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The effects of climate fluctuations and soil heterogeneity on the floristic composition of sown Mediterranean annual pastures

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The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL)

SBPPRL were developed in the 70’s by the agronomist David Crespo
The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL)

Species/cultivars diversity

- *Dactylis glomerata*
- *Lolium perenne*
- *L. multiflorum*
- *Phalaris tuberosa*
- *Astragalus (Biserrula) pelecinus*
- *Ornithopus compressus*
- *O. sativus*
- *Trifolium repens*
- *T. michelianum*
- *T. glanduliferum*
- *T. incarnatum*
- *T. fragiferum*
- *T. repens*
- *T. resupinatum*
- *T. subterraneum*
- *T. vessiculorum*
- *Cichorium intybus*
The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL)

Preponderance of *T. subterraneum*

- 3-4 *T. subterraneum* cv's with more than 50% of the seed mixtures weight, covering a considerable life cycle length spectrum
- *T. subterraneum* is a cleistogamic species, its natural populations being constituted by pure lines (KATZNELSON, 1974)
The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL)

SBPPRL mimics natural Mediterranean, silicicolous, heavily trampled and grazed dry swards of the *Poetea bulbosae* vegetation class.

Sward of *Poetea bulbosae* (NE Portugal) [n.b. *Parentucellia latifolia* and *T. subterraneum*]
Why SBPPRL area is increasing in Portugal?

**Productivity and costs**

- Average stocking rate 145% superior to contiguous semi-natural pastures (0.86 vrs. 0.35 LU yr⁻¹, p=0.03) in a five years study (Carneiro *et al.*, 2005)
- 4 - 8 t DM ha⁻¹ yr⁻¹, with more than 50% of legumes, and with production costs of about 15-20% of the compound feed costs (Crespo, 2011)

**Optimization of fodder production at the farm-level**

- SBPPRL DM production peak coincides with the period when hay-meadows are closed to herbivores to allow hay growth
Why SBPPRL area is increasing in Portugal?

C sequestration in SOM
- Achieving 5 t ha\(^{-1}\) yr\(^{-1}\) CO\(_2\)e (Teixeira et al., 2011)
- C sequestration payments in Portugal in 42,000 ha of SBPPRL that could reach 0.91 x 10\(^6\) t of CO\(_2\)e from 2010 to 2012

Other advantages
- Easy conversion of former agricultural soils to SBPPRL
- Persistence in time
- Simple maintenance
## Species diversity effects on ecosystem function

### Diversity and ecosystem functions

- Pastures sown with species diverse seed mixtures are more productive ([Clark, 2001](#)).
- Diverse pastures appear to be:
  - Less permeable to spontaneous species of low palatability and feed value ([Frankow-Lindberg et al., 2009](#)).
  - To track environmental heterogeneity ([Sanderson et al., 2004](#)).
  - To withstand extreme climate fluctuations ([Tilman & Downing, 1994](#)).

### But …

- Pasture diversity effects on ecosystem functions studies were carried out on:
  - Small scale with strictly controlled experimental conditions ([Symstad et al., 2003](#)).
  - Involving a small number of species ([Spehn et al., 2005](#)).
  - In homogeneous soil conditions ([Wacker et al., 2008](#)).
  - During short time spans ([Cardinale et al., 2007](#)).
  - Rarely were brought the analysis to the cultivar level (intraspecific diversity).
The slope system as a model for the study of Mediterranean pastures

- At the microtopographical scale (local relief) slope influences key environmental factors important in plants – soil relationship (Swanson et al., 1988)
- The slope system is the most appropriate model for the study of Mediterranean herbaceous communities subjected to grazing (Gómez et al., 1978)
The floristic structure of Mediterranean annual pastures is also remarkably sensitive to annual rainfall fluctuations (Ortega & Fernández Alés, 1987; Figueroa & David, 1991)

The two characteristics of Mediterranean climate

Accumulated rain (mm) over the agricultural years of 2007-2008 and 2009-2010, and mean accumulated rain (mm) over the climatic series 1961-1981 (Castelo Branco, Portugal, 390 m MSL nearby the studied area)
Diversity and productivity in patchy environments

- It is expectable that species diversity in pastures will have a stronger effect on productivity in habitats with patchy resources that fluctuate over time.
  - Effect probably amplified in Mediterranean therophytic plant communities (and in sown SBPPRL) where plant recruitment restarts with the first rains each autumn.

- This fundamental question hasn’t been properly addressed, and the published bibliography about it is scanty and not always straightforward (Wacker et al., 2008).
Tested hypothesis

- Due to their species-genotypes diversity, SBPPRL are then expected to be able to track and tune to soil attributes spatial variability and to climatic fluctuations.

Tested hypothesis:

1. Do SBPPRL track slope system microenvironments array?
2. Does the same happen with interannual climate fluctuations?
3. Do the SBPPRL responses to these microenvironments spatial arrays and climate fluctuations occur at the sown species and *T. subterraneum* cultivars levels?

If SBPPRL are an agronomic solution these hypotheses should be tested by observational studies under farm conditions at the plant community scale.
**Materials and methods**

**SBPPRL sward**

- Stabilized SBPPRL selected on a private farm – Quinta da França (Covilhã, Portugal), 40°16'N 7°30'W, ca. 425 m MSL
- Sown in arable land in 2001 with a commercial SBPPRL
- Intensely grazed with cattle and sheep and annually fertilized with 27 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>
Materials and methods

Sampling

- Stratified random sampling
  - Three microtopographic positions: hill shoulder, backslope and footslope
- Plant cover: point-quadrat method
  - Plants were identified to the species level or to the cultivar level in the case of *T. subterraneum*
  - Sampling in the springs of 2008 and 2010
- DM yields evaluated in the 2007-2008 agricultural year
- Soil sampling in the spring of 2010
Materials and methods

*T. subterraneum* cultivars discrimination and flowering dates

- Cultivation in glasshouse of *T. subterraneum* cultivars
  - Simulation of herbivory
  - Emergence of the first flower

Levels of botanical analysis

- All species level
- Sown species level
- *T. subterraneum* cultivar level

Data exploration

- Multivariate ordination algorithms
- Response variables
- Explanatory variables
  - “Slope” and “Year-climate”
- Linear ordination methods
  - PCA
  - Variation partition with RDA models and Monte Carlo permutation tests
- Data standardized by the norm to enhance the effect of species/cultivars relative cover on the ordinations
- ANOVA
## Results and discussion

### Sown species and cultivars

- ** Detected species
- ** *T. subterraneum* cv’s morphology
  - Vilous twigs – ‘Losa’
  - Glabrous twigs
    - Glabrous or almost glabrous petioles and stipules – ‘Denmark’
    - Sparsely to densely pilose petioles – ‘Gosse’, ‘Campeda’ + ‘Woogenellup’
- ** *T. subterraneum* cv’s flowering dates
  - Early season cultivar – ‘Losa’
  - Middle season cultivars – ‘Goss’, ‘Campeda’ and ‘Woogenellup’
  - Late season cultivar – ‘Denmark’

Biunivocal correspondence between sown cultivars and sampled *T. subterraneum* plants involves some uncertainty but ...
## Results and discussion

### Soil fertility parameters (2010)

- **Spatially variable**

Soil fertility data from the studied SBPPRL (Quinta da França, Portugal). Tukey’s HSD test, P<0.05.

<table>
<thead>
<tr>
<th></th>
<th>( \text{P}_2\text{O}_5 ) (means in mg.kg(^{-1}))</th>
<th>( \text{K}_2\text{O} ) (means in mg.kg(^{-1}))</th>
<th>Soil organic matter (means in %)</th>
<th>( \text{pH} \ \text{H}_2\text{O} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hill shoulder</td>
<td>94</td>
<td>120</td>
<td>1.3( b )</td>
<td>5.2( a )</td>
</tr>
<tr>
<td>Backslope</td>
<td>115( a )</td>
<td>128</td>
<td>3.6( a )</td>
<td>4.9( b )</td>
</tr>
<tr>
<td>Footslope</td>
<td>63( b )</td>
<td>159</td>
<td>3.4( a )</td>
<td>5.8</td>
</tr>
<tr>
<td>Mean</td>
<td>90</td>
<td>136</td>
<td>2.8</td>
<td>5.3</td>
</tr>
<tr>
<td>d.f.</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>p-value</td>
<td>0.039</td>
<td>0.179</td>
<td>&lt;0.001</td>
<td>0.051</td>
</tr>
</tbody>
</table>

Analytical methods: soil organic matter – Walkley-Black; \( \text{P}_2\text{O}_5 \) and \( \text{K}_2\text{O} \) – Egner-Riehm.
Results and discussion

DM yields (2007-2008)

- Spatially variable

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Legumes</th>
<th>% of total</th>
<th>Grass</th>
<th>% of total</th>
<th>Others</th>
<th>% of total</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hill shoulder</td>
<td>2521</td>
<td>51.0</td>
<td>928</td>
<td>18.8</td>
<td>1490</td>
<td>30.2</td>
<td>4939</td>
</tr>
<tr>
<td>Backslope</td>
<td>3358</td>
<td>51.0</td>
<td>1344</td>
<td>20.4</td>
<td>1883</td>
<td>28.6</td>
<td>6585</td>
</tr>
<tr>
<td>Footslope</td>
<td>3215</td>
<td>46.4</td>
<td>1640</td>
<td>23.7</td>
<td>2074</td>
<td>29.9</td>
<td>6929</td>
</tr>
<tr>
<td>d.f.</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.4</td>
<td>0.28</td>
<td>0.202</td>
<td>0.117</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DM production (total and per fraction) in 2007-2008 along the slope gradient in the studied SBPPRL (Quinta da França, Portugal)
Results and discussion

All species level

- **PCA**
  - Eigenvalues: $\lambda_1=0.297$ (correlated with Year-climate, $r=-0.95$), $\lambda_2=0.143$, $\lambda_3=0.120$ (correlated with Slope, $r=-0.54$), $\lambda_4=0.069$

- **Variation partition**
  - “Year-climate” – 27.3% ($p=0.02$)
  - “Slope” – 6.9% ($p=0.03$)
Results and discussion

Cultivated species level

- *Astragalus pelecinus* effect
- Overgrazing effect

Variation partitioning of sown species composition in the SBPPRL of Quinta da França (Portugal)

<table>
<thead>
<tr>
<th>Botanical level of analysis/explanatory variable</th>
<th>Explained variability (%)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sown species level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year-climate</td>
<td>14.7</td>
<td>0.05</td>
</tr>
<tr>
<td>Slope</td>
<td>2.9</td>
<td>0.65</td>
</tr>
</tbody>
</table>

*Astragalus (Biserrula) pelecinus*
Results and discussion

*T. subterraneum* cultivars level

**PCA biplot – 1st and 2nd axes with the data gathered in the SBPPRL of Quinta da França (Portugal) for *T. subterraneum* cultivars. Variables passively projected**

<table>
<thead>
<tr>
<th>Botanical level of analysis/explanatory variable</th>
<th>Explained variability (%)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sown species level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year-climate</td>
<td>14.7</td>
<td>0.05</td>
</tr>
<tr>
<td>Slope</td>
<td>2.9</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>T. subterraneum cultivars level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year-climate</td>
<td>10.8</td>
<td>0.08</td>
</tr>
<tr>
<td>Slope</td>
<td>18.0</td>
<td>0.004</td>
</tr>
</tbody>
</table>

**Variation partitioning of sown species or *T. subterraneum* cultivars composition**

<table>
<thead>
<tr>
<th></th>
<th>'Losa’ (early season cv.) mean relative cover (%)</th>
<th>'Gosse’, 'Campeda’ and 'Woogenellup’ (middle season cv.’s) mean relative cover (%)</th>
<th>'Denmark’ (late season cv.) mean relative cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-climate</td>
<td>10.4</td>
<td>17.0</td>
<td>20.2</td>
</tr>
<tr>
<td>2007-2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-2010</td>
<td>7.5</td>
<td>7.1</td>
<td>27.6</td>
</tr>
<tr>
<td>d.f.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>p-value</td>
<td>0.503</td>
<td><strong>0.015</strong></td>
<td>0.270</td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hill shoulder</td>
<td>21.3a</td>
<td>12.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Backslope</td>
<td>3.1b</td>
<td>16.5</td>
<td>26.6</td>
</tr>
<tr>
<td>Footslope</td>
<td>2.4b</td>
<td>7.0</td>
<td>25.7</td>
</tr>
<tr>
<td>d.f.</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>p-value</td>
<td><strong>0.002</strong></td>
<td>0.125</td>
<td>0.627</td>
</tr>
<tr>
<td>Slope x Year-climate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.695</td>
<td>0.445</td>
<td>0.482</td>
</tr>
</tbody>
</table>
Conclusions

- The statistical significance and the influence of the explanatory variables “Year-climate” (a proxy interannual climatic fluctuations) and “Slope” (a proxy of soil resources and soil proprieties spatial variability) on the plant composition of the studied SBPPRL varied between the three botanical levels of analysis.
  - Species variability explained by the explanatory variable “Year-climate” was significant, and higher than “Slope”, at all species and sown species levels.
  - The species variability explained by “Slope” reached a maximum at the *T. subterraneum* cultivar level; “Year-climate” had an insignificant effect at this level of botanical analysis.
Conclusions

- Diversifying the sown species/cultivar colonists’ pool in seed pasture mixtures favours interannual climatic and microtopographic gradients variability tracking
  - **Sown species diversity and** *T. subterraneum* **cultivar diversity are complementary** in this process; they promote, respectively, interannual climatic and microtopographic gradients variability tracking
  - This tracking is indeed translated into higher yields at the pasture scale, and in a buffering of DM production along soil catenas and between years

Our data is merely phenomenological: it corroborates the presented three hypotheses but doesn’t prove them
Thank you

Dziękuję

Obrigado