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The effect of soil microtopographic gradients on dry matter yields and species richness in two Mediterranean pastures

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Abstract. The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL) mix a large number of species and cultivars of improved annual pasture species adapted to Mediterranean climate, with a predominance of *Trifolium subterraneum*. On a commercial mixed farm were explored the effects of soil microtopographic gradients on dry matter (DM) yields and species richness in two intensively grazed nearby pastures – a stabilized SBPPRL and an old seminatural annual pasture (SNP) – established in the same soil catena, with a high P_2O_5 and K_2O availability. As expected the SBPPRL had higher DM yields than the SNP, more stable along the slope system, and with a larger legume fraction. The indigenous genotypes of the SNP seemed unable to translate into biomass soil fertility improvement. SBPPRL improved pasture species depressed significantly pasture species diversity and species spatial turnover. In the SBPPRL legumes mainly substituted many short living low productivity autochthonous species common in the SNP. The buffering of soil ecological gradients is probably important in the explanation of the superior agronomic performance of SBPPRL. SOM accumulation is certainly involved in this process.

Keywords. Permanent pastures – Sown pastures – Subterranean clover – Species diversity.

Effets des gradients microtopographiques du sol sur la production de matière sèche et la diversité spécifique sur deux pâturages méditerranéennes

Résumé. *Les Pâturages Permanents Biodiverses Riches en Légumineuses (PPBRL) mélangent un nombre élevé d'espèces et cultivars de plantes fourragères améliorées adaptées au climat méditerranéen, avec une prépondérance de* Trifolium subterraneum. *Dans une exploration agricole on a exploré l'effet de gradients microtopographiques sur la production de matière sèche (MS), la diversité spécifique et le turnover d'espèces dans deux pâturages adjacents intensément broutés – l'un, un PPBRL et l'autre un pâturage seminaturel annuel (PSN) – installés dans la même catena de sol avec niveaux de P_2O_5 and K_2O élevés. Comme il était prévue, le PPBRL a montré des productions de MS plus hautes et plus stables au long du gradient microtopographique que le PSN, et une composante supérieure en légumineuses. Les génotypes indigènes apparemment n'ont pas été capables de convertir en biomasse l'amélioration de la fertilité du sol. Les espèces améliorées du PPBRL ont réduit significativement la diversité spécifique, surtout d'espèces annuelles de cycle de vie court, et le turnover spatial d'espèces. L'atténuation des gradients écologiques au nivaux du sol est probablement importante pour expliquer la performance agronomique des PPBRL. La accumulation de matière organique au sol est probablement associée avec ce processus.*

Mots-clés. *Pâturages permanents – Pâturages semés – Trèfle souterrain – Diversité de plantes.*

I – Introduction

The Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL) are a well known sown pastures system in many Mediterranean countries. Seed mixtures with a high species and cultivars diversity, with a predominance of *Trifolium subterraneum*, are their main characteristic. They often involve 10-12 improved cultivars of 6-7 pasture species with a

Mediterranean optimum, the majority of them self-regenerating winter annuals (only grasses are perennial). The SBPPRL address a classical subject in community ecology: the effects of species richness on ecosystem function. Recently we have been able to corroborate the hypotheses that SBPPRL species/cultivars richness track interannual climate fluctuations and slope system microenvironments arrays (Aguiar *et al.*, 2011). Sown species and *T. subterraneum* cultivars richness are complementary in this process; they promote, respectively, interannual climatic fluctuations and microtopographic gradients tracking. These abilities are central to explain the SBPPRL superior agronomic performances.

Three hypotheses were tested in this article. 1) If SBPPRL's species and cultivars can track microtopographic ecological gradients, biomass yields should be higher in SBPPRL than in semi-natural pastures (SNP), in all slope positions. 2) In heterogeneous herbaceous plant communities the relationship between productivity and species richness generally follows a unimodal curb (Grime, 1973); consequently, if SBPPRL species inhabit soils with improved chemical fertility, and are substantially more productive than autochthonous biotypes, species richness at the local scale (alfa-diversity) is probably lower in SBPPRL than in SNP. 3) If a limited pool of improved species substitute indigenous species in fertilized soils, and SBPPRL's cultivar richness is fundamental in microtopographic ecological gradients tracking, then, species spatial turnover should be smaller in SBPPRL than in SNP.

II – Materials and methods

Two nearby pastures, a SNP and a SBPPRL, were selected on a private farm – Quinta da França (Covilhã, Portugal), 40°16'N7°30'W, ca.425m MSL. The SBPPRL was sown in arable land in 2001 with a commercial seed mixture. Since then it has been intensely grazed with cattle and sheep and annually fertilized with ca. 27 kg P_2O_5 ha^{-1}. Grazing management led to a *T. subterraneum* absolute dominance; its sown grasses biomass is irrelevant. The SNP was also fertilized with phosphorous and intensively grazed, and wasn't yet invaded by SBPPRL genotypes. The studied pastures are located on a gentle slope of a granite hill with 30 m elevation and 380 m length. Three microtopographic positions were identified: hill shoulder, backslope and footslope. In the springs of 2008 and 2010 four quadrats were randomly located on each slope position. Each of the quadrats was protected with an exclosure cage three weeks before measurements to allow species identification. Species richness and relative cover was evaluated in the third week of May of 2008 and 2010, with the point-quadrat method (frame of 70x70 cm with 49 points). The 2009 spring was exceptionally dry and the pastures were impossible to sample. DM yields were evaluated in the agricultural year of 2007-2008 in exclosure cages around the previously described quadrats. Soil samples were collected nearby the quadrats of 2010. 2007-2008 and 2009-2010 agricultural years were, respectively, moderately dry (589 mm) and moderately wet (1023 mm). Temperature integrals in the two growing seasons were close to the mean year.

Two explanatory variables were considered in the ANOVA analysis: SLOPE (three levels, Hill shoulder, Backslope and Footslope); and PTYPE (two levels, SBPPRL and SNP). In the "within subject effects" ANOVA (Table 1) the YEAR explanatory variable (two levels, 2008 and 2010) was taken as repeated measures. The species turnover (beta diversity) was indirectly evaluated through the "Lengths of gradient" (Lepš and Šmilauer, 2003) available in the output of Detrended Correspondence Analysis performed in the CANOCO program (Ter Braak and Šmilauer, 2002). The assessment of outcompeted species by the SBPPRL was done, indirectly, with a principal component analysis (PCA) ordination diagram with passively projected variables. Besides the variables used in the ANOVA, four new variables were created for the PCA adding the relative cover of sown species (SOWN SPECIES), annual oligotrophic species (HELIANTHEMETEA GUTTATI), species adapted to trampled soils (POLYGONO-POETEA ANNUAE), and annual species of temporary wet soils (ISOETO-NANOJUNCETEA). The plant species autoecology was indirectly assessed through the phytosociological optimum (Rivas-Martinez *et al.*, 2001).

III – Results and discussion

Soil P_2O_5 and K_2O (mean 135 mg.kg^{-1}, Egner-Riehm) availability in the two studied pastures was elevated and quite homogenous. Anyway, P_2O_5 levels were significantly higher in the SNP (142 *vs* 90 mg.kg^{-1}, Egner-Riehm, p<0.001), and in backslope positions (mean 141 mg.kg^{-1}). Biomass yield was much higher in the SBPPRL, consequently, in spite of the cyclical soil disturbance that occurred before 2001, SOM content was significantly higher in this pasture type then in the SNP (2.76 *vs* 2.12%, p<0.001). In 2007-2008 the DM production was 250% higher in SBPPRL than in the SNP (6151 *vs.* 1752 DM kg.ha^{-1}, p<0.001). PType had a statistically significant effect in all DM yield fractions (grasses, legumes and others). In the SNP occurred a severe reduction of DM yields uphill: hill shoulder DM yield was almost an half (55.5%) of the footslope DM yield (1355 *vs* 2451 kg.ha^{-1}, p<0.001). Inversely, SBPPRL had a much higher legumes content and proportion (3031 [49.3%] *vs* 248 kg.ha^{-1} [14.2%] in SNP, p<0.001), and buffered DM yields along the slope system (the Slope effect in total DM yield and in DM fractions of the SBPPRL was always insignificant). The higher grass biomass in the SBPPRL (1304 *vs* 681 kg.ha^{-1} in SNP) means that this yield fraction, almost only composed of indigenous plants, benefited from the legume presence.

In Table 1, the between subjects (both years together) ANOVA shows that PType and Slope had a significant effect on species richness. Species number per 0.49m^{-2} was higher in SNP (13.09 *vs* 10.56) and on hill shoulders (13.81 *vrs.* 10.38 and 11.31). The higher species richness in the hill shoulder was constant between years and between pasture types. In the within subject effects ANOVA only PType effect was significant. In 2008, the SBPPRL had a higher species richness than the SNP (12.08 *vs* 11.25), but SNP had a much higher species richness peak in 2010 (14.92 *vs* 9.03) that explains its higher species richness in the between subject effect ANOVA.

Table 1. Local species richness. ANOVA. Tukey's HSD test (P<0.05)

	Between subject effects			Within subject effects			
	Mean†	p-value	Error	Mean 2008†	Mean 2010†	p-value	Error
PType		0.001	5.319			**<0.001**	5.847
SBPPRL	10.56			12.08	9.03		
SNP	13.09			11.25	14.92		
Slope		0.002	5.319			0.318	5.847
Hill shoulder	13.81a			14	13.63		
Backslope	10.38b			10.63	10.13		
Footslope	11.31b			10.38	12.25		
PType x Slope		0.491	5.319			0.935	5.847

†Number of species per 0.49m^2.

The species turnover (beta-diversity) was much higher in the in SNP (DCA "Lengths of gradient" 3.791 in 2008 and 3.476 in 2010) then in SBPPRL (DCA "Lengths of gradient" 1.687 in 2008 and 1.733 in 2010).

The first axe of the PCA diagram of Fig. 1 is correlated with the pasture types (r=0.80). The second axe probably reflects a water gradient; is highly correlated with Isoeto-Nanojuncetea (r= 0.93) and less with the year of sampling and the slope position. The direction of the Isoeto-Nanojuncetea arrow indicates that wet years and footslope positions promote temporary wet soils adapted species (e.g. *T. cernuum*). The PCA diagram also shows that sown species are a characteristic of SBPPRL, together with some undesirable nitrophilous species (e.g. *Bromus hordeaceus* and *Sysimbrium officinale*) and of trampled soils plants. A large number of well fitted species inhabit the SNP. The majority of them are oligotrophic, ephemeral, annual plants of the *Helianthemetea guttati* vegetation class. This phytosociological group is the most prone to be outcompeted by SBPPRL improved species. *Aira caryophyllea*, *Logfia minima*, *Tolpis barbata* and *Crassula tillaea*, among other species, were not detected in the SBPPRL.

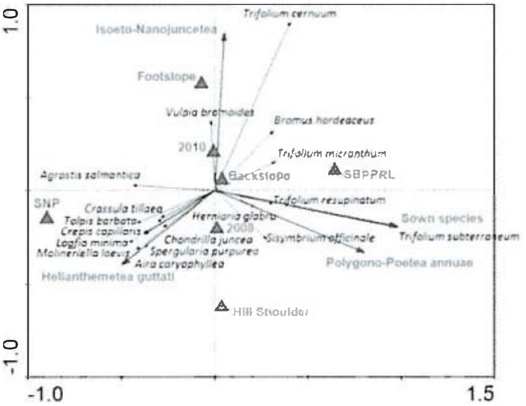

Fig. 1. PCA biplot with the 20 species with the highest fit with the first two axes.

IV – Conclusions

The studied pastures shared similar soil chemical fertility conditions. Our experiment was based in pseudoreplications. Although the sampled agricultural years 2007-2008 and 2009-2010 represent climatic extremes, the number of studied years was small. Anyway, the gathered experimental data is congruent with the three hypotheses formulated in the introduction. The 2007-2008 total biomass yield, and its fractions, were higher in the SBPPRL than in the SNP, in all slope positions. The higher grass biomass in the SBPPRL means that this yield fraction, almost totally composed of indigenous species, was beneficiated by the legume presence. Nevertheless the indigenous pasture flora was unable to convert into biomass the improved fertility soil conditions, has SBPPRL legumes did. DM yield and its fractions variation along the slope system were buffered in the SBPPRL. This characteristic helps to explain the superior agronomic performance of the SBPPRL pasture system. SOM accumulation is certainly one of its causes. Species richness maxima occurred in SNP and in hill shoulder positions. SBPPRL improved pasture species outcompeted indigenous species – especially oligotrophic, ephemeral, unproductive annual plants – and depressed significantly pasture species richness. SBPPRL also reduced species turnover along the slope system.

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