Lessons learnt for grazed oak wood pasture in Sardinia, Italy

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1. Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2 and Deliverable 2.5 which describes the lessons learnt from innovations within agroforestry systems of high natural and cultural value. Within the project, there were ten stakeholder groups focused on such systems (e.g. grazed forests, semi-open pastures, wood pastures, and bocage). This report focuses on a stakeholder group which focussed on grazed oak woodland in Sardinia and on the research activity that followed.

2. Background

An initial stakeholder meeting focused on grazed oak woodland in Sardinia was held at Monte Pisanu Forest in July 2014 (Pisanelli et al. 2014). The Sardinian stakeholder group proposed innovations to be tested at field scale by the AGFORWARD team in Sardinia. The innovations were to respond to the need to enhance the availability of forage resources, to improve the valuation of pasture resources, and to increase pasture productivity and quality in silvopastoral systems.

One specific request was to identify pastures rich in legumes adapted to shading conditions (due to oak trees) and grazing pressure. This research issue was integrated by the adoption of wider strategies focused on the development and the implementation of appropriate management frameworks for Sardinian agro-silvo-pastoral systems, aiming to increase productivity of all the components of the system (for example, identifying the adequate stocking rate and protecting resources from wildlife animals damages) and promoting synergies between the grazing animals, the pasture and the trees.

In particular, the overseeding of legumes species is a potential strategy to improve the productivity and the quality of understorey pastures within degraded silvopastoral systems. Annual legumes are a key feature for the improvement of low quality native pastures in these systems (e.g. Dehesa in Spain and Montado in Portugal). When a natural seed bank of pasture legumes is present, fertilisation without over-seeding may be sufficient to obtain satisfactory agronomic results, particularly when repeated over several years. However, if the seed bank of pasture legumes in a natural unfertilised pasture is insufficient, the problem can be addressed by the introduction of selected varieties.

Following the initial meeting, a research and development protocol was developed (Franca et al. 2015). Based on the initial discussion, two areas of research were identified:

1. to study the effect of shading by cork oak trees on the establishment and persistence of annual legume-based mixtures in a silvopastoral system.
2. to study the impact of several environmental variables (related to topography and climate, plant biodiversity and soil properties), and grazing management on the seed bank composition in the grazed silvopastoral system.

The activities included three experiments:

1. Effect of shading on the establishment and persistence of annual legume-based mixtures in a scattered trees silvopastoral system (Monti experimental site).
2. Effect of shading on the establishment and persistence of annual legume-based mixtures in a dense trees silvopastoral system (Buddusò experimental site).
3. Combined effect of grazing exclusion and environmental variability on the soil seed bank of a Mediterranean grazed oak wood pasture (Monte Pisanu Forest experimental site).

3. Effect of shading on legume species

3.1 Objectives and treatments

The main objective was to study the effect of shading on the establishment and persistence of two annual legume-based mixtures in a silvopastoral system.

Specific objectives were:

1. Assessing the adaptability and the factors responsible for better adaptation of different pasture mixtures to shade.
2. Assessing the effects of isolated oak trees on soil seed bank dynamics and productivity of pasture species.
3. Assessing the relationships among pasture productivity, vegetation diversity and soil fertility in sown vs spontaneous wooded pastures.

The experiment was carried out in two different sites with different tree coverage and different shading level: Monti with scattered trees and Buddusò with dense tree coverage.

Three pasture types (pasture oversown with Fertiprado commercial legume mixture; pasture oversown with ISPAAM mixture based on native pasture species; and unsown pasture) were compared under and outside of the tree canopy (Table 1). A total of 18 plots was under study. The plot size was 5 m x 3 m and they were replicated in three blocks.

Table 1. Description of the two seed mixtures

Seed mixture	Composition
ISPAAM	40% *Trifolium subterraneum* cv Campeda, 40% *Medicago polymorpha* cv Anglona, 10 % *Lolium rigidum* cv Nurra
Fertiprado	60 % *Trifolium subterraneum*, 4% *T. michelianum* var Balansae, 3% *T. vesiculosum*, 3% *T. resupinatum*, 6% *T. incarnatum*. 2% *T. isthmocarpum*, 2% *T. glanduliferum* and 20% *Ornithopus sativus*.

3.2 Scattered trees silvopastoral system

3.2.1 System description

The experimental site was located within a private farm at Monti in the North-East of Sardinia, Italy. It is representative of the Mediterranean cork oak silvopastoral systems (Table 2 and Figure 1).

Figure 1. The experimental site in the summer of 2014 (Photo: A. Franca)

Table 2. Description of the Monti site, with soil, stand, understorey and climate characteristics

Site characteristics	
Area (ha)	2.32
Co-ordinates:	40° 49' 22.27'' N 09° 19' 18.06" E
Slope	Maximum 6.4%
Elevation	308 m
Site contact:	Mr. Sebastiano Mu email: marinomu87@gmail.com
Soil characteristics	
Soil type (WRB)	Typic Dystroxerept
Soil texture	Sandy-loam
Soil depth	Around 100 cm
Source:	Lab analyses on samples collected in 2012
Stand system characteristics	
System	Agroforestry system
Tree species	Cork oak (*Quercus suber*) (ha^{-1})
Tree density	10 – 40
Tree crown cover (%)	< 10%
Understorey characteristics	
Species	Natural pastures Annual forage crops (*Lolium multiflorum*, *Trifolium michelianum*)
Climate data	
Mean monthly temperature	14.5°C
Mean annual precipitation	629 mm
Weather station	Station of the Regional Environmental Protection Agency The weather station is located about 1.5 km from the site

The farm size was about 100 ha, and its main activity was livestock breeding (without 500 head of “Sarda” dairy sheep), with large utilization of natural pastures and supplementary hay production using annual forage crops. The main products were sheep milk and lambs. Cork production was periodic and represented a complement to the farm income. Milk was produced on the farm and was directly collected and transported to supply the local cheese industry. The new seed mixtures were sown on 28 November 2014, with a seed rate of 20 kg ha^{-1} of germinating seeds for both mixtures and application of 200 kg ha^{-1} of diammonium phosphate.

3.2.2 Measurements

Soil samples were collected before sowing and seedling establishment was estimated counting the seedlings within two sampling areas of 1/8 m^2 per plot. A series of measurements were taken in the experiment during 2015 and 2016 (Table 3).

Table 3. Measurements

Component	Planned measurements
Tree	Tree canopy coverage (PAR- Sunscan/Fisheye photographs)
Pasture	Establishment (number of seedlings m^{-2}) of mixtures Morphology of sown pasture species (plant height, number of stems $plant^{-1}$, stem length) LAI of the pasture canopy (SunScan) Dry matter yield, floristic composition and leaves/stems ratio of mixtures Seedlings re-establishment on autumn Nutritive value (only at Buddusò) Hardseededness of legume species (only at Monti)
Soil	Soil fertility traits at the end of the experiment Soil seed bank at the end of summer after sowing

3.3 Results

Hemispherical (fisheye) photographs elaborated with Gap Light Analyser (GLA) version 2.0 indicated that the total transmitted light differed from 94% in the “not shaded” treatment down to 60% in the shaded treatments.

No significant differences were found between the establishment of shaded and not shaded canopies of Fertiprado and ISPAAM mixtures (Figure 2). Tree shading did not affect seedling densities, whether for introduced mixtures and native vegetation.

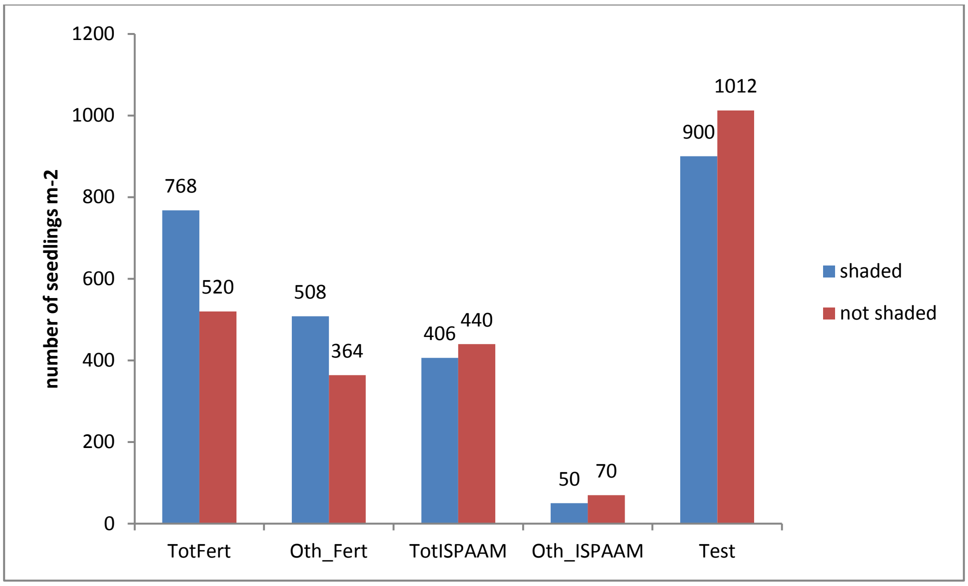

Figure 2. Establishment (number of seedlings m^{-2}) of the Fertiprado (Fert) and ISPAAM seed mixtures one month after sowing in shaded and not shaded conditions. Total number of seedlings and partial number of native species (Oth_Fert and Oth_ISPAAM) for each mixture are reported

Among the nine legume species examined, only *T. subterraneum* and *T. vesiculosum* showed significantly different morphological responses to shading conditions, all lengthening the stems more than two times as much as in the absence of shade conditions (Table 4). Leaf area was significantly influenced by shade conditions only in *T. vesiculosum* plants.

Table 4. Effect of shade on plant morphology of the nine legume species composing the mixtures

Species	Stem length		Leaf area	
	Not shaded	Shaded	Not shaded	Shaded
M. polymorpha	66.9	54.2	1.9	2.7
T. resupinatum		29.8		
T. subterraneum Fert Short stem	7.0b	19.1a	4.4	4.6
T. subterraneum Fert Long stem	28.6	37.4	10.0	8.5
T. subterraneum ISPAAM	16.3b	32.4a	6.0	7.6
T. vesiculosum	30.2b	66.9a	11.2a	8.8b
T. michelianum	33.8	36.8		
T. incarnatum	54.6	48.8	9.2	11.6
O. sativus	68.4	63.3	4.6	4.4

Shading significantly affected the dry matter yield in both the ISPAAM and Fertiprado improved pastures (Figure 3). The native canopy also produced a higher dry matter yield beyond the tree canopy, than within, but the difference was not significant.

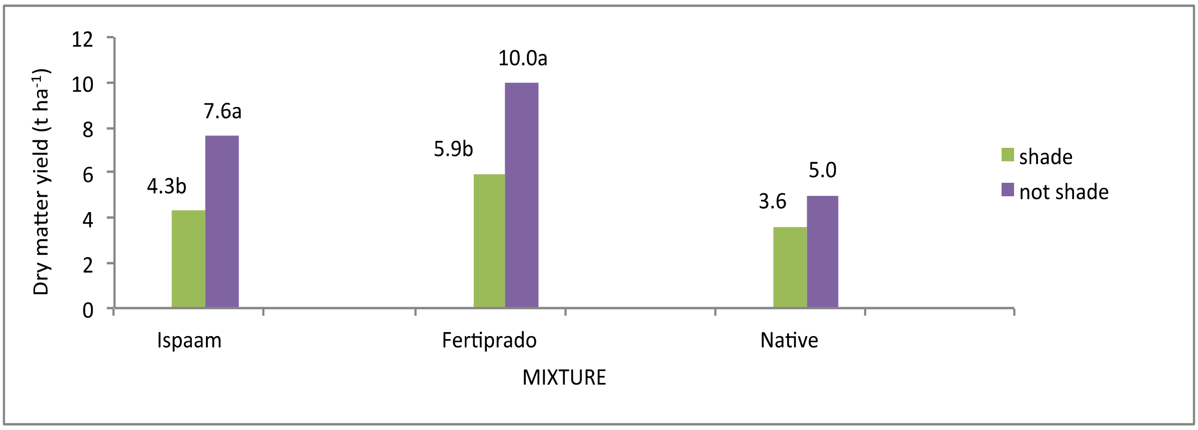

Figure 3. Primary productivity in shaded and not shaded pastures

In the spring of the second year, after the first self-reseeding, the ISPAAM mixture showed higher competitiveness against native species than Fertiprado mixture, primarily as a result of the high contribution to floristical composition of *Lolium rigidum* and, partially, of *T. subterraneum* CAMPEDA (Table 5). Among Fertiprado legumes, only *O. sativus* showed a high coverage in the second year probably because of its very low level of hardseededness (1%). *T. michelianum* increased significantly its hardseededness under shaded conditions. Otherwise, *T. subterraneum* hardseededness took advantage from not shading (significantly for Fertiprado subclovers) (Figure 4).

Table 5. Floristical composition (%) of mixtures at the second year after sowing (self-reseeding)

Species	ISPAAM mixture		Fertiprado mixture	
	Not shaded	Shaded	Not shaded	Shaded
Lolium rigidum	50	73		
Trifolium subterraneum	15	11	3	3
Medicago polymorpha	0	4		
Ornithopus sativus			17	8
Trifolium incarnatum			0	1
Trifolium michelianum			0	0
Other species	35	12	80	88

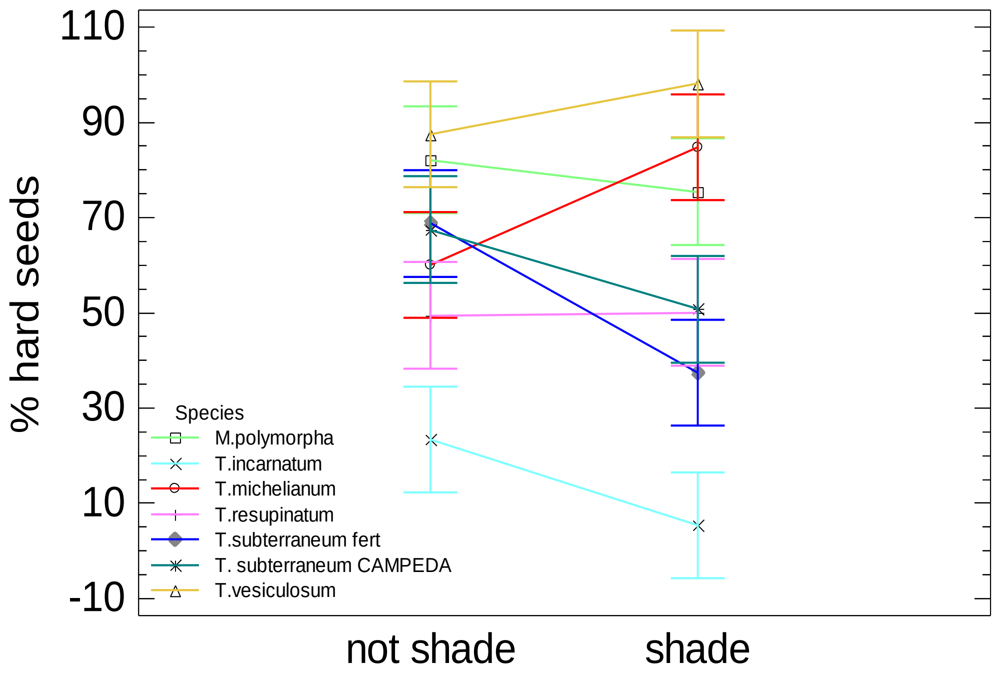

Figure 4. Variation of hardseededness (% of hard seeds) of the legume species between shaded and not shaded conditions.

The native temporary seed bank was always higher than that of the two mixtures, both in shaded and not shaded conditions. Fertiprado showed a total temporary seed bank (comprising the percentage of Other spp.) of 11358 and 17445 seeds m^{-2}, in shaded and not shaded conditions respectively. ISPAAM total TSB was lower than that of Fertiprado, with 9498 and 11701 seeds m^{-2}, respectively in shaded and not shaded conditions (Table 6).

Table 6. Temporary seed bank (TSB, number of germinated seed m^{-2} in rainfed and undisturbed conditions) of mixture species at autumn 2015 after the first self-reseeding

	Fertiprado			Ispaam			Native
	TSB	Other spp. (%)	Total TSB	TSB	Other spp. (%)	Total TSB	TSB
Shaded	3209	82	11358	3669	58	9498	14545
Not shaded	1899	88	17445	4375	62	11701	22144

3.4 Dense tree coverage

This section describes the experiment work in at dense tree silvopastoral system at the Buddusò site (Figure 5).

3.4.1 System description

The experimental site was located at Buddusò, Sardinia, Italy into the Nino Taras's farm (40°37.998N; 9°15.335E, 700 m a.s.l.). The silvopastoral system was characterized by a Cork oak woodland with tree density of 450 trees ha^{-1}, grazed by 1 LSU ha^{-1} of Brown Swiss cattle. The soil characteristics are summarized in Table 7. Measurements and methods were according to the previous experiment on scattered trees (Table 2)

Figure 5. The experimental site at Buddusò (Photo: GA Re)

Table 7. Main soil characteristics

		pH	N ($g\ kg^{-1}$)	C.O. (%)	Organic matter (%)	P_2O_5 (ppm)
Shaded	Ploughed	5.9	1.8	1.9	3.3	5.5
Shaded	Natural pasture	4.8	1.6	2.3	3.9	3.0
Not shaded	Ploughed	5.5	2.5	2.6	4.5	11.0
Not shaded	Natural pasture	5.5	2.5	2.2	3.8	3.4

3.4.2 Results

Pasture productivity differed significantly between shaded and not shaded conditions for Fertiprado, ISPAAM, Native pasture and Native clover. ISPAAM mixture was more productive than the other mixtures. Both in shaded and not shaded canopies, ISPAAM mixture results more competitive against unsown species than Fertiprado and Native clover.

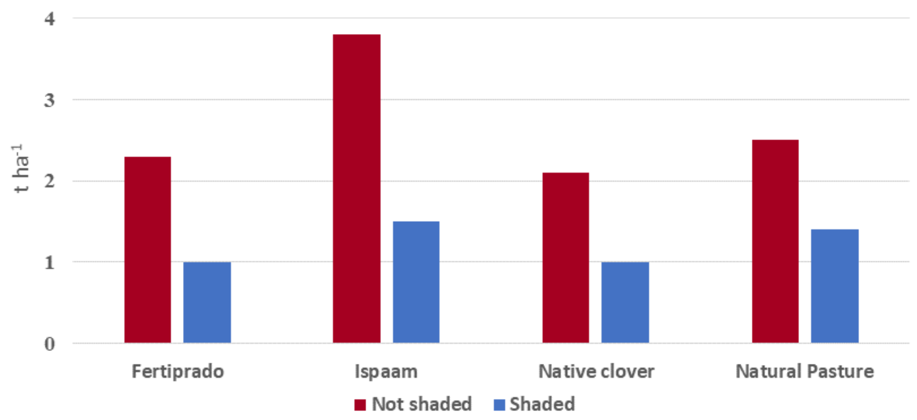

Figure 6. Effect of four treatments on dry matter yield (t ha^{-1}) in not-shaded and shaded pastures

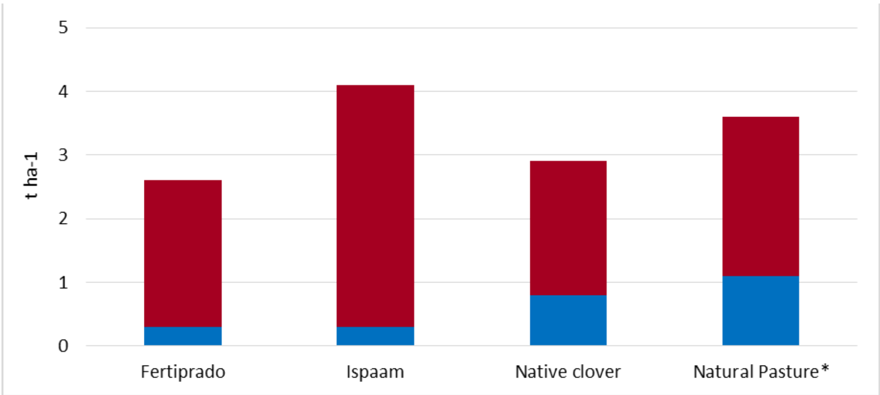

Figure 7. Dry matter yield (t ha^{-1}) of sown (red) + unsown (blue) species in unshaded pastures

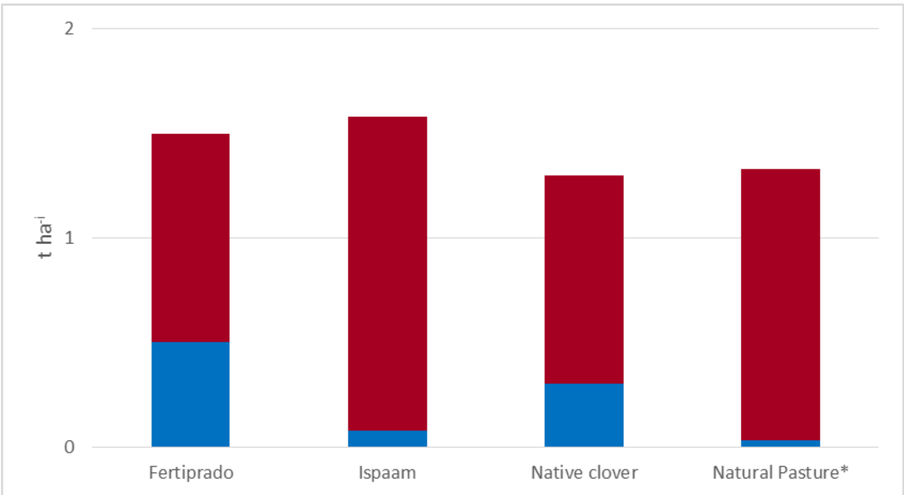

Figure 8. Dry matter yield (t ha^{-1}) of sown (red) + unsown (blue) species in shaded pastures

There were significant differences in morphological traits (Stem length and Leaf area) between shaded and not shaded conditions) (Table 8). *M. polymorpha* "Anglona" (ISPAAM mixture), *T. incarnatum*, *T michelianum* (Fertiprado mixture) and native clover had longer stems in shaded conditions. Although the difference was not significant, *T. subterraneum* in both the ISPAAM and Fertiprado mixtures exhibited an opposite trend. The leaf area significantly differed between treatments for every species belonging to ISPAAM and Fertiprado mixtures, as well as in native clover, with greater leaf area in shaded condition.

Table 8. Morphological traits in relation to Shaded and Not Shaded condition. Asterisk indicates a significant difference ($p<0.05$) between shaded and not shaded conditions

	Stem length (cm)		Leaf area (cm^2)	
	Shaded	Not Shaded	Shaded	Not Shaded
Medicago polymorpha "Anglona"	68.8*	39.3	5.1*	2.5
Trifolium subterraneum "Campeda"	27.8	35.2	5.5*	2.9
Ornithopus sativus	52.7	43.1	9.3*	4.4
Trifolium incarnatum	48.1*	34.2	12.3*	6.9
Trifolium michelianum	57.6*	32.0	4.9*	3.2
Trifolium resupinatum	50.5*	33.4	4.9*	2.0
Trifolium subterraneum a	12.0	17.2	4.9*	1.4
Trifolium subterraneum b	38.3	49.8	5.9*	3.3
Trifolium vesiculosum	47.4	49.5	11.1*	8.5
Native clover	43.1*	18.4	7.5*	5.9

Significant differences in crude protein and ash percentage contributions were found between shaded and not shaded conditions for Fertiprado, ISPAAM and Native clover canopies. Samples taken in shaded conditions showed higher value (%) in CP, NDF, ADF content and showed a better quality than not shaded pasture (Table 9).

Table 9. Percentage contribution (%) of Crude Protein (CP), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and ashes (ASH)) to dry matter of different mixtures in shaded and not shaded pastures. Acid Detergent Lignin (ADL) and Ether Extract did not show significant differences between treatments and were excluded.

	C.P. (%)		NDF (%)		ADF (%)		ASH (%)	
	Shaded	Not shaded	Shaded	Not shaded	Shaded	Not shaded	Shaded	Not shaded
Ispaam	14.9a	9.5b	47.3a	44.7b	32.6a	28.5b	9.8a	6.1b
Fertprado	18.5a	12.5b	41.6a	37.2b	29.3	27.6	12.3a	9.3b
Natural pasture	9.5	8.6	52.5	54.0	30.2b	33.8a	6.0	6.2
Natural clover	17.9a	14.1b	40.7	40.0	29.5	28.7	11.4a	8.6b

Figure 9. Shaded and not shaded plots (May 2016)

4. Effect of grazing and environmental variability on legumes seed bank

The seed bank ecology allows a substantial flexibility for potential changes in the plant community and can provide important information on the dynamic of vegetation and its persistence. In changing conditions, such as undergrazing or grazing exclusion, plasticity of pasture composition species is achieved by a consistent persistent seed bank. In the present study, we studied over three years the effect of grazing exclusion on the soil seed bank of 23 gaps of a Mediterranean grazed oak woodland of *Quercus suber* L., *Q. ilex* L. and *Q. pubescens* Willd., characterized by different pedoclimatic and topographic conditions. In this part of the project, we studied the impact of several environmental variables (related to topography and climate, plant biodiversity and soil properties), and grazing management on the seed bank composition in the grazed gaps of the wood pasture.

4.1 System description

The trial was carried out in the Forest of Monte Pisanu (Central Sardinia, Italy), identified as Site of Community Importance (SIC). The climate of this area is bi-seasonal, with rain in the autumn-winter period and an almost completely dry spring and summer season, which can be aggravated by intense winds. Annual average temperature is 13°C (± 5.8 SD) and annual average precipitation is 908 mm (± 40 SD). The frequency of snowfall in this mountainous area of central Sardinia does not exceed 5-10 days per year. Frost can occur in the autumn, winter and spring. The geology comprises volcanic soils and clastic deposits which can be permeable and fractured near the land surface, but less permeable at depth. Soils derive from crystalline schists, which have high levels of potassium, moderate contents of phosphoric anhydride, and low contents of calcium and clay. The landscape vegetation at Monte Pisanu is dominated by downy oak (*Quercus pubescens* L.) and holm oak (*Quercus ilex* L.) that extend up to more than 1000 m above sea level. The downy oaks often have a bushy habit and are interspersed with small mountain meadows. There are no trees around the summit of Monte Rasu (1259 m), the highest peak in the area, where the vegetation is restricted to shrubs-like perennials, such as thyme, helichrysum and rockrose. However, areas of oak and maple trees, with some holly, coexist on the east side of Monte Rasu (which has been less affected by fires and logging).

4.2 Measurements

The transient and persistent seed bank (TS and PS, respectively) were determined for each gap, under grazed and ungrazed conditions. A canonical correspondence analysis was performed with the aim of determining the effect of topo-climatic (elevation, aspect, slope, average annual rainfall, average annual temperature, tree coverage), soil (pH, nitrogen, phosphorous, organic carbon and organic matter content, soil texture) and biodiversity (Shannon Index, Species Richness Index, Pastoral Value) variables on the composition of transient and persistent seed bank, whether under grazed and ungrazed conditions.

4.3 Results

4.3.1 Relationships between grazing regime and seed bank traits

Seed bank size was severely affected by grazing regime. In the ungrazed sample areas, the average number of seeds m^{-2} was halved compared to that of the grazed surface, both for the transient and for the persistent seed bank. On average, the number of transient seeds in the grazed and ungrazed areas were 42795 m^{-2} and 27036 m^{-2}, respectively. The number of persistent seeds varied from 30272 m^{-2} and 14367 m^{-2}, respectively for grazed and ungrazed areas.

In terms of overall composition of the seed bank, seeds of grasses colonized the transient seed bank, representing on average 63% and 70% of transient seeds in grazed and ungrazed conditions, respectively. Legume seeds doubled their abundance in the persistent seed bank compared to the transient, being the 6% in the transient seedbank and 12.5% in the persistent seedbank. Legumes, Compositae and Other species dominated the persistent seed bank composition, with the 64% of cumulative percentage contribution. Passing from transient to persistent seed bank, grasses lost more than 45% of their abundance, respectively with 66.5% and 20%.

4.3.2 Relationships between microsite environmental variables and seed bank size

The cumulative percentage variance of **transient and persistent seed bank size** explained by topoclimatic variables was 38% of the total variance. The first axis explained 26.7% of the variance, while the second, third and fourth axes the 8.9, 1.3 and the 1.0%, respectively. There was a significant impact of rainfall ($P \leq 0.018$) which had a positive effect on the size of ungrazed transient and persistent seed bank (Figure 10a).

About 45% of the variance of seed bank size is explained by the site's soil traits (Figure 10b). The results showed a significant effect of Organic Carbon ($P \leq 0.02$) and P_2O_5 ($P \leq 0.046$) content. Both transient and persistent seed bank under grazed conditions were positively correlated with P_2O_5 content. All ungrazed seed banks were positively correlated with organic carbon content.

Biodiversity variables affected the 18% of the total variance of seed banks size (Figure 10c). None of the variables taken into account had a significant influence on the size of the seed bank, both under grazed and ungrazed conditions. The average Pastoral Value was significantly higher under ungrazed conditions, while average Shannon index and Richness Index were significantly higher under grazing (Table 10).

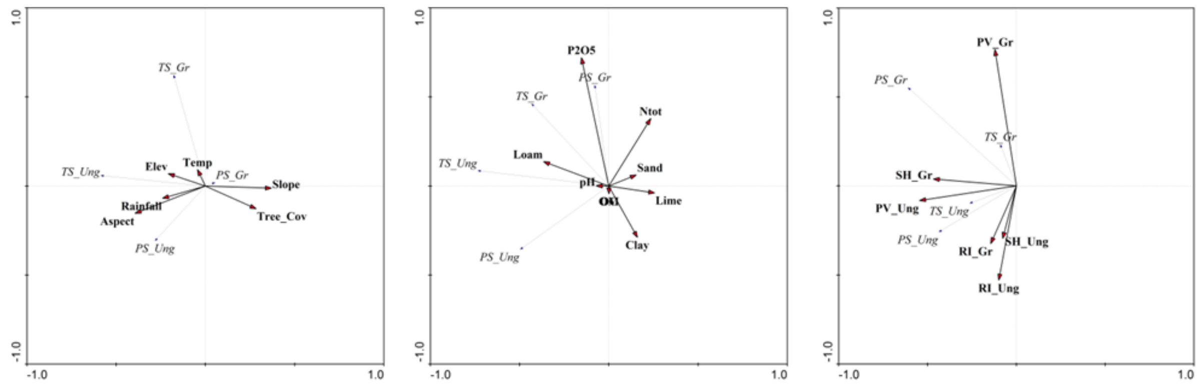

Figure 10. Biplot from redundancy analysis between the transient (TS) and persistent (PS) seed bank sizes and (a) the topoclimatic variables elevation (Elev), aspect (Aspect), slope (Slope), average annual rainfall (Rainfall), average annual temperature (Temp) and tree coverage (Tree_cov); (b) the soil variables pH (pH), nitrogen (Ntot), available phosphorus (P_2O_5), organic carbon (OC) and organic matter (OM) content, soil texture (Lime, sand, clay, loam) and (c) the biodiversity variables Shannon Index (SH), Species Richness Index (RI) and Pastoral Value (PV). TS_Ung, transient seed bank under ungrazed conditions. TS_Gr transient seed bank under grazed conditions. PS_Ung, persistent seed bank under ungrazed conditions. PS_Gr, persistent seed bank under grazed conditions

Table 10. Results of Fisher's test: least significant differences (LSD) between Shannon index, species richness index and Pastoral value determined for the 23 sites under grazed and ungrazed conditions. Different letters indicate a significant difference for P ≤ 0.05. St. dev.= Standard deviation.

Biodiversity index	Grazing conditions			
	Grazed		Ungrazed	
	Mean	St. dev.	Mean	St. dev.
Shannon index	3.8a	±0.31	2.7b	±0.63
Species richness index	28.5a	±3.45	11.0b	±3.54
Pastoral value	26.0b	±5.52	29.5a	±7.75

4.3.3 Relationships between microsite environmental variables and seed bank composition

About 45% of the variance of **transient** seed bank composition is explained by the site's topoclimatic **traits** (Figure 11a). A significant effect of elevation (P ≤ 0.028) and aspect (P ≤ 0.048) was observed. In particular, the transient seed bank of legumes was negatively correlated with elevation, while that of grasses was negatively affected by aspect. Soil variables affected the 32% of the total variance of transient seed bank composition. Sand fraction had a high significant influence on the composition of the transient seed bank (P ≤ 0.002), particularly on the abundance of grasses (Figure 11b).

Under grazed conditions, plots with high Pastoral Value showed abundance of transient seeds of Legumes and Compositeae was observed (Figure 11c). On the contrary, plots with low Pastoral Value showed abundance of other spp.'s transient fraction.

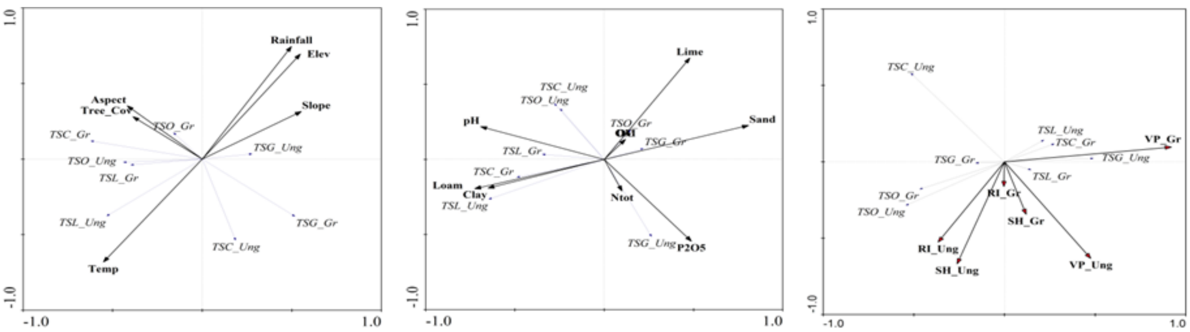

Figure 11. Biplot from redundancy analysis between the transient (TS) seed bank composition and (a) the topoclimatic variables elevation (Elev), aspect (Aspect), slope (Slope), average annual rainfall (Rainfall), average annual temperature (Temp) and tree coverage (Tree_cov) ; (b) the soil variables pH (pH), nitrogen (Ntot), available phosphorus (P_2O_5), organic carbon (OC) and organic matter (OM) content, soil texture (lime, sand, clay, loam); and (c) the biodiversity variables Shannon Index (SH), Species Richness Index (RI) and Pastoral Value (PV). TSG_Ung, transient seed bank of grasses under ungrazed conditions. TSG_Gr, same under grazed conditions. TSL_Ung, transient seed bank of legumes under ungrazed conditions. TSL_Gr, same under grazed conditions. TSC_Ung, transient seed bank of Compositeae under ungrazed conditions. TSC_Gr, same under grazed conditions. TSO_Ung, transient seed bank of Other spp. under ungrazed conditions. TSO_Gr, same under grazed conditions.

Figure 12a shows the effect of site's topoclimatic traits on the composition of the **persistent** seed bank under grazed and ungrazed conditions. Twenty-nine percent of the variance was explained by topoclimatic variables, but none of these variables affected significantly the persistent seed bank composition. Nevertheless, high temperatures and NW aspect (compass direction comprises between 315 and 360°, data not shown) slightly influenced the permanent seed bank of grasses and legumes. The cumulative percentage variance of persistent seed bank composition explained by biodiversity variables was the 42% of the total variance. The first and second axis explained the 22.7% and the 15.4% of the variance, respectively. A significant impact of available P content (P_2O_5, $P \leq 0.05$), with a positive effect on the abundance of the legume fraction persistent seed bank (Figure 12b).

The composition of persistent seed bank was significantly characterized by a high abundance of legumes seeds when high was the Pastoral Value of the plant community, under ungrazed and grazed conditions ($P \leq 0.01$ and 0.03, respectively) (Figure 12c). Also, high values of Richness Index are significantly ($P \leq 0.024$) and positively correlated with the abundance of Other spp. and Compositae in both grazing conditions.

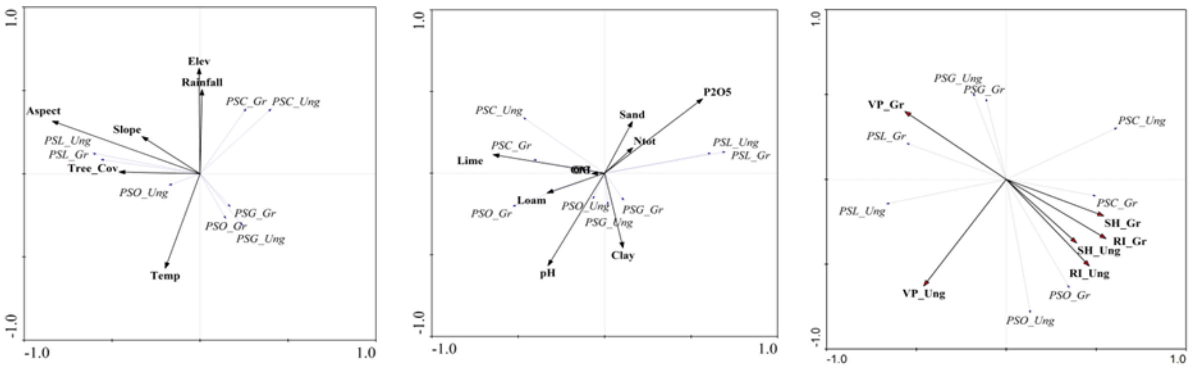

Figure 12. Biplot from redundancy analysis between the persistent (PS) seed bank composition and (a) the topoclimatic variables elevation (Elev), aspect (Aspect), slope (Slope), average annual rainfall (Rainfall), average annual temperature (Temp) and tree coverage (Tree_cov) ; (b) the soil variables pH (pH), nitrogen (Ntot), available phosphorous (P2O5), organic carbon (OC) and organic matter (OM) content, soil texture (lime, sand, clay, loam) ; and (c) the biodiversity variables Shannon Index (SH), Species Richness Index (RI) and Pastoral Value (PV). PSG_Ung, persistent seed bank of grasses under ungrazed conditions. PSG_Gr, same under grazed conditions. PSL_Ung, persistent seed bank of legumes under ungrazed conditions. PSL_Gr, same under grazed conditions. PSC_Ung, persistent seed bank of Compositeae under ungrazed conditions. PSC_Gr, same under grazed conditions. PSO_Ung, persistent seed bank of Other spp. under ungrazed conditions. PSO_Gr, same under grazed conditions

Considering the effect all the environmental factors on the size of both transient and persistent seed bank size, 66% and 57% of the variance was explained by the model, respectively for the transient and persistent seed bank. Four out of all the environmental variables significantly affected the transient seed bank size, with an order of significance from the highest to lowest ranging from sand to elevation, slope to clay. The size of the permanent seed bank was significantly negatively affected by the clay percentage in the soil. Grazing regime did not affect significantly the size of both two seed bank components.

5. Lessons learnt

The openness of scattered trees in the studied silvopastoral system restricted the difference in the levels of light transmission between shaded plots and not shaded plots. However, some adaptation responses to shading of the **introduced legume species** have been observed.

- the oversowing of legumes mixtures improved the native pasture productivity.
- the most adapted species for the use in legume-rich pastures were *T. subterraneum* CAMPEDA (ISPAAM mixture) and *O. sativus* (Fertiprado mixture).
- the high levels of hardseededness of *T. vesiculosum* and *M. polymorpha* reduced their contribution to temporary seed bank and, thus, their capability to produce at the second year after sowing.
- shading reduced the productivity of the legume-rich mixtures of 70%-90%
- shading conditions facilitated the seed hardening of *T. michelianum.*

The high tree density (450 plants ha^{-1}) found in Buddusò site was different from that of Monti (Sardinia) and, in general, of Spanish dehesas. Nevertheless, such a density is frequent for *Q. Suber*, *Q. pubescens* or *Q. ilex* silvopastoral environments in Sardinia. Although results referred only to the first year, shading affected productivity, quality and morphological characteristics:

- *M. polymorpha*, *T. incarnatum* and *T. michelianum* showed significantly longer stems in shaded conditions.
- Shade reduced the productivity of mixtures and native clover by 50-60%, even if the nutritive value in shaded conditions may benefit of an increase in crude protein levels.
- Leaf area was significantly higher in all species in shaded conditions.
- The ISPAAM mixture was more competitive against unsown species than Fertiprado mixture.

In the grazed gaps of Mediterranean oak woodlands, complex combinations of negative and positive interactions, operating simultaneously between the oak trees, shrubs and herbaceous plants, under the influence of animals, microorganisms and microhabitat conditions, must be considered to understand the function of the whole ecosystem.

The resilient capability of the understorey grasslands in the grazed areas of Monte Pisanu oak woodland, expressed by the composition and the size of the persistent seed bank, can vary according to rainfall variation, grazing management and available P in the soil. The conservative management of this silvopastoral area can be reached by putting into practice adequate grazing management, by applying specific site-by-site grazing regimes, and P fertilization, as strategies for improving the seed bank of legumes and the overall quality of the pastures into the low tree density or open areas of the Monte Pisanu silvopastoral system.

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