Dynamics and patterns of plant development in restored mining areas. Practical examples

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1. **BACKGROUND**: environmental impacts of mining; succession on anthropogenic substrates.

2. **VEGETATION DYNAMICS** after coal mining restoration in Northern Spain (Sub-humid Mediterranean climate).
   - Influence of topography (aspect and slope gradient)
   - Influence of grazing
   - Influence of forest edge on woody colonization (distance, boundary form, soil gradient)
   - Nurse effect of native shrubs on oak regeneration.

3. **FINAL REFLECTION**: empirical value of succession studies in revegetation.

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1. BACKGROUND
• **Opencast mining** → Agressive activity with the environment

- It has altered large areas
- Generating strong environmental impacts

Restoration → **an urgent need**

• **The effective restoration** → complex process

hampered primarily by the total elimination of vegetation and soil

Martínez-Ruiz & Fernández-Santos (2001)
In the absence of plant cover → these areas may be subject to:

- wind and water erosion,
- leaching,
- polluting rivers, streams, aquifers, and arable lands,
- as well as being unsightly.

Plant covering →

- stabilises wastes, and
- promotes the formation of a stable soil

- Source of nutrients and microorganisms
- Complex metals
- Provided buffer capacity (pH)
- Improves structure (clay)
- ↑ Cationic exchange capacity…

Uranium mining in La Haba (Badajoz)

with surface horizon enriched in organic matter

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The soil is one of the most important limiting factors for vegetation establishment in mine lands. Natural revegetation is a slow process due to toxicity, physical and nutritional shortcomings of mine wastes. Revegetation approaches for faster vegetation development (often) discourage results because of the lack of knowledge of the ecological principles involved. The soil is one of the most important limiting factors for vegetation establishment in mine lands.
Ecological succession:

- Changes that take place in an ecosystem over time, which not only affect the floristic composition.

- The transcendence of the sucession concept surpasses the taxonomic component and extends to all the processes that characterize the dynamics of the ecosystem as a whole.

Restoration after coal mining in northern Spain

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Peculiarities of succession on mine wastes

- on an undeveloped “soil”
- not previously colonized by plants
- without hardly a seed bank (colonization from surroundings)

Type of succession: primary, autotroph and autogenic. That is, succession on new inorganic substrates, where the first step must be colonization from the outside by green plants, and in the absence of changing abiotic influences.

Also partially allogenic succession, if the waste is covered with topsoil containing seeds or other finer materials, fertilized or amended.

Covering substrates ⇒ physical agents (allogenics, external to the new substrate, mine wastes) responsibly in part of succession acceleration?
Challenge:
• To identify the environmental factors that prevent or restrict the vegetation establishment and its subsequent dynamics
• And those that facilitate and enhance revegetation.

Premise: if we are able to successfully restore an ecosystem it is because we really know how it works.
2. Vegetation dynamics after coal mining restoration in Northern Spain (Sub-humid Mediterranean climate)
Contour mining
Sub-humid Mediterranean climate

This period of summer drought is easily surpassed by vegetation by having the soil with a good structure and water retention capacity, as shown by the surrounding planocaducifolios forests.
Soil profile in the natural forest of *Quercus pyrenaica* and *Q. petraeae*

Soil profile in the rehabilitated coal mines

- without edaphic structure
- with low water holding capacity

(López-Marcos et al., 2020)
Main limiting factors for revegetation

- Summer drought + absence of soil structure of mine substrates (low capacity to store water)
- Grazing: domestic livestock and wild ungulates (deer, wild boar)
• Without topsoil → unstable and poor in species plant communities
  (‘arrested succession’) (Alday et al., 2014)
  → woody colonization can take more than 40 years

• Topsoil addition → improve soil properties → ↑ vegetation cover
  → doesn’t return the original seed bank (it barely contains seeds; González-Alday et al., 2009)
  it is necessary
  • the introduction of seeds (hydroseeding)
    (to achieve a rapid plant cover of herbaceous species)
  • and/or to activate the natural colonization processes
• **Topsoil + Hydroseeding** → **↑ revegetation?**

- A more or less continuous coverage of non-native herbaceous species
- No more restoration actions by humans
- Natural woody colonization from surroundings

- **plant succession relatively fast**
  - in 15 years → a community of native shrubs (whose seeds were not present in the mixture of hydroseeding)
    - with cover of 36 to 85 %
    - colonizing the soil sparsely

*(Alday et al., 2011a)*
2.1. Influence of topography (aspect, slope) on vegetation and soil dynamics
The development of herbaceous vegetation after hydroseeded coal wastes in this Mediterranean region is affected by aspect through a combination of direct effects of differences in microclimate (different amounts of solar radiation received) and the relationship of solar radiation to water availability.

González-Alday et al. (2008)

Lower plant cover on southern slopes (S) compared to northern ones (N).
The development of herbaceous vegetation after hydroseeded coal wastes in this Mediterranean region is affected by aspect.

No initial differences in soil properties were found between north- and south-facing slopes.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>North</th>
<th>South</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>48.54 ± 0.88</td>
<td>44.64 ± 1.90</td>
<td>0.135</td>
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<tr>
<td>Silt (%)</td>
<td>24.23 ± 0.33</td>
<td>25.23 ± 1.33</td>
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<tr>
<td>Clay (%)</td>
<td>27.23 ± 0.67</td>
<td>30.13 ± 1.54</td>
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<tr>
<td>pH (H₂O)</td>
<td>8.19 ± 0.04</td>
<td>8.26 ± 0.04</td>
<td>0.307</td>
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<tr>
<td>Electrical conductivity (mmhos.cm⁻¹)</td>
<td>0.13 ± 0.01</td>
<td>0.11 ± 0.01</td>
<td>0.184</td>
</tr>
<tr>
<td>Organic matter (% weight)</td>
<td>1.49 ± 0.19</td>
<td>1.15 ± 0.29</td>
<td>0.388</td>
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<tr>
<td>Total Nitrogen (mg.kg⁻¹)</td>
<td>1100 ± 100</td>
<td>900 ± 100</td>
<td>0.196</td>
</tr>
<tr>
<td>Available Phosphorous (mg.kg⁻¹)</td>
<td>50.43 ± 2.50</td>
<td>28.20 ± 10.20</td>
<td>0.102</td>
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<tr>
<td>Exchangeable Potassium (mg.kg⁻¹)</td>
<td>204.65 ± 46.20</td>
<td>147.63 ± 10.50</td>
<td>0.342</td>
</tr>
</tbody>
</table>

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González-Alday et al. (2008)
Aspect also influenced the early dynamics of hydroseeded grasses and legumes establishing on these slopes.

- Grass cover was always greater on north- compared to south-facing slopes.
- Differences in legume cover related to aspect took longer to appear (legume cover was lower on south facing slopes by autumn one year after hydroseeding, probably because of the strong summer drought in 2004).
Aspect also influenced the relative contribution to total plant cover of hydroseeded grasses versus legumes

- On northern slopes → grass cover > legume cover
- On the southern slopes → a seasonal variation in the relative contribution of grass versus legumes to total plant cover, with grasses dominating during winter and autumn and legumes in early summer.
At the level of individual species, the effect of aspect was especially important for some species.
Differences in floristic composition due to aspect increase with time (in the short term)

Correlation between DCA 1 and time (**)  
Correlation between DCA 2 and aspect (**)  

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Soil properties change along time regardless of aspect

2.1. Influence of aspect

Alday et al. (2012)
Soil properties change along time regardless of aspect

Alday et al. (2012)
Vegetation structural parameters change along time depending on aspect.

Alday et al. (2011b)
Conclusions

- It is necessary to take into account the different orientation of slopes in the selection of species for early revegetation, and to study, in the longer term, the aggressiveness of some hydroseed species (Lolium perenne) that could delay or prevent natural colonization.

- Age since restoration is the main driving agent, at least in the short-term, of soil and vegetation compositional changes (when no initial differences in soil properties exist).

- Soil properties change along time regardless of aspect, but there is little relationship between floristic compositional dynamics and soil parameters (mainly related to the accumulation of organic matter and sand content, and pH reduction).

- If soil forming material is sufficiently good for vegetation development, floristic compositional differences are mainly driven by a combination of abiotic and stochastic factors in the short-term.

- Differences in topography determine different trajectories of plant communities dynamics with respect to the reference community, greatest between flat and sloping areas.
2.1. Influence of slope gradient

Linking soil variability with plant community structure and dynamics in mine slopes

- Small differences in soil properties are revealed as a constrain of important ecological processes that determine different paths in the dynamics of plant communities and different individual species response patterns.

- 11 years post-reclamation, the water holding capacity was the soil property most strongly related to the vegetation dynamics towards more mature stages.

(López-Marcos et al., 2020)
Vegetation and soil sampling methods

2.1. Influence of slope gradient

Vegetation and soil sampling methods

Two patches of vegetation
(grasland, shrubland)

Six soil sub-samples per soil sampling point

Unaltered soil sample per soil sampling point

Two consecutive quadrats per vegetation sampling point

(1 m²)

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(López-Marcos et al., 2020)
Linking soil variability with plant community composition in mine slopes

2.1. Influence of slope gradient

(López-Marcos et al., 2020)
2.1. Influence of slope gradient

- A segregation in the abundance of individual plant species was observed according to changes in soil properties along the mine-slope topographic gradient.

- This segregation mainly responds to the gradient of water availability and organic matter content in the soils.
• Plant succession advances at different rates on different parts of the slope and, in turn, the plant species compositional change along the mine-slope topographic gradient is related to stages of different maturity of vegetation and soil properties.

• The water and organic-matter content in the soil revealed the maturity status of reclaimed plant communities along the mine-slope gradient.

• The most labile carbon forms were related to early successional stages such as pastures (dominated by grasses), which occupied the upper parts of the slopes, whereas the higher water holding capacity content was related to late vegetation stages such as shrubland communities of legumes, which occupied the lower parts of the slopes.

The improvement of the topsoil properties (depth, water holding capacity, carbon content…) contributes to accelerating plant succession, allowing more mature plant communities to settle earlier.

Conclusions

<table>
<thead>
<tr>
<th></th>
<th>Down</th>
<th>Middle</th>
<th>Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHC</td>
<td>+</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>OxC/C</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

(López-Marcos et al., 2020)
2.2. Influence of grazing exclusion on vegetation and soil characteristics
2.2. Influence of grazing

Effects of short-term grazing exclusion on vegetation and soil

- Grazing exclusion clearly influence many soil properties, and many traits of plant community structure and floristic composition (but did not affect global species diversity).
- However, only few soil parameters were related to the differences in floristic composition.
- Species responses to the soil gradient from ungrazed to grazed areas were also related to their particular life history traits.

Stocking rate < 2 sheeps/ha

Sigcha et al. (2018)
Vegetation and soil sampling (June 2010)

- A north-facing mine-slope, steepness of 22–25°, hydroseeded in autumn 2006 to grassland community.
- 2 main plots (50×50 m), one fenced (in 2008) the other not.
- 5 sub-plots (5x40m) per main plot.
- 10 quadrats of 50 × 50 cm per sub-plot.
- No initial differences in soil properties.
### Effects of short-term grazing exclusion on soil properties

<table>
<thead>
<tr>
<th>Variable</th>
<th>Grazed (mean ±SE)</th>
<th>Ungrazed (mean ±SE)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>59.9±0.9</td>
<td>53.3±1.4</td>
<td>**</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>25.0±0.2</td>
<td>31.2±1.5</td>
<td>**</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>15.1±0.8</td>
<td>16.3±0.6</td>
<td>n.s.</td>
</tr>
<tr>
<td>pH</td>
<td>7.1±0.02</td>
<td>7.1±0.04</td>
<td>n.s.</td>
</tr>
<tr>
<td>EC (μS/cm)</td>
<td>0.07±0.01</td>
<td>0.14±0.01</td>
<td>**</td>
</tr>
<tr>
<td>K⁺ (meq/100g)</td>
<td>0.4±0.03</td>
<td>0.5±0.02</td>
<td>**</td>
</tr>
<tr>
<td>Mg²⁺ (meq/100g)</td>
<td>1.4±0.1</td>
<td>1.8±0.2</td>
<td>*</td>
</tr>
<tr>
<td>Na⁺ (meq/100g)</td>
<td>0.15±0.01</td>
<td>0.17±0.02</td>
<td>n.s.</td>
</tr>
<tr>
<td>Ca²⁺ (meq/100g)</td>
<td>9.4±0.2</td>
<td>13.4±1.3</td>
<td>**</td>
</tr>
<tr>
<td>OM (%)</td>
<td>1.9±0.1</td>
<td>4.6±0.8</td>
<td>**</td>
</tr>
<tr>
<td>OxOM (%)</td>
<td>1.6±0.1</td>
<td>3.9±0.8</td>
<td>**</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.1±0.01</td>
<td>0.3±0.05</td>
<td>**</td>
</tr>
<tr>
<td>POlsen (mg/kg)</td>
<td>13.9±0.8</td>
<td>34.0±7.5</td>
<td>**</td>
</tr>
</tbody>
</table>
Effects of short-term grazing exclusion on soil properties

2.2. Influence of grazing

Ungrazed

Grazed

O, oxOM, N, K, P, Ca, Mg, EC, clay

Sand

Silt, pH, Na

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Effects of short-term grazing exclusion on vegetation structure

2.2. Influence of grazing

No change in:
- Diversity ($H'$) and its components (richness, eveness)
- Richness of grasses, legumes, compositae and ‘others’
- Cover of barochorous, endo- and ecto-zoochorous species
Effects of short-term grazing exclusion on vegetation structure

2.2. Influence of grazing

- Total cover and biomass; Maximum height; Cover of perennials, anemochorous and authocorous spp.; Cover and biomass of grasses, legumes and compositae; Cover and richness of hemicriptophytes.

- Bare soil, Richness of endo-zoochorous spp.

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Effects of short-term grazing exclusion on vegetation composition and its relationship with differences in soil properties
2.2. Influence of grazing

Species response patterns to differences in soil properties

- **Festuca spp.**
- **Dactylis glomerata**
- **Lotus corniculatus**
- **Trifolium repens**
- **Poa pratense**

Plant cover (%) vs. CCA1 for Grazed and Ungrazed conditions.

Soil properties:
- **Sand**
- **OM, K, Mg**

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Conclusions

• Twenty-seven months of fencing enclosure had a great effect on many soil properties of the grasslands under study, as well as important changes in the structure of vegetation (but not in species diversity).

• However, only three soil parameters (organic matter, K, and Mg, with higher values in the ungrazed community) were related to the differences in floristic composition.

• Herbivores can be a key factor preventing revegetation at early stages of succession, although they could play a key role as efficient seed dispersers, particularly of endozoochorous legume species, favouring in the long-term the relative biomass of legumes, and controlling the expansion of dominant introduced species.

• *Trifolium repens* and *Lolium perenne* were the species better adapted and, therefore, favoured by grazing in the study area.

• More efforts should be made to clarify the short- and long-term effects of the exclusion of herbivores in relation with the goals of restoration.
2.3. Influence of the forest edge on woody colonization
The colonization pattern of woody species is affected by fine-scale variations in abiotic factors, including soil properties, which change from the forest to the mine

- Grasslands communities install in reclaimed coal-mine areas are colonized by woody species from the surrounding forest.
- The structure of the new plant community varies not only in time (succession) but also in space (distance to the seed source), and the process is strongly determined by interactions between the forest edge and the initial grassland patch.

Milder *et al.* (2013)
2.3. Influence of the forest edge

Vegetation and soil sampling (Autumn 2005)  

- **23 transects** were sampled. 19 plots per transect.
- Transects **every 15 or 30 m**.

**In Plots of 2 x 2 m**

- Number of individual stems
- Separate stems at ground level were recorded as individuals.
- One soil sample per plot.
2.3. Influence of the forest edge

Milder et al. (2013) observed fine scale variation in some abiotic factors along the forest-mine gradient.

<table>
<thead>
<tr>
<th>Plot number along a transect</th>
<th>pH</th>
<th>Organic matter (per cent)</th>
<th>Available P (ppm)</th>
<th>Exchangeable K (ppm)</th>
<th>Total N (ppm)</th>
<th>Ratio C/N</th>
<th>L (1-9)(^a)</th>
<th>F (1-12)(^a)</th>
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<td>1(^b)</td>
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<td>4900</td>
<td>13.31</td>
<td>3.37</td>
<td>1.80</td>
</tr>
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</table>

\(L, F =\) Ellenberg indicator values for light and soil moisture, respectively (an increase in the number of category means an increase in requirements for light or moisture of species present within each plot along the transect (the forest–mine gradient).
2.3. Influence of the forest edge

Relationship between woody vegetation composition and abiotic factors along the forest-mine gradient

OM, K, N, C/N, F

Kendall Correlation Coefficient

pH, P, L

(*** Correlation between DCA1 and Forest-Mine position, and Distance to the forest edge.

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Milder et al. (2013)
Response pattern of main woody colonizing species along the forest-mine gradient

HOF Models

Qupe = Quercus petraea
Cysc = Cytisus scoparius
Gefl = Genista florida
Roca = Rosa canina
Ruul = Rubus ulmifolius

Crmo = Crataegus monogyna
Eueu = Euonymus europaeus
Ilaq = Ilex aquifolium
Erar = Erica arborea
Soar = Sorbus aria

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Influence of the distance to the forest edge in the colonization intensity

\[ y = 20.29 - 4.049 \ln(x) \]
\[ R^2 = 0.754 \quad p = 1.29 \times 10^{-5} \]

Milder et al. (2008)

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Influence of forest-edge form in the distance and colonization intensity

Milder et al. (2008)

Concave  Convex  Straight

Concave  Convex  Straight

(d) All together

Number of stems / m²

Distance from forest boundary (m)

Concave  y = 8.772 - 1.317 ln(x)  convex  y = 7.989 - 1.908 ln(x)  straight  y = 5.693 - 0.867 ln(x)

R²  = 0.5349  p  = 0.001285  R²  = 0.7789  p  = 6.027 × 10⁻⁶  R²  = 0.4172  p  = 0.06872
Conclusions

- Natural woody colonization on lands mined for coal in Spain is due to relatively few woody species from the forest edge, and it is concentrated in the proximity of the forest (colonization increases as distance to the forest decreases).

- The shape of the boundary between the forest and the mine determines the woody colonization intensity, which is higher in concave edges and lower in the convexes.

- Most of Quercus petraea seedlings were found in the first 5 m from the forest, where shrubs colonization is higher. The only individuals found over 5 m of distance to the edge, were capable to settle there thanks to the refuge that Cytisus scoparius and Genista florida offer.

- Planting trees and shrubs along the edge of the forest-mine to form concavities, thus accentuating initially shallow concavities, could facilitate the expansion of the forest into the mining area from the edge.
2.4. Nurse effect of native shrubs on oak regeneration (in part by soil improvement)
The native shrubs that colonize the mines (Genista florida and Cytisus scoparius) facilitate the establishment of native oaks (Quercus pyrenaica and Q. petraea) and thus the natural forest expansion

94% Q. petraea → in the first 5 m

Alday et al. (2016)
Effect of shrubs on survival of planted trees (1-yr saplings) of native oaks (*Quercus pyrenaica* and *Q. petraea*)

**Plantation in February of 2011**

<table>
<thead>
<tr>
<th>Date</th>
<th>Percentage of tree survival</th>
<th>(Q. petraea)</th>
<th>(Q. pyrenaica)</th>
<th>(Q. petraea)</th>
<th>(Q. pyrenaica)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 2011</td>
<td>UNDER Shrub (Q. petraea)</td>
<td>90.7</td>
<td>91.0</td>
<td>5.5</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>UNDER Shrub (Q. pyrenaica)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 2012</td>
<td></td>
<td>44.6</td>
<td>54.3</td>
<td>2.5</td>
<td>11.5</td>
</tr>
<tr>
<td>October 2013</td>
<td></td>
<td>42.5</td>
<td>48.5</td>
<td>2.0</td>
<td>7.0</td>
</tr>
<tr>
<td>October 2014</td>
<td></td>
<td>35.0</td>
<td>41.5</td>
<td>2.0</td>
<td>5.5</td>
</tr>
<tr>
<td>October 2015</td>
<td></td>
<td>34.0</td>
<td>39.0</td>
<td>2.0</td>
<td>5.5</td>
</tr>
<tr>
<td>October 2016</td>
<td></td>
<td>33.5</td>
<td>39.0</td>
<td>1.0</td>
<td>4.5</td>
</tr>
<tr>
<td>October 2017</td>
<td></td>
<td>29.5</td>
<td>35.0</td>
<td>0.5</td>
<td>4.5</td>
</tr>
<tr>
<td>October 2018</td>
<td></td>
<td>25.0</td>
<td>32.0</td>
<td>0.5</td>
<td>2.0</td>
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<tr>
<td>October 2019</td>
<td></td>
<td>24.5</td>
<td>30.0</td>
<td>0.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Partially unpublished data*

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*Torroba et al. (2015)*
## Nurse effect of shrubs on oak establishment mediated, in part, by soil improvement

*Unpublished data*

<table>
<thead>
<tr>
<th>Soil parameters</th>
<th>Under shrub</th>
<th>Open sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>5.3±0.10 a</td>
<td>&lt; 5.7±0.13 b</td>
</tr>
<tr>
<td><strong>Conductivity (mS/cm)</strong></td>
<td>0.117±0.011 a</td>
<td>&gt; 0.088±0.006 b</td>
</tr>
<tr>
<td><strong>Sand (%)</strong></td>
<td>58.18±1.23 a</td>
<td>&gt; 58.02±1.13 b</td>
</tr>
<tr>
<td><strong>Clay (%)</strong></td>
<td>23.41±1.42 a</td>
<td>&lt; 26.17±1.24 b</td>
</tr>
<tr>
<td><strong>Silt (%)</strong></td>
<td>18.41±0.77</td>
<td>= 17.80±0.61</td>
</tr>
<tr>
<td><strong>Organic matter (%)</strong></td>
<td>6.12±0.45 a</td>
<td>&gt; 5.20±0.48 b</td>
</tr>
<tr>
<td><strong>Total N (g/100g)</strong></td>
<td>0.47±0.02 a</td>
<td>&gt; 0.37±0.03 b</td>
</tr>
<tr>
<td><strong>C/N</strong></td>
<td>10.87±0.25 a</td>
<td>&gt; 9.58±0.40 b</td>
</tr>
<tr>
<td><strong>Available P (mg/kg)</strong></td>
<td>2.5±1.14</td>
<td>= 2.5±1.14</td>
</tr>
<tr>
<td><strong>Exchangeable K⁺ (meq/100g)</strong></td>
<td>184.40±12.80 a</td>
<td>&gt; 147.25±8.98 b</td>
</tr>
<tr>
<td><strong>Exchangeable Na⁺ (meq/100g)</strong></td>
<td>0.052±0.01 a</td>
<td>&lt; 0.076±0.01 b</td>
</tr>
<tr>
<td><strong>Exchangeable Ca²⁺ (meq/100g)</strong></td>
<td>6.77±0.81</td>
<td>= 7.87±1.15</td>
</tr>
<tr>
<td><strong>Exchangeable Mg²⁺ (meq/100g)</strong></td>
<td>1.27±0.41 a</td>
<td>&gt; 0.99±0.27 b</td>
</tr>
<tr>
<td><strong>Cation exchange capacity (meq/100g)</strong></td>
<td>22.86±0.90 a</td>
<td>&gt; 20.28±0.68 b</td>
</tr>
</tbody>
</table>
Conclusions

• The successful colonization patterns and positive neighbor effect of native shrubs on Quercus seedlings support the use of shrubs (especially Genista florida) as ecosystem engineers to increase heterogeneity in micro-environmental conditions improving late-successional Quercus species establishment in the coal mines.

• The positive effects of shrubs upon seedling survival and growth and acorn emergence found in our studies is partially mediated by soil improvement. Also, the microclimate amelioration under shrubs to reduce water stress for plants is suspected, as well as a defensive mechanical effect against ungulates.

• Future reclamation strategies in similar areas should include shrub species (seeds or seedlings), especially G. florida, in order to create a quick and heterogeneous shrub cover that will provide suitable microsites for Quercus seedling establishment.
3. Final reflection

• In order to improve the decision-making during restoration management, it is necessary to be based on the knowledge of the mechanisms that condition the establishment of vegetation and the underlying succession processes.

• The long-term monitoring of existing experimental devices and their extension to other areas and restoration objectives are essential to establish a protocol of performance to adjust decisions to the particular circumstances of each area to be restored and thus reconcile environmental restoration with the economic activity of the area.

**Bradshaw (1996):**
‘restoration is an acid test of our ecological understanding’
Many thanks
Thank you for your attention!