Plant quality in forest restoration: morphological and physiological components

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Factors that determine revegetation success

If selected species are suitable and climatic conditions are not unusually extreme

1) Soil preparation

2) Plant care in the field:
   - herb competition and in some cases shrub competition
   - herbivores exclusion

3) The quality of seedlings or of any other material used in afforestation (stecklings, emblings, and seeds)
What is a plant of high quality?

- Plants that meet defined levels of survival and growth on a particular site.
  
  If seedlings fail to meet these out-planting performance standards then seedlings need to be replanted (Duryea, 1985).

- In Spain, many reforestation projects define 80% survival as a tolerable limit.
Plant quality is more relevant the harsher the planting environment is.

Plant quality changes through time.

Plant quality has short- and long-term consequences.
Why it is important to use and produce high-quality plants?

• Ecological reasons

• Economical reasons
  • Reduces plantation costs
  • Warrants the prestige of nurseries
  • Allows to identify precisely the factors that explain low out-planting performance
Plant quality is defined by 4 components

1) Genetic
2) Sanitary
3) Morphological
4) Physiological

Can be defined by a set of attributes: MATERIAL attributes
Sanitary quality

Avoid plants infected or damaged by diseases or pests because they can jeopardize all the restoration.
Sanitary quality

... but do not confound fungi diseases (mould) with mycorrhizas
Morphological quality

• It is defined by a set of attributes (material attributes) related to the form and structure of the plant

• Morphological attributes are the basis of the plant quality legislation of the European Union

• Quantitative and qualitative
Avoid injured plants, specially if wounds are recent and not related to pruning

Thomas D. "Tom" Landis, USDA Forest Service
In EUROPEAN legislation

Qualitative morphological attributes

Avoid plants with signs of desiccation, overheating, specially if they have been stored.
Qualitative morphological attributes

Avoid plants with excessive stem curvature

Rejected

Accepted

If crooking affects the upper shoot part
In EUROPEAN legislation

Avoid plants with multiple stems

Exceptions!!
Qualitative morphological attributes

Avoid plants with strongly deformed roots

In EUROPEAN legislation
Qualitative morphological attributes

Avoid plants not well balanced (shoot and root system)

However legislation doesn’t define what is an unbalanced plant
Avoid plants with growing and not hardened shoots

- **Hardened seedling**
- **Unhardened seedling**

Presence of apical buds helps to recognize hardened seedlings. However, not all species develop apical buds.
Avoid seedlings with no or few branches (but not all species)

In many species the lack of branches in 1-year old seedlings is the rule.
Qualitative morphological attributes

NOT In EUROPEAN legislation

Avoid plants with poorly developed secondary roots or with excised roots
Quantitative morphological attributes

**Shoot length**

**Root collar diameter**

**Shoot and root mass**

**Root to shoot mass ratio**

Cheap, easy to measure and predicts quite well out-planting performance potential if plants are not damaged.

*Quercus faginea*

- Shoot length: 6 - 30 cm / 2 mm
- Root collar diameter: 10-50 cm / 3mm

*Quercus ilex*

- Shoot length: 8 - 30 cm / 2 mm
- Root collar diameter: 15 - 50 cm / 3 mm

*Pinus halepensis*

- Shoot length: 10 - 30 cm / 2 mm
- Root collar diameter: 15 - 45 cm / 3 mm
Plant size and out-planting performance

*Quercus ilex* (holm oak)

\[ y = -23.56x + 70.27 \]

\[ r^2 = 0.32 \quad P=0.018 \]

\[ y = 3.7145x - 3.2271 \]

\[ r^2 = 0.47 \quad P=0.002 \]

Villar-Salvador et al. 2004 Forest Ecology and Management 196:257-266
Experimental results suggest that large plants do also tend to perform better in Mediterranean environments.
The balance between plant dimensions is also important.
Proportion between the size of the shoot and the root

Shoot/root ratios

- Quercus ilex < 1
- Quercus faginea < 1
- Pinus halepensis 1 - 2
- Pinus pinea: 1.4 - 2
- Juniperus thurifera: 1 - 2
- Olea europaea: 1 - 4

Increasing vulnerability to drought??
Proportion between the size of the shoot and the root

**Quercus ilex**

A very low shoot to root ratio can impair out-planting performance
Proportion between the size of the shoot and the root

McDonald et al., 1984. J. Env. Hort. 2:5-8
¿Do seedlings with small shoots and root to shoot ratios have better out-planting performance than seedlings with large shoots and root to shoot ratios in Mediterranean environments?
21 Experimental plots

*Pinus pinaster* (7) and *P. halepensis* (7)

*P. pinea* (5)

*P. nigra* (1) and *P. sylvestris* (1)

<table>
<thead>
<tr>
<th>Locations</th>
<th>Rainfall (mm)</th>
<th>Mean max. Temp July (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Pto Lumbreras</td>
<td>350</td>
<td>34.0</td>
</tr>
<tr>
<td>2- El Serranillo</td>
<td>414</td>
<td>32.1</td>
</tr>
<tr>
<td>3- Almoguera</td>
<td>415</td>
<td>33.7</td>
</tr>
<tr>
<td>4- Munébrega</td>
<td>440</td>
<td>31.0</td>
</tr>
<tr>
<td>5- Almagro</td>
<td>450</td>
<td>34.1</td>
</tr>
<tr>
<td>6- Uceda</td>
<td>567</td>
<td>31.7</td>
</tr>
<tr>
<td>7- Priéjano</td>
<td>660</td>
<td>24.4</td>
</tr>
<tr>
<td>8- Los Navalucillos</td>
<td>690</td>
<td>33.7</td>
</tr>
</tbody>
</table>
Hypothesis

- Survival
- Growth

- Shoot size: mass, diameter, height
- Shoot mass / root mass

Significant if $r^2 \geq 0.1$ at $\alpha=0.1$
## Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>SURVIVAL</th>
<th>GROWTH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All species</td>
<td>All species</td>
</tr>
<tr>
<td></td>
<td>+  -  0</td>
<td>+  -  0</td>
</tr>
<tr>
<td>Height</td>
<td>4  0  13</td>
<td>7  0  12</td>
</tr>
<tr>
<td>Diameter</td>
<td>3  0  14</td>
<td>7  0  11</td>
</tr>
<tr>
<td>Shoot mass</td>
<td>2  0  12</td>
<td>9  0  8</td>
</tr>
<tr>
<td>Shoot / Root mass</td>
<td>0  1  13</td>
<td>1  0  16</td>
</tr>
</tbody>
</table>
Revision of 30 studies published by Spanish authors

CONCLUSION: In Mediterranean environments, in most cases (50-60% cases) plant size is not related with out-planting performance. However, when it is related larger plants tend to perform better than smaller ones.
<table>
<thead>
<tr>
<th>Species</th>
<th>Shoot length (cm)</th>
<th>Root collar diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus halepensis</em></td>
<td>15 - 30</td>
<td>3 - 4</td>
</tr>
<tr>
<td></td>
<td>(10 - 25)</td>
<td>(&gt;2)</td>
</tr>
<tr>
<td><em>Pinus pinea</em></td>
<td>20 - 30</td>
<td>3.5 - 4.5</td>
</tr>
<tr>
<td></td>
<td>(10 - 30)</td>
<td>(&gt;3)</td>
</tr>
<tr>
<td><em>Quercus ilex</em></td>
<td>20 - 30</td>
<td>4 - 5</td>
</tr>
<tr>
<td></td>
<td>(8 - 30)</td>
<td>(&gt;2)</td>
</tr>
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</table>
Physiological quality: physiological attributes

• Set of attributes (material attributes) related to the function of the plant
• Most of them are expensive and time consuming
• Provide information that morphological attributes cannot. Therefore they should complement morphological attributes

• Concentration of mineral nutrients and storage carbohydrates
• Dormancy of apical buds (Mitotic index and days to budburst)
• Chlorophyll fluorescence

• Infrared thermography
• Stress-induced volatile emission
• Plant vigour estimation by vital colorants
• Chlorophyll concentration
• Stomatal conductance and photosynthetic rate
• Water potential
Nutrient concentration and out-planting performance

**Pinus halepensis**

\[ r^2 = 0.94 \quad P = 0.01 \]

Oliet *et al.*, 1997 Cuadernos Soc. Española C. For. 4:69-79

Storage carbohydrates and out-planting performance

*Pinus sylvestris*

Why do large plants and with high nutrient content have better out-planting performance? A mechanistic explanation.
Why do large plants and with high nutrient content have better out-planting performance? A mechanistic explanation

- Photosynthesis
- Soluble carbohydrates
- Plant maintenance
- Starch
- Shoot growth
- Root growth
- Water and nutrient uptake
- Water status of the plant
- Survival

Productive plants

- High nutrient concentration
- Large leaf surface
- Low proportion of heterotrophic tissue
Performance attributes

They measure the response of plants when subjected to specific conditions

• Root growth potential (root growth capacity)
  • Frost resistance
  • Desiccation resistance

Disadvantage: are expensive in comparison with morphological attributes, most are time consuming and in some cases personnel involved in their determination need a qualified training
Performance attributes: root growth capacity

Pinus halepensis

\[ r^2 = 0.75 \quad P < 0.001 \]
Plants are frozen and their viability tested:
- electrolyte leakage
- visual damage score
- chlorophyll fluorescence
Plants are subjected to a specific level of drought and then their viability tested: mainly by electrolyte leakage.

Some take-home messages about the predictive capacity of plant quality attributes

It is impossible to predict the exact out-planting survival and growth of seedlings

Performance attributes

1) Tell us if seedlings are damaged: this allows to distinguish plant lots with high death probability
2) Tell us if seedlings are resistant to stress factors
3) Tell us about the potential out-planting performance (specially growth) of plants and therefore it permits to classify plant lots

Morphology, nutrient concentration and most material attributes tell us about the potential out-planting performance of plants IF THESE ARE NOT DAMAGED

The best case for plant quality assessment is to characterize plant morphology, nutritional status and complement it with any performance attribute
Factors that determine plant quality

• Growing conditions in the nursery

<table>
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<th>Factor</th>
<th>Description</th>
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<tr>
<td><strong>FERTILIZATION</strong></td>
<td>Determines plant morphology and nutrient concentration. Fertilization should be moderate to high</td>
</tr>
</tbody>
</table>
| **CONTAINER**      | 1) Volume >250 mL  
                       | 2) plant spacing <250 plants m\(^{-2}\)  
                       | 3) Container height: must be high in species with tap root |
| **IRRIGATION**     | 1) Quality of water  
                       | 2) Amount of water |
| **GROWING MEDIUM** | Plant morphology and nutrition |
| **SHADING**        | Excessive in shade in shade intolerant species can reduce quality |
Factors that determine plant quality

• Nursery location: it is important when winter conditions differ between nurseries

Quercus ilex

Mollá et al. (unpublished data)
Factors that determine plant quality

- **Plant age:** 1-year old seedlings tend to perform better than 2-year old plants

![Graph showing survival rates for Quercus faginea over three years. The graph compares 1-year old and 2-year old plants, indicating that 1-year old plants have higher survival rates throughout the observation period.](image-url)
Factors that determine plant quality

Transport, plant storage and rough handling

Pinus halepensis
**HOW TO IMPLEMENT A PLANT QUALITY PROGRAM**

- **From each stock type we must know**
  1. Provenance of reproduction material
  2. Cultivation conditions (fertilization, container, irrigation, plant age, environmental conditions, etc.)
  3. Sanitary status

- **From each stock type**
  1. Sample randomly 100 plants for **MORPHOLOGY**: height, diameter, and shoot and root mass
  2. Separate the 100 plants in at least 5 groups and measure **NUTRIENT CONCENTRATION** (N, P, K, Fe, Mg, Ca, Mn)
  3. Carry out at least one **PERFORMANCE ATTRIBUTE TEST**: frost test

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**Nursery managers**

**Foresters**

**Joint cooperation**

**Inventory of stock types and SELECTION FOR STUDY**

**Morphological and physiological characterization of plants**
1. Plant in three contrasted environments
2. Use 100 plants /stock in each environment, distributed in at least 5 repetitions
3. Planting personnel must be professional and motivated with the study. Use the same personnel for planting all stock types in the three environments
4. Soil preparation must be the same in all places
5. Remove competing/facilitating plants in the experimental plots

- Analyse data and check for patterns
- Relate with climatic conditions in each site

Make plantations with each stock type

Report survival after 1 month and before summer

Report GROWTH and SURVIVAL after the first summer

Report GROWTH and SURVIVAL for three years
Nurseries modify cultural practices

Nursery managers

Joint cooperation

Foresters

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SELECTION FOR STUDY

Morphological and physiological
characterization of plants

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