10.70711/eph.v2i5.7495

# Comprehensive Evaluation of Substrate Selection for Container Seedling Cultivation of Three Xerophytic Tree Species Based on the Entropy Weight Method

**Pengfei Shi[1, a], Qiangfeng Li[1, b, *], Linlin Li[1, c]**

**1. College of Agriculture and Animal Husbandry, Qinghai University, Xining, Qinghai 810016, China**

**[a]1687162791@qq.com, [b]1324985124@qq.com, [c]908084026@qq.com**

***Abstract:*** To optimize substrates for container cultivation of xerophytic trees, Haloxylon ammodendron, Tamarix chinensis, and Atraphaxis bracteata were tested using an $L_9(3^4)$ orthogonal design with nine mixtures of native soil, organic fertilizer, landscape waste, and vermiculite. Substrate properties and seedling growth were significantly affected. Bulk density ranged from 1.4-1.72g/cm$^{-3}$; porosity from 48.61%-59.27%. T7 and T8 showed superior overall performance. T8 promoted chlorophyll in H. ammodendron (1.21mg·g$^{-1}$) and biomass in T. chinensis; T6 favored A. bracteata. Entropy weight analysis identified T3, T7, and T6 as optimal for the three species. Results support substrate selection and landscape waste reuse in arid-region nurseries.

***Keywords:*** Xerophytic species; Container seedling; Substrate combination; Orthogonal design; Growth indicators

## 1. Introduction

Container seedling cultivation began in the U.S. in the 1930s with Sequoia sempervirens, improving survival in arid, nutrient-poor areas [1]. It was later widely adopted in Canada, Sweden, Brazil, and South Africa, where container seedlings now dominate nursery production [2]. In China, trials began in the 1950s with Eucalyptus and Casuarina equisetifolia in Guangzhou [3]. Recent research emphasizes lightweight substrates. Liu Yiwei found they improved Machilus pingii traits [4], and Sheng Qianqian identified a 1:1:1 mix of native soil, vermiculite, and peat as optimal for Quercus rubra [5]. Though peat is ideal due to its light weight and water retention, it is non-renewable [6], prompting interest in alternatives like landscape waste, which offers similar benefits at lower cost [7, 8]. However, few systematic studies have evaluated such substrates for xerophytic species like Haloxylon ammodendron, Tamarix chinensis, and Atraphaxis bracteata.

## 2. Materials and Methods

### 2.1 Experimental Design and Materials

The study involved Haloxylon ammodendron, Tamarix chinensis (seeds and cuttings), and Atraphaxis bracteata. Substrates included native soil, vermiculite, perlite, and fermented landscape waste from Najia Mountain. All materials were locally sourced. A greenhouse experiment in Xining used an $L9(3^4)$ orthogonal design with nine substrate combinations (Table 1), each with three replicates of ten pots. Standard management was applied after sowing and cutting, and observations began two weeks later.

### 2.2 Measurement of Growth Indicators

Seedling height was measured with a tape measure, ground diameter with a vernier caliper, root morphology with the WinRHIZO 2004 system, and chlorophyll content by ethanol-acetone extraction [9].

### 2.3 Data Analysis

All experimental data were compiled using Excel 2022. One-way ANOVA was performed using SPSS 27.0, and the Entropy Weight Method (EWM) was employed to comprehensively evaluate the performance of different substrate treatments.

EWM is an objective weighting method based on the information entropy of each indicator. The main steps are as follows:

(1) Original data were standardized. For positive indicators, the standardization formula is:

$$Y_{ij} = \frac{X_{ij} - X_{jmin}}{X_{jmax} - X_{jmin}}$$

For negative indicators, the normalization formula is as follows:

$$Y_{ij} = \frac{X_{jmax} - X_{ij}}{X_{jmax} - X_{jmin}}$$

In the formula: $Y_{ij}$ represents the normalized value of the j-th indicator for the i-th substrate combination; $X_{ij}$ is the measured value of the j-th indicator for the i-th substrate combination; $X_{jmin}$ and $X_{jmax}$ denote the minimum and maximum values of the j-th indicator, respectively.

(2) Calculation of information entropy ($H_j$) for the seven growth indicators.

$$H_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} \left[\frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \ln\left(\frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}\right)\right]$$

In the formula: n represents the number of substrate combinations.

(3) Calculate the weights ($W_j$) of the seven growth indicators.

$$W_j = \frac{1 - H_j}{\sum_{j=1}^{m} (1 - H_j)}$$

In the formula: m represents the number of growth indicators.

(4) Calculate the comprehensive score ($Z_i$) for each treatment based on the weighted sum of the seven indicator weights.

$$Z_i = \sum_{j=1}^{m} W_j Y_{ij}$$

# 3. Results and Analysis

## 3.1 Effects of Substrate Combinations on Aboveground Growth

T8 and T6 consistently promoted optimal growth across all three species. For Tamarix chinensis, they achieved the highest seedling height and ground diameter, with lower height-to-diameter ratios indicating stronger stems. Haloxylon ammodendron also performed best under T8 and T6 in both height and diameter. In Atraphaxis bracteata, T8 and T6 produced the largest seedlings with robust architecture. Overall, these two substrate combinations demonstrated the greatest potential for enhancing seedling development.

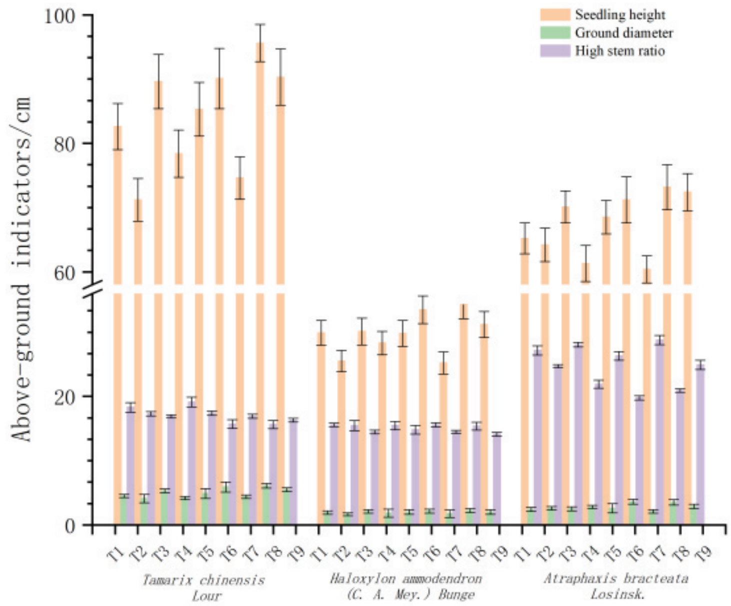


**Figure 1. Growth Performance of Seedlings under Different Substrate Combinations.**

## 3.2 Effects of Substrate Combinations on Root Growth

### 3.2.1 Effects on Tamarix chinensis

Table 1 shows substrate type greatly affected Tamarix chinensis root growth. T7 and T3 had the longest taproots, T4 the shortest. Lateral roots were longest in T7, shortest in T2 and T4. T7 had the highest root volume and tip number, while T9 was lowest. Overall, T7 best promoted root development in T. chinensis.

### 3.2.2 Effects on Haloxylon ammodendron

As shown in Table 1, substrate combinations had significant effects on root traits. T8 yielded the longest taproots (23.21 cm) and lateral roots (16.08 cm), followed by T3 and T9; T2 and T7 were shortest. Root volume was highest in T7 (142.69 $cm^3$), then T3; T8 and T9 were lowest. T7 also had the most root tips (682.13), followed by T3 and T5. Overall, T8 promoted root elongation, while T7 enhanced volume and root tip development.

### 3.2.3 Effects on Atraphaxis bracteata

Table 1 shows substrate combinations significantly influenced root traits. T3 had the longest taproots (21.30 cm), followed by T6, T1, and T8 (>20 cm); T2 was shortest (14.05 cm). Lateral roots were longest in T4 (19.71 cm) and T6 (18.94 cm), exceeding T1 and T7. T8 had the largest root volume (177.97 $cm^3$) and most root tips (746.93), followed by T4 and T6; T9 had the lowest values. Overall, T8 and T6 best promoted root development in A. bracteata.

**Table 1. Effects of Different Substrate Combinations on the Belowground Traits of Three Plant Species.**

| | Substrate Combination | Taproot Length (cm) | Maximum Lateral Root Length (cm) | Root Volume ($cm^3$) | Number of Root Tips (pcs) |
|---|---|---|---|---|---|
| Tamarix chinensis | T1 | 17.41±2.87 cd | 18.25±3.85 cd | 127.41±24.83 bc | 446.13±91.26 cd |
| | T2 | 16.70±2.76 d | 16.61±3.50 d | 95.25±18.94 d | 458.59±87.53 cd |
| | T3 | 19.27±3.58 ab | 22.23±5.74 bc | 132.02±26.71 b | 603.35±118.42 ab |
| | T4 | 15.39±2.68 d | 17.13±4.10 d | 111.01±22.16 cd | 525.83±94.81 bc |
| | T5 | 19.23±3.92 ab | 21.77±5.92 bc | 145.65±27.89 ab | 603.35±123.67 ab |
| | T6 | 16.57±3.42 d | 18.01±5.33 cd | 118.98±25.33 bc | 544.84±115.29 bc |
| | T7 | 19.47±3.84 a | 23.33±7.08 a | 152.09±28.45 a | 663.63±127.38 a |
| | T8 | 17.63±3.37 cd | 20.63±5.61 bc | 98.72±20.57 cd | 439.59±96.24 cd |
| | T9 | 19.30±3.96 ab | 22.18±6.89 bc | 92.06±19.83 d | 405.73±89.12 d |
| Haloxylon ammodendron (C. A. Mey.) Bunge | T1 | 18.31±2.77 d | 14.46±1.44 bc | 99.58±21.83 cd | 407.44±91.05 d |
| | T2 | 17.82±3.14 d | 13.68±1.36 c | 96.83±19.88 d | 454.53±101.15 cd |
| | T3 | 20.93±3.06 bc | 15.21±1.44 ab | 134.28±27.41 ab | 585.68±130.18 ab |
| | T4 | 18.56±3.72 cd | 14.31±1.45 bc | 104.33±18.53 bcd | 527.05±93.30 bc |
| | T5 | 19.10±3.42 bcd | 14.85±1.47 abc | 111.28±22.78 bcd | 582.08±117.38 ab |
| | T6 | 20.47±2.70 bc | 15.11±1.92 ab | 108.43±22.21 bcd | 538.91±119.84 bc |
| | T7 | 17.49±3.63 d | 14.85±1.47 abc | 142.69±29.07 a | 682.13±134.26 a |
| | T8 | 23.21±2.69 a | 16.08±1.89 a | 95.15±19.55 d | 390.55±86.93 d |
| | T9 | 20.60±4.07 b | 15.11±1.92 ab | 88.75±19.58 d | 397.71±86.96 d |
| Atraphaxis bracteata Losinsk. | T1 | 20.63±1.97 ab | 14.89±1.42 c | 128.46±11.83 c | 506.60±48.35 c |
| | T2 | 14.05±1.44 c | 16.77±1.76 bc | 117.59±10.92 c | 516.80±43.67 c |
| | T3 | 21.30±2.23 a | 16.21±1.38 bc | 167.22±16.14 a | 601.80±53.62 ab |
| | T4 | 19.83±2.18 b | 19.71±1.82 ab | 169.15±15.47 a | 638.40±54.89 a |
| | T5 | 17.53±2.01 bc | 17.39±1.71 bc | 145.93±14.92 b | 526.07±51.73 bc |
| | T6 | 21.13±2.11 a | 18.94±1.79 ab | 157.64±14.68 ab | 693.87±58.24 a |
| | T7 | 18.89±2.05 b | 15.61±1.63 c | 151.65±15.21 ab | 679.60±56.17 a |
| | T8 | 20.54±2.14 ab | 16.27±1.68 bc | 177.97±16.83 a | 746.93±62.35 a |
| | T9 | 19.21±1.99 b | 17.89±1.75 bc | 122.41±12.74 c | 401.00±47.52 d |

### 3.4 Comprehensive Evaluation of Substrate Effects

Using the Entropy Weight Method, substrate effectiveness was ranked as follows:

H. ammodendron: T3 > T8 > T7 > T5 > T6 > T9 > T4 > T1 > T2

T. chinensis: T7 > T3 > T5 > T6 > T8 > T9 > T1 > T2 > T4

A. bracteata: T6 > T8 > T4 > T5 > T3 > T9 > T2 > T7 > T1

These results reveal species-specific responses and guide optimal substrate selection in nursery practices.

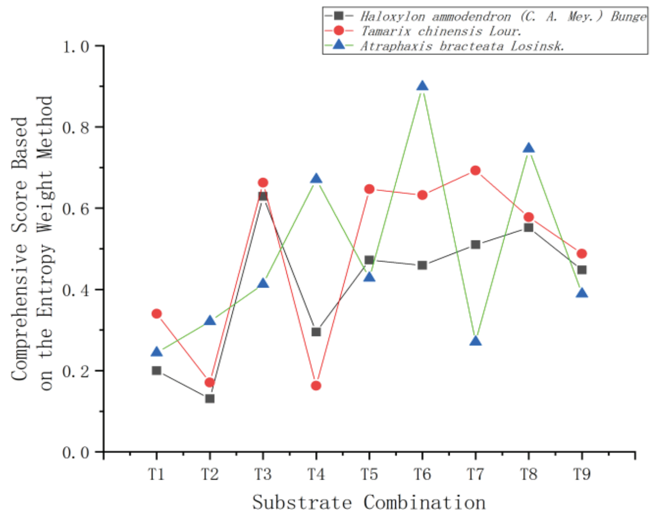


**Figure 2. Comprehensive Scores of Seedlings under.**

## 4. Conclusion

Using an L9($3^4$) orthogonal design, this study systematically evaluated nine substrate combinations on three xerophytic species: Haloxylon ammodendron, Tamarix chinensis, and Atraphaxis bracteata. Significant differences were found in substrate physical and chemical properties and their effects on seedling growth, consistent with previous studies and revealing species-specific responses. The results validate the use of landscape waste in substrates, with T4 and T8 (high in landscape waste) showing favorable physical traits and nutrient contributions, aligning with Carmona et al. [7]. While beneficial for sustainability, composting methods and substrate stability require further improvement [10].

Based on Entropy Weight Method analysis, recommended substrates are:

· H. ammodendron: T3

· T. chinensis: T7

· A. bracteata: T6

These findings offer a theoretical basis for optimizing container substrates in arid regions.

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