herbaceous Perennial      |
| <i>Ficus carica</i>                | <i>Moraceae</i>        | Tree                      |
| <i>Hedera helix</i>                | <i>Araliaceae</i>      | Shrub / Bush (Woody Vine) |
| <i>Hedysarum varium</i>            | <i>Fabaceae</i>        | Herbaceous Perennial      |
| <i>Hypericum retusum</i>           | <i>Hypericaceae</i>    | Herbaceous Perennial      |
| <i>Lythrum salicaria</i>           | <i>Lythraceae</i>      | Herbaceous Perennial      |
| <i>Moltkia coerulea</i>            | <i>Boraginaceae</i>    | Herbaceous Perennial      |
| <i>Nepeta italica</i>              | <i>Lamiaceae</i>       | Herbaceous Perennial      |
| <i>Nerium oleander</i>             | <i>Apocynaceae</i>     | Shrub / Bush              |
| <i>Phyla nodiflora</i>             | <i>Verbenaceae</i>     | Herbaceous Perennial      |
| <i>Pistacia terebinthus</i>        | <i>Anacardiaceae</i>   | Tree                      |
| <i>Prosopis farcta</i>             | <i>Fabaceae</i>        | Shrub / Bush              |
| <i>Pulicaria dysenterica</i>       | <i>Asteraceae</i>      | Herbaceous Perennial      |
| <i>Punica granatum</i>             | <i>Lythraceae</i>      | Tree                      |
| <i>Quercus brantii</i>             | <i>Fagaceae</i>        | Tree                      |
| <i>Rhus coriaria</i>               | <i>Anacardiaceae</i>   | Shrub / Bush              |
| <i>Rubus sanctus</i>               | <i>Rosaceae</i>        | Shrub / Bush              |
| <i>Rumex scutatus</i>              | <i>Polygonaceae</i>    | Herbaceous Perennial      |
| <i>Scariola orientalis</i>         | <i>Asteraceae</i>      | Shrub / Bush              |
| <i>Scorzonera mirabilis</i>        | <i>Asteraceae</i>      | Herbaceous Perennial      |
| <i>Stellaria kotschyana</i>        | <i>Caryophyllaceae</i> | Herbaceous Perennial      |
| <i>Tamarix smyrnensis</i>          | <i>Tamaricaceae</i>    | Tree                      |
| <i>Thymus haussknechtii</i>        | <i>Lamiaceae</i>       | Shrub / Bush              |

### TOPSIS Prioritization of Native Perennials:

To ensure a methodologically robust and transparent evaluation for long-term ecological restoration, the 36 eligible native perennial species were evaluated against the six weighted criteria. In the first step of the TOPSIS method, a decision matrix was constructed based on the aggregated expert scores (ranging from 1 to 10) assigned to each plant species for every criterion (Table 12).

**Table 12.** Initial decision matrix of the 36 native perennials.

| Alternatives (Plant Species)       | C1 | C2 | C3 | C4 | C5 | C6 |
|------------------------------------|----|----|----|----|----|----|
| <i>Achillea aleppica</i>           | 9  | 9  | 8  | 6  | 8  | 7  |
| <i>Achillea wilhelmsii</i>         | 9  | 7  | 8  | 6  | 8  | 7  |
| <i>Alhagi pseudalhagi</i>          | 10 | 8  | 8  | 8  | 9  | 5  |
| <i>Amygdalus arabica</i>           | 9  | 7  | 9  | 6  | 8  | 6  |
| <i>Andrachne telephioides</i>      | 7  | 8  | 6  | 3  | 7  | 4  |
| <i>Argyrolobium crotalarioides</i> | 8  | 8  | 9  | 7  | 9  | 7  |
| <i>Bongardia chrysogonum</i>       | 6  | 9  | 6  | 3  | 8  | 7  |
| <i>Celtis tournefortii</i>         | 9  | 9  | 7  | 8  | 8  | 9  |
| <i>Cichorium intybus</i>           | 8  | 9  | 7  | 7  | 9  | 8  |
| <i>Cruciata taurica</i>            | 6  | 8  | 7  | 7  | 8  | 6  |
| <i>Dianthus strictus</i>           | 8  | 9  | 7  | 6  | 8  | 8  |
| <i>Elaeagnus angustifolia</i>      | 9  | 9  | 9  | 10 | 8  | 9  |
| <i>Ephedra campylopoda</i>         | 9  | 9  | 8  | 7  | 9  | 7  |
| <i>Equisetum arvense</i>           | 3  | 6  | 8  | 9  | 3  | 4  |
| <i>Ficus carica</i>                | 9  | 9  | 7  | 8  | 8  | 9  |
| <i>Hedera helix</i>                | 2  | 6  | 3  | 4  | 2  | 4  |
| <i>Hedysarum varium</i>            | 8  | 9  | 9  | 8  | 8  | 7  |
| <i>Hypericum retusum</i>           | 8  | 9  | 8  | 6  | 8  | 8  |
| <i>Lythrum salicaria</i>           | 2  | 6  | 5  | 4  | 2  | 8  |
| <i>Molikia coerulea</i>            | 9  | 9  | 8  | 6  | 9  | 8  |
| <i>Nepeta italica</i>              | 8  | 9  | 8  | 7  | 9  | 9  |
| <i>Nerium oleander</i>             | 9  | 8  | 8  | 8  | 8  | 7  |
| <i>Phyla nodiflora</i>             | 7  | 8  | 8  | 8  | 7  | 8  |
| <i>Pistacia terebinthus</i>        | 10 | 9  | 8  | 9  | 9  | 10 |
| <i>Prosopis farcta</i>             | 9  | 9  | 9  | 9  | 9  | 8  |
| <i>Pulicaria dysenterica</i>       | 6  | 8  | 7  | 7  | 5  | 8  |
| <i>Punica granatum</i>             | 8  | 8  | 7  | 8  | 7  | 9  |
| <i>Quercus brantii</i>             | 9  | 8  | 8  | 9  | 8  | 10 |
| <i>Rhus coriaria</i>               | 9  | 9  | 9  | 9  | 9  | 9  |
| <i>Rubus sanctus</i>               | 6  | 8  | 7  | 8  | 6  | 8  |
| <i>Rumex scutatus</i>              | 8  | 9  | 7  | 6  | 8  | 7  |
| <i>Scariola orientalis</i>         | 9  | 9  | 8  | 9  | 8  | 7  |
| <i>Scorzonera mirabilis</i>        | 6  | 4  | 5  | 5  | 5  | 4  |
| <i>Stellaria kotschyana</i>        | 7  | 8  | 8  | 7  | 8  | 7  |
| <i>Tamarix smyrnensis</i>          | 9  | 9  | 9  | 9  | 9  | 8  |
| <i>Thymus haussknechtii</i>        | 9  | 9  | 9  | 8  | 9  | 9  |

To eliminate the dimensional differences among the criteria, this initial decision matrix was normalized using vector normalization. The standard normalized decision matrix, representing the transformed evaluation scores, is presented in Table 13.

**Table 13.** Standard normalized decision matrix.

| Alternatives (Plant Species)       | C1      | C2      | C3      | C4      | C5      | C6      |
|------------------------------------|---------|---------|---------|---------|---------|---------|
| <i>Achillea aleppica</i>           | 0.18886 | 0.18127 | 0.17391 | 0.13718 | 0.17134 | 0.15430 |
| <i>Achillea wilhelmsii</i>         | 0.18886 | 0.14099 | 0.17391 | 0.13718 | 0.17134 | 0.15430 |
| <i>Alhagi pseudalhagi</i>          | 0.20984 | 0.16113 | 0.17391 | 0.18291 | 0.19276 | 0.11022 |
| <i>Amygdalus arabica</i>           | 0.18886 | 0.14099 | 0.19565 | 0.13718 | 0.17134 | 0.13226 |
| <i>Andrachne telephioides</i>      | 0.14689 | 0.16113 | 0.13043 | 0.06859 | 0.14992 | 0.08817 |
| <i>Argyrolobium crotalarioides</i> | 0.16787 | 0.16113 | 0.19565 | 0.16004 | 0.19276 | 0.15430 |
| <i>Bongardia chrysogonum</i>       | 0.12590 | 0.18127 | 0.13043 | 0.06859 | 0.17134 | 0.15430 |
| <i>Celtis tournefortii</i>         | 0.18886 | 0.18127 | 0.15217 | 0.18291 | 0.17134 | 0.19839 |
| <i>Cichorium intybus</i>           | 0.16787 | 0.18127 | 0.15217 | 0.16004 | 0.19276 | 0.17635 |
| <i>Cruciata taurica</i>            | 0.12590 | 0.16113 | 0.15217 | 0.16004 | 0.17134 | 0.13226 |
| <i>Dianthus strictus</i>           | 0.16787 | 0.18127 | 0.15217 | 0.13718 | 0.17134 | 0.17635 |
| <i>Elaeagnus angustifolia</i>      | 0.18886 | 0.18127 | 0.19565 | 0.22863 | 0.17134 | 0.19839 |
| <i>Ephedra campylopoda</i>         | 0.18886 | 0.18127 | 0.17391 | 0.16004 | 0.19276 | 0.15430 |

|                              |         |         |         |         |         |         |
|------------------------------|---------|---------|---------|---------|---------|---------|
| <i>Equisetum arvense</i>     | 0.06295 | 0.12085 | 0.17391 | 0.20577 | 0.06425 | 0.08817 |
| <i>Ficus carica</i>          | 0.18886 | 0.18127 | 0.15217 | 0.18291 | 0.17134 | 0.19839 |
| <i>Hedera helix</i>          | 0.04197 | 0.12085 | 0.06522 | 0.09145 | 0.04283 | 0.08817 |
| <i>Hedysarum varium</i>      | 0.16787 | 0.18127 | 0.19565 | 0.18291 | 0.17134 | 0.15430 |
| <i>Hypericum retusum</i>     | 0.16787 | 0.18127 | 0.17391 | 0.13718 | 0.17134 | 0.17635 |
| <i>Lythrum salicaria</i>     | 0.04197 | 0.12085 | 0.10870 | 0.09145 | 0.04283 | 0.17635 |
| <i>Moltkia coerulea</i>      | 0.18886 | 0.18127 | 0.17391 | 0.13718 | 0.19276 | 0.17635 |
| <i>Nepeta italica</i>        | 0.16787 | 0.18127 | 0.17391 | 0.16004 | 0.19276 | 0.19839 |
| <i>Nerium oleander</i>       | 0.18886 | 0.16113 | 0.17391 | 0.18291 | 0.17134 | 0.15430 |
| <i>Phyla nodiflora</i>       | 0.14689 | 0.16113 | 0.17391 | 0.18291 | 0.14992 | 0.17635 |
| <i>Pistacia terebinthus</i>  | 0.20984 | 0.18127 | 0.17391 | 0.20577 | 0.19276 | 0.22043 |
| <i>Prosopis farcta</i>       | 0.18886 | 0.18127 | 0.19565 | 0.20577 | 0.19276 | 0.17635 |
| <i>Pulicaria dysenterica</i> | 0.12590 | 0.16113 | 0.15217 | 0.16004 | 0.10709 | 0.17635 |
| <i>Punica granatum</i>       | 0.16787 | 0.16113 | 0.15217 | 0.18291 | 0.14992 | 0.19839 |
| <i>Quercus brantii</i>       | 0.18886 | 0.16113 | 0.17391 | 0.20577 | 0.17134 | 0.22043 |
| <i>Rhus coriaria</i>         | 0.18886 | 0.18127 | 0.19565 | 0.20577 | 0.19276 | 0.19839 |
| <i>Rubus sanctus</i>         | 0.12590 | 0.16113 | 0.15217 | 0.18291 | 0.12850 | 0.17635 |
| <i>Rumex scutatus</i>        | 0.16787 | 0.18127 | 0.15217 | 0.13718 | 0.17134 | 0.15430 |
| <i>Scariola orientalis</i>   | 0.18886 | 0.18127 | 0.17391 | 0.20577 | 0.17134 | 0.15430 |
| <i>Scorzonera mirabilis</i>  | 0.12590 | 0.08057 | 0.10870 | 0.11432 | 0.10709 | 0.08817 |
| <i>Stellaria kotschyana</i>  | 0.14689 | 0.16113 | 0.17391 | 0.16004 | 0.17134 | 0.15430 |
| <i>Tamarix smyrnensis</i>    | 0.18886 | 0.18127 | 0.19565 | 0.20577 | 0.19276 | 0.17635 |
| <i>Thymus haussknechtii</i>  | 0.18886 | 0.18127 | 0.19565 | 0.18291 | 0.19276 | 0.19839 |

Subsequently, the standard normalized matrix was multiplied by the specific criteria weights derived from the AHP analysis to generate the weighted normalized decision matrix (Table 14). This matrix forms the mathematical foundation for determining the positive and negative ideal solutions, reflecting the relative importance of each criterion in the context of the study area's specific edaphic and climatic constraints.

**Table 14.** Weighted normalized decision matrix.

| Alternatives (Plant Species)       | C1      | C2      | C3      | C4      | C5      | C6      |
|------------------------------------|---------|---------|---------|---------|---------|---------|
| <i>Achillea aleppica</i>           | 0.06106 | 0.04271 | 0.02396 | 0.02207 | 0.01495 | 0.00850 |
| <i>Achillea wilhelmsii</i>         | 0.06106 | 0.03322 | 0.02396 | 0.02207 | 0.01495 | 0.00850 |
| <i>Alhagi pseudalhagi</i>          | 0.06784 | 0.03797 | 0.02396 | 0.02943 | 0.01682 | 0.00607 |
| <i>Amygdalus arabica</i>           | 0.06106 | 0.03322 | 0.02696 | 0.02207 | 0.01495 | 0.00729 |
| <i>Andrachne telephioides</i>      | 0.04749 | 0.03797 | 0.01797 | 0.01104 | 0.01308 | 0.00486 |
| <i>Argyrolobium crotalarioides</i> | 0.05427 | 0.03797 | 0.02696 | 0.02575 | 0.01682 | 0.00850 |
| <i>Bongardia chrysogonum</i>       | 0.04070 | 0.04271 | 0.01797 | 0.01104 | 0.01495 | 0.00850 |
| <i>Celtis tournefortii</i>         | 0.06106 | 0.04271 | 0.02097 | 0.02943 | 0.01495 | 0.01093 |
| <i>Cichorium intybus</i>           | 0.05427 | 0.04271 | 0.02097 | 0.02575 | 0.01682 | 0.00971 |
| <i>Cruciata taurica</i>            | 0.04070 | 0.03797 | 0.02097 | 0.02575 | 0.01495 | 0.00729 |
| <i>Dianthus strictus</i>           | 0.05427 | 0.04271 | 0.02097 | 0.02207 | 0.01495 | 0.00971 |
| <i>Elaeagnus angustifolia</i>      | 0.06106 | 0.04271 | 0.02696 | 0.03679 | 0.01495 | 0.01093 |
| <i>Ephedra campylopoda</i>         | 0.06106 | 0.04271 | 0.02396 | 0.02575 | 0.01682 | 0.00850 |
| <i>Equisetum arvense</i>           | 0.02035 | 0.02848 | 0.02396 | 0.03311 | 0.00561 | 0.00486 |
| <i>Ficus carica</i>                | 0.06106 | 0.04271 | 0.02097 | 0.02943 | 0.01495 | 0.01093 |
| <i>Hedera helix</i>                | 0.01357 | 0.02848 | 0.00899 | 0.01472 | 0.00374 | 0.00486 |
| <i>Hedysarum varium</i>            | 0.05427 | 0.04271 | 0.02696 | 0.02943 | 0.01495 | 0.00850 |
| <i>Hypericum retusum</i>           | 0.05427 | 0.04271 | 0.02396 | 0.02207 | 0.01495 | 0.00971 |
| <i>Lythrum salicaria</i>           | 0.01357 | 0.02848 | 0.01498 | 0.01472 | 0.00374 | 0.00971 |
| <i>Moltkia coerulea</i>            | 0.06106 | 0.04271 | 0.02396 | 0.02207 | 0.01682 | 0.00971 |
| <i>Nepeta italica</i>              | 0.05427 | 0.04271 | 0.02396 | 0.02575 | 0.01682 | 0.01093 |
| <i>Nerium oleander</i>             | 0.06106 | 0.03797 | 0.02396 | 0.02943 | 0.01495 | 0.00850 |
| <i>Phyla nodiflora</i>             | 0.04749 | 0.03797 | 0.02396 | 0.02943 | 0.01308 | 0.00971 |
| <i>Pistacia terebinthus</i>        | 0.06784 | 0.04271 | 0.02396 | 0.03311 | 0.01682 | 0.01214 |
| <i>Prosopis farcta</i>             | 0.06106 | 0.04271 | 0.02696 | 0.03311 | 0.01682 | 0.00971 |
| <i>Pulicaria dysenterica</i>       | 0.04070 | 0.03797 | 0.02097 | 0.02575 | 0.00935 | 0.00971 |
| <i>Punica granatum</i>             | 0.05427 | 0.03797 | 0.02097 | 0.02943 | 0.01308 | 0.01093 |
| <i>Quercus brantii</i>             | 0.06106 | 0.03797 | 0.02396 | 0.03311 | 0.01495 | 0.01214 |
| <i>Rhus coriaria</i>               | 0.06106 | 0.04271 | 0.02696 | 0.03311 | 0.01682 | 0.01093 |
| <i>Rubus sanctus</i>               | 0.04070 | 0.03797 | 0.02097 | 0.02943 | 0.01121 | 0.00971 |
| <i>Rumex scutatus</i>              | 0.05427 | 0.04271 | 0.02097 | 0.02207 | 0.01495 | 0.00850 |
| <i>Scariola orientalis</i>         | 0.06106 | 0.04271 | 0.02396 | 0.03311 | 0.01495 | 0.00850 |
| <i>Scorzonera mirabilis</i>        | 0.04070 | 0.01898 | 0.01498 | 0.01839 | 0.00935 | 0.00486 |
| <i>Stellaria kotschyana</i>        | 0.04749 | 0.03797 | 0.02396 | 0.02575 | 0.01495 | 0.00850 |

|                             |         |         |         |         |         |         |
|-----------------------------|---------|---------|---------|---------|---------|---------|
| <i>Tamarix smyrnensis</i>   | 0.06106 | 0.04271 | 0.02696 | 0.03311 | 0.01682 | 0.00971 |
| <i>Thymus haussknechtii</i> | 0.06106 | 0.04271 | 0.02696 | 0.02943 | 0.01682 | 0.01093 |

Following the establishment of the weighted normalized decision matrix, the Euclidean distances of each perennial species to the positive ideal ( $S_i^+$ ) and negative ideal ( $S_i^-$ ) solutions were calculated. Finally, the relative closeness coefficients ( $C_i^*$ ) were computed to rank the plant alternatives from the most suitable to the least suitable for the targeted industrial site conditions (Table 15).

**Table 15.** Distances to ideal solutions ( $S^+$ ,  $S^-$ ), closeness coefficients ( $C_i^*$ ), and final TOPSIS ranking.

| Rank | Alternatives (Plant Species)       | $S^+$   | $S^-$   | $C_i^*$ |
|------|------------------------------------|---------|---------|---------|
| 1    | <i>Pistacia terebinthus</i>        | 0.00474 | 0.06666 | 0.93361 |
| 2    | <i>Elaeagnus angustifolia</i>      | 0.00714 | 0.06298 | 0.89816 |
| 3    | <i>Rhus coriaria</i>               | 0.00781 | 0.06194 | 0.88805 |
| 4    | <i>Prosopis farcta</i>             | 0.00796 | 0.06191 | 0.88607 |
| 5    | <i>Tamarix smyrnensis</i>          | 0.00796 | 0.06191 | 0.88607 |
| 6    | <i>Thymus haussknechtii</i>        | 0.01004 | 0.06103 | 0.85868 |
| 7    | <i>Alhagi pseudalhagi</i>          | 0.01083 | 0.06023 | 0.84759 |
| 8    | <i>Scariola orientalis</i>         | 0.00862 | 0.06015 | 0.87465 |
| 9    | <i>Quercus brantii</i>             | 0.01016 | 0.05948 | 0.85410 |
| 10   | <i>Ficus carica</i>                | 0.01168 | 0.05877 | 0.83420 |
| 11   | <i>Celtis tournefortii</i>         | 0.01168 | 0.05877 | 0.83420 |
| 12   | <i>Nerium oleander</i>             | 0.01150 | 0.05696 | 0.83201 |
| 13   | <i>Ephedra campylopoda</i>         | 0.01358 | 0.05777 | 0.80966 |
| 14   | <i>Hedysarum varium</i>            | 0.01633 | 0.05315 | 0.76496 |
| 15   | <i>Moltkia coerulea</i>            | 0.01621 | 0.05607 | 0.77573 |
| 16   | <i>Nepeta italica</i>              | 0.01815 | 0.05436 | 0.74968 |
| 17   | <i>Achillea aleppica</i>           | 0.01662 | 0.05587 | 0.77072 |
| 18   | <i>Cichorium intybus</i>           | 0.01925 | 0.05272 | 0.73252 |
| 19   | <i>Punica granatum</i>             | 0.01676 | 0.05051 | 0.75085 |
| 20   | <i>Hypericum retusum</i>           | 0.02052 | 0.04940 | 0.70652 |
| 21   | <i>Dianthus strictus</i>           | 0.02115 | 0.04901 | 0.69854 |
| 22   | <i>Rumex scutatus</i>              | 0.02117 | 0.04900 | 0.69830 |
| 23   | <i>Argyrolobium crotalarioides</i> | 0.02014 | 0.04787 | 0.70386 |
| 24   | <i>Phyla nodiflora</i>             | 0.02235 | 0.04351 | 0.66064 |
| 25   | <i>Achillea wilhelmsii</i>         | 0.01944 | 0.05244 | 0.72956 |
| 26   | <i>Amygdalus arabica</i>           | 0.01918 | 0.05252 | 0.73249 |
| 27   | <i>Stellaria kotschyana</i>        | 0.02381 | 0.04169 | 0.63648 |
| 28   | <i>Bongardia chrysogonum</i>       | 0.03848 | 0.03714 | 0.49113 |
| 29   | <i>Rubus sanctus</i>               | 0.02901 | 0.03798 | 0.56695 |
| 30   | <i>Cruciata taurica</i>            | 0.03058 | 0.03530 | 0.53582 |
| 31   | <i>Pulicaria dysenterica</i>       | 0.03073 | 0.03456 | 0.52932 |
| 32   | <i>Andrachne telephioides</i>      | 0.03362 | 0.03964 | 0.54108 |
| 33   | <i>Equisetum arvense</i>           | 0.05030 | 0.02534 | 0.33500 |
| 34   | <i>Scorzonera mirabilis</i>        | 0.04012 | 0.03099 | 0.43580 |
| 35   | <i>Lythrum salicaria</i>           | 0.05949 | 0.01257 | 0.17443 |
| 36   | <i>Hedera helix</i>                | 0.06173 | 0.01053 | 0.14572 |

The TOPSIS ranking revealed that *Pistacia terebinthus* was the most suitable plant alternative for the research area, exhibiting the highest closeness coefficient (0.93361). This species was closely followed by *Elaeagnus angustifolia* (Tree, 0.89816) and *Rhus coriaria* (Shrub, 0.88805). The superior performance of these specific taxa is primarily attributed to their exceptional physiological tolerance against high calcareous soils, severe summer drought, and their strong capacity for root-based soil stabilization without requiring intensive maintenance.

Other highly ranked species included *Prosopis farcta* and *Tamarix smyrnensis*, which share a well-documented resilience to the identified edaphic constraints and thermal stress. Conversely, species such as *Hedera helix* (0.14572) and *Lythrum salicaria* (0.17443), which typically depend on higher soil moisture levels, lower atmospheric water demand, and more fertile organic conditions, exhibited the lowest suitability scores. These lower-ranking results accurately reflect the decision model's sensitivity in filtering out species that cannot independently sustain themselves in severely degraded, high-lime, and semi-arid industrial environments.

#### **Sensitivity Analysis of the Ranking Stability:**

To rigorously validate the robustness of the TOPSIS ranking and ensure that the selection of the top-performing species is not an artifact of specific expert-assigned weights, a comprehensive sensitivity analysis was conducted for all six criteria (C1-C6). This process tested the stability of the decision model by applying a perturbation of  $\pm 20\%$  to the weight of each criterion individually. To maintain the mathematical requirement that the sum of all

criterion weights equals 1.00, the difference resulting from the perturbation of a single criterion was proportionally redistributed among the remaining five criteria.

The stability of the top 5 ranked perennial species was monitored under 12 different scenarios (a  $\pm 20\%$  variation for each of the 6 criteria). The results of this comprehensive stability test are summarized in Table 16.

**Table 16.** Comprehensive sensitivity analysis: Rank stability of the top 5 perennials across 12 perturbation scenarios.

| Perturbed Criterion | Scenario   | Weight Change | <i>P. terebinthus</i> | <i>E. angustifolia</i> | <i>R. coriaria</i> | <i>P. farcta</i> | <i>T. smyrnensis</i> |
|---------------------|------------|---------------|-----------------------|------------------------|--------------------|------------------|----------------------|
| Base Case           | -          |               | 1                     | 2                      | 3                  | 4                | 5                    |
| C1                  | $\pm 20\%$ | 0.258/0.388   | 1                     | 2                      | 3                  | 4                | 5                    |
| C2                  | $\pm 20\%$ | 0.188/0.282   | 1                     | 2                      | 3                  | 4                | 5                    |
| C3                  | $\pm 20\%$ | 0.110/0.165   | 1                     | 2                      | 3                  | 4                | 5                    |
| C4                  | $\pm 20\%$ | 0.128/0.193   | 1                     | 2                      | 3                  | 4                | 5                    |
| C5                  | $\pm 20\%$ | 0.069/0.104   | 1                     | 2                      | 3                  | 4                | 5                    |
| C6                  | $\pm 20\%$ | 0.044/0.066   | 1                     | 2                      | 3                  | 4                | 5                    |

The analysis confirms that the ranking of the top 5 perennial species is highly resilient to weight fluctuations. Regardless of the criterion being perturbed, *Pistacia terebinthus*, *Elaeagnus angustifolia*, and *Rhus coriaria* consistently maintain their positions in the top three. Minor variations in the closeness coefficients ( $C_i^*$ ) were observed, but these did not alter the fundamental hierarchy of the preferred species. This finding indicates that the model is robust and that the identified species are genuinely the most ecologically and agronomically suitable alternatives for the restoration of the research area, independent of minor subjective variations in expert weighting.

## Discussion:

### Integration of Edaphic and Climatic Constraints in Industrial Site Planning

The soil survey demonstrated that revegetation constraints within the Şanlıurfa OIZ do not stem from a single limiting factor but from the overlap of several edaphic deficiencies: 88% of the sampled locations were classified as highly or very highly calcareous, and 96% exhibited severe organic matter deficiency, together with widespread phosphorus (44% of samples) and potassium (56% of samples) shortfalls. These conditions occur against a climatic background in which the mean annual temperature reaches 18.6°C, average summer maxima approach 38°C, and monthly rainfall during June–August falls to only 2–4.6 mm, accompanied by high evaporative demand. Considered separately, none of these constraints is unusual for a semi-arid Mediterranean-influenced setting; considered together, however, they compound into a single, mutually reinforcing stress matrix. Very low organic matter reduces the soil's capacity to buffer moisture loss under a high-evaporation regime, while high calcium carbonate content further restricts the availability of phosphorus and micronutrients that are already scarce, so that root establishment must occur under simultaneous chemical, structural, and thermal stress rather than under any one of these pressures in isolation.

This pattern supports the view, echoed in the broader industrial-restoration literature, that soil and climate data are frequently reported as parallel but separate lines of evidence rather than as an integrated pressure system. Studies of degraded industrial land have often prioritized contamination screening or the spatial mapping of individual soil parameters, with aridity treated as background context rather than as an interacting stressor. The present findings indicate that in semi-arid industrial settings such as the Şanlıurfa OIZ, edaphic and climatic constraints should instead be read jointly: a moderately calcareous soil under humid conditions poses a fundamentally different establishment challenge than the same calcareous condition under prolonged summer drought. Framing site assessment in these combined terms provides a more realistic basis for anticipating which taxa can plausibly persist and is the rationale underlying the criterion structure adopted in the subsequent multi-criteria evaluation.

### Methodological Insights from Multi-Criteria Decision-Making (AHP-TOPSIS)

The AHP results, in which “Resistance to drought and high temperature” (C1, 32.33%) and “Adaptation to calcareous and alkaline soils” (C2, 23.56%) together accounted for more than half of the total criterion weight, are consistent with the site conditions documented in Section 3.1 and 3.2. Because 88% of samples were highly calcareous and the climate imposes near-total summer aridity, it is coherent that the expert panel assigned the greatest importance to the two criteria most directly tied to physiological survival rather than to criteria addressing amenity or ecological ornamentation. The comparatively low weight placed on “Landscape and ecological use value” (C6, 5.51%) similarly reflects a defensible expert judgment that, in a severely constrained industrial substrate, persistence and establishment must precede aesthetic or habitat considerations rather than compete with them. The low consistency ratio obtained for the pairwise comparisons (CR = 0.02988) further supports the reliability of this weighting structure as an input to the ranking stage.

The subsequent application of TOPSIS translated these weights into a transparent, criterion-by-criterion decision matrix, allowing each candidate taxon to be positioned relative to both the ideal and the anti-ideal solution rather

than ranked through qualitative expert impression alone. This step is methodologically significant because plant-selection literature for degraded or industrial land has often relied on descriptive species lists compiled from local floras, without an explicit and reproducible procedure for weighing trade-offs between competing selection criteria. By contrast, the AHP-TOPSIS sequence used here converts expert judgment into quantifiable weights and then applies those weights consistently across all 36 candidate taxa, so that the resulting ranking can, in principle, be reproduced or re-evaluated by other researchers using the same decision matrix. The sensitivity analysis reinforced this transparency: perturbing each of the six criterion weights by  $\pm 20\%$  across twelve scenarios left the top three ranked species unchanged, indicating that the prioritization is driven by the underlying trait–criterion relationships rather than by an incidental configuration of expert weights.

### ***Ecological Significance and Physiological Resilience of Top-Ranked Native Perennials***

The species that occupied the top positions in the TOPSIS ranking, *Pistacia terebinthus* ( $C_i^* = 0.93361$ ), *Elaeagnus angustifolia* ( $C_i^* = 0.89816$ ), and *Rhus coriaria* ( $C_i^* = 0.88805$ ), share a recognizable physiological profile: deep and extensive root systems capable of accessing subsoil moisture, documented tolerance of calcareous and slightly alkaline substrates, and the capacity to persist under prolonged drought with minimal irrigation once established. This combination of traits maps closely onto the two dominant criteria identified in Section 3.3, resistance to drought and heat (C1) and adaptation to calcareous soils (C2) and helps explain why these taxa separated so clearly from the remainder of the candidate pool despite the relatively small differences observed among several mid-ranked species.

The lower end of the ranking provides a complementary form of validation. Species such as *Hedera helix* ( $C_i^* = 0.14572$ ) and *Lythrum salicaria* ( $C_i^* = 0.17443$ ) are ecologically associated with consistently moist, organically rich substrates and comparatively low atmospheric water demand, conditions essentially absent from the OIZ, where 96% of samples were severely deficient in organic matter and summer rainfall is negligible. Their consistent placement at the bottom of the ranking, well separated from the calcareous- and drought-tolerant taxa at the top, indicates that the model is not merely ordering species by a generic “hardiness” impression but is actively discriminating against taxa whose ecological requirements are structurally incompatible with the measured site conditions. This outcome supports the ecological validity of the decision framework: the ranking reproduces, in a quantitative and reproducible form, relationships between plant traits and site constraints that are already well established in the regional botanical and ecological literature.

### ***Practical Applications and Management Recommendations for Sustainable Landscaping***

Beyond its methodological contribution, the prioritization matrix generated in this study offers a directly usable planning tool for local authorities and organized industrial zone management. Because the restoration-priority classification in Table 5 identifies which sampling points require the most intensive organic matter, phosphorus, or potassium intervention, this spatial information can be paired with the TOPSIS ranking so that top-performing, low-maintenance taxa such as *Pistacia terebinthus*, *Elaeagnus angustifolia*, and *Rhus coriaria* are preferentially allocated to the most constrained parcels, while species positioned lower in the ranking, but still ecologically eligible, may be reserved for locations with comparatively favourable soil indicators. Prioritizing deep-rooted, drought- and lime-tolerant perennials in this way is expected to reduce long-term irrigation and fertilization demand, which is particularly relevant for industrial zone managers operating under limited landscape-maintenance budgets.

From a broader sustainable-landscaping perspective, the root architecture and ground-cover characteristics captured under the soil-stabilization criterion (C4) suggest that the top-ranked species can also contribute to erosion control on exposed roadside verges, embankments, and unsealed parcels that are otherwise prone to surface loss under the intense, short-duration rainfall events typical of the region. Because the framework explicitly separates measured site evidence from expert-based management preferences, municipalities and OIZ authorities can adapt the underlying decision matrix to future planting programs, revised soil surveys, or additional candidate taxa without repeating the full elicitation process from the outset. Consistent with the exploratory scope stated for this study, the resulting priority list should be treated as a pre-implementation screening output; site-level establishment trials and post-planting monitoring remain necessary before the prioritized taxa can be considered validated for large-scale operational use.

### **Conclusion and Recommendations:**

This study successfully operationalized an evidence-based decision framework for prioritizing native perennial plants for low-input revegetation in semi-arid industrial landscapes. By integrating site-specific edaphic constraints, climatic data, regional floristic records, and expert judgments into a functional-group-specific MCDM protocol, the framework bridges the gap between environmental assessment and actionable planting design. The proposed methodology successfully identified ecologically compatible taxa specifically *Pistacia terebinthus*, *Elaeagnus angustifolia*, and *Rhus coriaria* while providing a transparent, reproducible, and robust decision-making process that remains stable even under varied weighting scenarios.

Beyond the Şanlıurfa case study, the structural logic of this framework linking measurable environmental stressors to plant traits via a weighted, functional-group-specific protocol is inherently transferable to other degraded industrial landscapes, including post-mining sites, highway corridors, and urban brownfields.

To advance this framework and support its adoption across diverse contexts, the following recommendations are proposed:

- Empirical Performance Validation: While the AHP-TOPSIS protocol offers a rigorous screening tool, its predictive validity should be tested through empirical establishment trials. Future research should prioritize monitoring survival, growth, and soil-stabilization outcomes to iteratively recalibrate the model, transforming it from a static screening tool into a dynamic, learning-based decision system.
- Spatial and Dynamic Integration: To enhance precision, practitioners should couple this framework with spatially explicit data (GIS-based soil/micro-climate mapping). Furthermore, future iterations should incorporate climate-change projections (SSP scenarios) to assess how the relative importance of drought-tolerance criteria may evolve, ensuring that revegetation investments remain resilient under long-term climatic shifts.
- Probabilistic Robustness: To strengthen cross-regional comparability, future studies should supplement AHP weights with stochastic multi-criteria acceptability analysis (SMAA). This provides a confidence metric for each prioritization decision, allowing managers to quantify the probability of a taxon's success under varying expert interpretations.
- Operational Feasibility Screening: Ecological suitability is the first tier of the decision; however, practical application requires a logistical screening layer. Future frameworks should incorporate a secondary tier filtering the ecologically prioritized candidates through a feasibility index that evaluates commercial seed supply, propagation protocols, and cost-efficiency.
- Open-Science Transparency: To facilitate broader adoption, researchers are encouraged to deposit anonymized scoring matrices and weight-elicitation protocols in open repositories. Establishing an open database of trait-based restoration outcomes will allow for meta-analytical comparisons across global industrial landscapes, accelerating the evolution of sustainable restoration practices.

In conclusion, this framework demonstrates that integrating measured site data with multi-criteria prioritization provides a defensible, traceable, and adaptable basis for revegetation. Practitioners are encouraged to adjust criterion definitions to local ecological contexts while preserving the framework's procedural rigor, ensuring that plant selection remains grounded in site reality rather than generic recommendation lists.

#### Statements & Declarations:

**Conflict of Interest:** The authors have no relevant financial or non-financial interests to disclose.

**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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