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Rehabilitation of degraded "Espinales" in the Mediterranean zone of Chile using annual legumes and multipurpose trees

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SUMMARY – The "Espinal" is a Mediterranean agroforestry system of the dryland areas of central Chile. Over the past century, the Espinal has become ecologically degraded. In this paper, results from the first four years of a long-term experiment, are presented. The objective was to study the effect of introducing mixtures of annual legumes (mixture 1 with *Trifolium subterraneum*, *Medicago polymorpha* and *Trifolium michelianum* and mixture 2 with *Ornithopus compressus, Ornithopus sativus* and *Biserrula pelecinus*) and woody species (*Chamaecytisus proliferus* subsp. *palmensis* and *Quercus suber*) on ecosystem productivity. After four years, P fertilization did not increase dry matter production (DM) of the natural pastures. The contribution of annual legumes to the pasture ranged 71-92% and 40-57%, in the first and four years, respectively. Pasture production was between two to three times greater than that of the natural pasture. The two woody species had high survival rates and high production of biomass.

Keywords: Burr medic, serradela, biserrula, tagasaste, cork oak.

RESUME *– "Réhabilitation de "Espinales" dégradés dans la zone méditerranéenne du Chili par l'utilisation de légumineuses annuelles et d'arbres multi-usages". L'"Espinal" est un système agroforestier méditerranéen des zones sèches du Chili. Au cours du siècle dernier, l'Espinal a subi une dégradation écologique. Cet article présente les résultats des quatre premières années de recherche d'un programme de longue durée. L'objectif vise à étudier les effets de l'introduction de mélanges de légumineuses annuelles (mélange 1 avec* Trifolium subterraneum*,* Medicago polymorpha *et* Trifolium michelianum*, et mélange 2 avec* Ornithopus compressus*,* Ornithopus sativus *et* Biserrula pelecinus*) et d'espèces arbustives (*Chamaecytisus proliferus *subsp.* palmensis *et* Quercus suber*) sur la productivité de l'écosystème. Après quatre ans, la fertilisation en P n'a pas augmenté la production de matière sèche des pâturages naturels. La contribution spécifique des légumineuses annuelles aux pâturages atteint 71-92% et 40-57%, au cours des première et quatrième années, respectivement. La production de pâturage est donc de deux à trois fois plus forte que celle des pâturages naturels. Les deux espèces d'arbres présentent des taux de survie importants, ainsi qu'une production élevée de biomasse consommable.*

Mots-clés : *Légumineuses annuelles, serradela, biserrula, tagasaste, chêne-liège.*

Introduction

The natural vegetation in Central Chile (Mediterranean pastures and shrubs) is highly altered; the soils are severely compacted and generally depleted in organic matter, nutrients and microbial life (Ovalle *et al*., 2006). A vast research program of introduction and selection of herbaceous and woody legume species - whether native, naturalized or introduced - has been developed in the last years in order to select herbaceous and woody, specially, legume species, susceptible to be used in programs of rehabilitation of these degraded agro-ecosystems (Ovalle *et al.,* 1999; del Pozo *et al*., 2000, 2001). The objectives of this study were: (i) to contribute to the ecological rehabilitation of the "Espinal" agroforestry system subjected to a strong lost of productivity, diversity and ecological value; (ii) to incorporate mixtures of legume species, able to produce and persist in strong restrictive climatic and edaphic environmental conditions; (iii) to evaluate responses in terms of agronomic variables as: plant density, phytomass production, botanical composition of the natural and incorporated pastures; (iv) to increase species diversity as a base for the improvement of stability, resilience and productivity of the agroforestry system; and (v) to study the contributions of organic matter and nitrogen to the soil, carried out by the herbaceous and woody legumes.

Materials and methods

The field experiment was set up in INIA Cauquenes Experimental Center (35º58' S; 72º17` W, 140 m.a.s.l.), located in the subhumid Mediterranean zone of Chile, in 2003. Soil is granitic (Entisol) of alluvial origin, organic matter content 2%, pH 5.7. The "Espinal" in this area was degraded with 10% of tree cover (*Acacia caven*). Rainfall régime is mostly concentrates (70%) in winter months; precipitation average is 644 mm year^{-1}. The revegetation treatments of the degraded Espinal were (i) traditional land use system, i.e., unimproved ("natural") pasture without fertilization (T1); (ii) natural pasture with phosphorus (P) fertilization (T2); (iii) mixture 1 of self-seeding annual legumes (*Trifolium subterraneum*, *Medicago polymorpha* and *Trifolium michelianum*) plus P fertilization (T3); (iv) mixture 2 of self-seeding annual legumes (*Ornithopus compressus, Ornithopus sativus* and *Biserrula pelecinus*) plus P fertilization (T4); (v) planting of tagasaste with mixture 1 (T5); and (vi) cork oak with mixture 1 (T6). There were four replicate plots for each of six treatments in a randomized block design. The size of the plots was 20 x 10 m.

One year old plants of tagasaste and cork oak were planted in mounds of 40 cm high and 80 cm width, after using deep ploughing. Plant density was 2500 and 1250 trees ha^{-1} for tagasaste and cork oak, respectively. Seeding rate was 25 kg ha^{-1} for mixture 1 (*M. polymorpha*, 8 kg ha^{-1}; *T. subterraneum*, 14 kg ha^{-1}; and *T. michelianum*, 3 kg ha^{-1}). Mixture 2 was seeded at 16 kg ha-^{1} (*Biserula pelecinus*, 10 kg ha^{-1}; *Ornithopus sativus*, 4 kg ha^{-1}; and *Ornithopus compressus*, 2 kg ha^{-1}). According to soil analysis, pasture fertilization consisted of 65 kg P ha^{-1}, 100 kg K_2O ha^{-1}, 2.2 kg B ha^{-1}, 165 kg Ca ha^{-1} and 90 kg S ha^{-1} at sowing (2003), and then 20 kg P ha^{-1}, in autumn 2004, 2005 and 2006.

The plots were fenced individually and grazed by treatment. Pastures were grazed three times en each season with 40 sheep during 24 to 48 hrs distributed by treatments according to forage availability.

Results and discussion

At pasture establishment, plant density was higher than 1000 plant m^{-2} which is considered an optimum stand of plants in these types of pastures, and the relative contribution of legumes was greater than 70% (Table 1). The pattern of variation of the plant population was different among the legume mixtures tested. In mixture 1 (T3, T5 and T6) a strong dominance of sub clover and burr medic (except in the second year) was observed throughout the study period. In mixture 2 (T4), plant density and relative contribution of biserrula and serradella decreased in the second year, due to the high hardseedness, but increased thereafter, with a strong dominance of biserrula (75%) in the fourth year (Table 1). The self regeneration of balansa clover was low, which can be explained by the high percentage of hardseedness and probably it is not well adapted to this type of degraded soils. The low population of yellow serradella can be explained by the small seed dose that was used.

In the first year, the biomass production of mixture 2 (T4) and mixture 1 (T3, T5 and T6) was 100% and 40% higher, respectively, than the natural pasture (Table 2). In the second year, the biomass of annual legume mixtures was significantly ($P<0.05$) higher than the natural pasture, but not in the third year where the productivity of legumes was lower than the previous seasons. In the fourth season, the productivity of annual legume mixtures was higher than the natural pasture, particularly in T4 that included biserrula and serradella. The addition of phosphorus (P) fertilization to natural pastures (T2) did not increase biomass production (Table 2). The soil P content in the third year of the experiment was higher ($P\leq0.05$) in treatments that received P fertilization. These high levels of P are attributable basically to the phenomenon of residual effect that is generated in these soils, when receiving mineral P fertilization.

Tagasaste associated with mixture 1 of annual legumes increased 77 cm in height, on average, in the first year and reached 120 cm after four years, on average, despite controlled browsing by sheep in years 2, 3 and 4. The basal diameter also increased 17 mm between years 1 and 4. In contrast, cork oak increased only an average of 30 cm in height after four years, while trunk diameter increased by an average of 8 cm during the same period of growth (data not shown).

Table 1. Plant population (plants m^{-2}) and floristic composition (in brackets) of the sowed species from different pasture revegetation system, in degraded "Espinales" of Central Chile

Treatment	Burr Medic	Sub clover	Balansa clover	Biserrula	Yellow serradella	Pink serradella	Total
Year 1(2003)							
T3	614 (40.0)	406 (25.4)	419 (5.6)				1439 a
T4				901 (80.7)	40 (5.9)	80 (5.3)	1021 b
T5	706 (32.3)	594 (37.2)	379 (5.4)				1679 a
T6	640 (41.3)	530 (30.6)	346 (6.7)				1516 a
Year 2 (2004)							
T3	853 (0.8)	1079 (38.8)	16 (0.3)				1939 a
T4				86 (39.4)	0 (0.0)	159 (11.0)	245 b
T5	637 (1.8)	1223 (38.8)	29 (0.4)				1889 a
T6	754 (5.0)	1302 (51.7)	11 (0.2)				2067 a
Year 3 (2005)							
T3	2645 (24.4)	1442 (32.9)	0 (0.4)				4087 a
T4				789 (28.1)	0 (4.8)	936 (15.0)	1725 b
T5	2932 (21.5)	2217 (33.1)	4 (0.9)				5153 a
T6	3468 (21.9)	2620 (38.0)	41 (0.5)				6129 a
Year 4 (2006)							
T3	1159 (41.9)	911 (20.9)	0 (0.0)				2070 c
T4				4183 (74.8)	0 (1.7)	13 (1.1)	4196 a
T5	1358 (48.5)	1140 (18.9)	0 (0.0)				2498 c
T6	1760 (32.4)	1254 (38.6)	0 (0.0)				3014 b

Means followed by different letters in a column are significantly different ($P \leq 0.05$) according to Duncan test.

Table 2. Biomass production of natural and sowed pastures (kg DM $ha^{-1}year^{-1}$) under grazing conditions, in the degraded "Espinales" of central Chile

Treatment	May-July	August	September	November	Total biomass
Year 1 (2003)					
T1	--	--	--	785 c	785 c
T2	--	--	--	772 c	772 c
T3	--	--	--	1070 b	1070 b
T4	--	--	--	1781 a	1781 a
T5	--	--	--	1070 b	1070 b
T6	--	--	--	1120 b	1120 b
Year 2 (2004)					
T1	505 b	490 b	--	818 bc	1830 b
T2	750ab	725 b	--	644 c	2110 b
T3	730ab	1580 a	--	760 bc	3070 a
T4	990 a	1650 a	--	988 ab	3620 a
T5	790ab	1820 a	--	1171 a	3780 a
T6	773ab	1385 a	--	1052 ab	3210 a
Year 3 (2005)					
T1	470 a	200 a	310 c	857 bc	1837 b
T2	460 a	220 a	490bc	749 c	1809 b
T3	558 a	140 a	850ab	1123abc	2596 ab
T4	440 a	160 a	620 abc	1366 a	2501 ab
T5	662 a	280 a	1130 a	1322 ab	3250 a
T6	435 a	245 a	870ab	1124abc	2551 ab
Year 4 (2006)					
T1	450 c	763 b	1600 b	--	2813 c
T2	450 c	843 b	1925 b	--	3218 c
T3	903 a	1548 a	2117 b	--	4567 b
T4	825ab	2105 a	3470 a	--	6400 a
T5	643bc	1729 a	1979 b	--	4351 b
T6	895 a	1647 a	1975 b	--	4517 b

Means followed by different letters in a column are significantly different ($P \leq 0.05$) according to Duncan test.

Evaluations carried out between 0 and 10 cm depth in the third year of the experiment, indicated higher levels (P≤0.05) of available N (N03 + NH4), in treatments that included legumes (T3, T4, T5 and T6), in relationship to that found in natural pastures (with or without P fertilization). The soil P content in the third year of the experiment was higher (P≤0.05) in treatments that received P fertilization. Non significant differences between treatments were found in soil pH or organic matter.

Conclusions

After the first four years of a long term experiment focused on the development of practical tools for the ecological and economic rehabilitation of the Espinal agro-ecosystem of central Chile, the results presented above clearly confirm the hypothesis that legumes adapted to dryland conditions in the "secano interior" can have rapid, beneficial effects on productivity and on soil processes relevant to productivity, biodiversity and total value.

The two mixtures of annual pasture legumes, by themselves or in association with tagasaste, gave the most promising results. The effect of planting cork oak in association with pastures will be monitored on a long term basis, due to the low rate growth of the tree under the environmental conditions of the study area.

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