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Advances in grassland research in the Mediterranean region of Chile

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Abstract. The Central Zone of Chile, the only part of South America that presents a Mediterranean climate, has about 5 million hectares of pasture. A large proportion are annual species from the Mediterranean Basin. This article presents a summary of the results of 20 years of research carried out in order to improve productivity of livestock production systems and contribute to the rehabilitation of these degraded agroecosystems. The studies have considered both the collection and domestication of naturalized annual legumes in Chile (*Medicago polymorpha*) and the assessment of several accessions and cultivars of annual legumes of the genus *Trifolium*, *Medicago*, *Ornithopis* and *Biserrula*. The works have also considered the design and assessment of pasture mixtures, the evaluation of N fixation in addition to the integration of legumes in crop rotations and as cover crop in vineyards and orchards. Evaluations were performed in a gradient of rainfall between 600 and 1000 mm annual rainfall on volcanic soils (Andisols) and Entisols derived from granitic rocks. The productivity and persistence of *B. pelecinus* in the interior dryland and *O. compressus* in the Andean foothill are clearly superior to other annual legumes (*M. polymorpha* or *T. subterraneum*) seeded in those areas. The use of legume mixture is also highly recommended due to their higher productivity and persistence compared to monospecific pastures. The amount of N₂ fixed by annual legumes is closely related to the shoot dry matter production of the pasture, and the rate is 18-20 kg shoot N fixed per ton shoot DM accumulated. Finally, annual legumes contribute to the N nutrition of wheat or grapevines in a Mediterranean environment.

Keywords. Pastures – Legumes – Mixtures – Productivity – Persistence – N fixation– Rotations – Cover crops.

Progrès dans la recherche sur les pâturages et les prairies dans la région méditerranéenne du Chili

Résumé. La zone centrale du Chili, la seule partie de l'Amérique du Sud qui présente un climat méditerranéen, a environ 5 millions d'hectares de pâturages. Une grande partie sont des espèces annuelles du bassin méditerranéen. Cet article présente un résumé des résultats de 20 années de recherches menées dans le but d'améliorer la productivité des systèmes de production animale et de contribuer à la réhabilitation de ces agro-écosystèmes dégradés. Les études ont porté sur la collecte et la domestication des légumineuses annuelles naturalisées au Chili (*Medicago polymorpha*) et sur l'évaluation de plusieurs accessions et cultivars de légumineuses annuelles des genres *Trifolium*, *Medicago*, *Ornithopis* et *Biserrula*. Les travaux ont également examiné la conception et l'évaluation des mélanges de pâturages, l'évaluation de la fixation d'azote en plus de l'intégration de légumineuses dans les rotations de cultures et comme plante de couverture dans les vignobles et les vergers. Les évaluations ont été réalisées dans un gradient de pluviométrie d'entre 600 et 1000 mm annuelles sur les sols volcaniques (Andisols) et entisols dérivés de roches granitiques. La productivité et la persistance de *B. pelecinus* dans les terres arides de l'intérieur et d'*O. compressus* dans les contreforts des Andes sont nettement supérieures à d'autres légumineuses annuelles (*M. polymorpha* ou *T. subterraneum*) ensemencées dans ces domaines. L'utilisation d'un mélange de légumineuses est aussi fortement recommandé en raison de leur plus grande productivité et de leur persistance par rapport aux pâturages monospécifiques. La quantité de N₂ fixé par les légumineuses annuelles est lié à la production de matière sèche des pousses du pâturage, et le taux est de 18-20 kg N pousses fixé par tonne DM accumulé. Enfin, les légumineuses annuelles contribuent à la nutrition azotée du blé ou de la vigne dans un environnement méditerranéen.

Mots-clés. Pâturages – Légumineuses – Mélanges – Productivité – Persistance – Fixation de N – Rotations – Cultures de couverture.

I – Introduction

More than 5 million ha of natural grassland are found in the Mediterranean climate region of Chile, most of them in advanced stages of degradation. According to the last agriculture census (INE, 2007), about 58% of these natural grasslands are in the arid (150-250 mm), 8% in the semiarid (300-450 mm), 23% in the subhumid (400-700 mm) and 11% in the humid-perhumid (800-1200 mm) regions. The area of improved (i.e. regenerated or managed with fertilization) and new established grasslands are only 0.24 and 0.20 million ha, respectively.

Natural grasslands are dominated by annual composites and grasses, mostly introduced intentionally or accidentally from Eurasia (Ovalle *et al.*, 2006). The diversity and abundance of annual legumes is low being *Trifolium glomeratum*, *T. dubium* and *Medicago polymorpha* the most frequent species (del Pozo *et al.*, 2006; Ovalle *et al.*, 2006). In order to improve grassland productivity and persistence, as well as soil fertility, a R&D program has been developed during the last 15 years in order to select nitrogen-fixing legumes adapted to the various agro-ecological conditions of the Mediterranean region of Chile. In this article we report the potential and multiple uses of legumes species in agro-ecosystems, as permanent pasture, in rotation with wheat and as cover crops.

II – Productivity and persistence of annual legumes species

Annual legumes are typically from Mediterranean grasslands and there are a number of species that can be used as a forage crops. Initially, we collected and characterized a large number of accessions on *M. polymorpha*, which is a naturalized species distributed in the whole Mediterranean region of Chile (del Pozo *et al.*, 2002). Then we explored other annual legumes species, particularly those containing small and hard seeds, and which are relatively ease to harvest, like *Ornithopus compressus*, *Biserrula pelecinus* and *T. micheleanum* (Ovalle *et al.*, 2003). The productivity of these legumes was evaluated in two Mediterranean environments in Central Chile, the interior dryland (Cauquenes: 35°58' S, 72°17' W, mean annual precipitation 695 mm) and Andean foothills (Yungay: 37°10' S, 71°58' W, mean annual rainfall is 1200 mm). *B. pelecinus* showed high dry matter production and a remarkable seed yield in the interior dryland but not in the Andean foothill, whereas *O. compressus* had a high productivity in both environments (Table 1). On the third growing season, the regeneration, production and persistence of *B. pelecinus* (in the interior dryland) and *O. compressus* (in both environments) was much higher than that of *M. polymorpha* or *T. subterraneum*. Another good option for the Andean foothill is *T. vesiculosum* (Table 1), which has deeper root system and longer growing period than *T. subterraneum*.

Table 1. Days to first flower (DF) , hard seedness (HS), cumulative above-ground dry matter of three growing seasons (2000-2002) and seed yield (SY) of annual legumes growing in two Mediterranean environments of central Chile, interior dryland and Andean foothill

Species	DF [†]	HS ^{††} (%)	Dry matter (g/m ²)		Seed yield (g/m ²)	
			Interior dryland ^{††}	Andean foothill ^{†††}	Interior dryland ^{††}	Andean foothill ^{†††}
<i>M. polymorpha</i>	97	95	909±136	116±54	137±24	28±8
<i>T. subterraneum</i>	118	67	932±108	802±57	95±11	194±11
<i>B. pelecinus</i>	123	100	1222±406	225±72	265±70	57±19
<i>O. compressus</i>	112	99	1251±389	872±225	143±45	80±12
<i>O. sativus</i>	135	4	912±289	576±33	153±56	94±10
<i>T. micheleanum</i>	136	43	537±204	570±90	99±29	101±12
<i>T. vesiculosum</i>	160	89	347±65	942±223	67±22	209±20

[†]From Ovalle *et al.* (2003).

^{††}From Ovalle *et al.* (2005b) and del Pozo and Ovalle (2009).

^{†††}From Ovalle *et al.* (2005a).

Data are from the highest productive cultivar of each species and environment.

III – Mixtures of annual legumes to improve productivity and persistence

The use of annual legume mixtures could improve pasture production, quality and persistence of Mediterranean pastures. Also, the length of the grazing season can be expanded when different legume species are combined in mixtures. In a study conducted in the interior dryland (Cauquenes, Chile) mixtures of 2 (M2) to 5 (M5) legume species were evaluated; the control was a pasture of 100% of *T. subterraneum* (Avendaño *et al.*, 2005). Dry matter production was increased at the third growing season in mixtures compared to the monospecific pasture (Fig. 1); pasture with 2 or more species were dominated by *M. polymorpha*, and the proportion of *O. compressus* and *B. peniculus* were very low in M5, despite the species where sown in equal proportion (20% each).

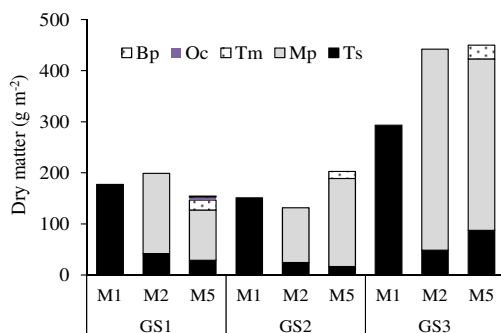


Fig. 1. Dry matter production of annual legume pastures with one (M1), two (M2) or five species (M5), during three growing seasons (GS). M1: 100% *T. subterraneum* (Ts); M2: 50% of Ts and 50% of *M. polymorpha*; M5: is 20% of Ts, Mp, *T. micheleanum* (Tm), *O. compressus* (Op) and *B. pelecinus* (Bp). Data from Avendaño *et al.* (2005).

IV – Annual legumes in rotation with cereals

Legumes can play a major role in: (i) providing additional N into cropping soils, (ii) increasing the soil N availability, and (iii) improving the grain yield of following cereal crops. Grain yields achieved by wheat in the absence of fertilizer N following annual legume mixtures (of three species) or the unfertilized oat crop, were compared to the current farmer practice of supplying N fertilizer to wheat grown after oats, during four growing seasons (2008-2011). Wheat yields following two different annual legumes mixtures of 1, 2 or 3 years old were on average 65, 98 and 63%, respectively, of the 3.4 t/ha of grain harvested in the oat-wheat with N fertilizer (160 kg N/ha) in the interior dryland, and 78, 93 and 73%, respectively, of the 6.0 t/ha attained by the N fertilized (207 kg N/ha) wheat crops in the Andean foothill. Grain yield attained in the oat-wheat rotation without N fertilization was on average 1.4 and 3.8 t/ha.

V – Nitrogen fixation

The capacity of N₂ biological fixation (NBF) by annual legumes has been evaluated by the ¹⁵N natural abundance technique using four non legumes species as references plants. In granitic soils of the interior dryland the percentage of legume N derived from air (%Nd_{fa}) of *M. polymorpha*, *T. subterraneum*, *O. compressus*, *O. sativus* and *T. michelianum* was high (74.3 to 93.9%); *O. compressus* presented the greatest N content in dry matter and the amount of N fixed was 91 kg N/ha (Ovalle *et al.*, 2006). In Alfisols of the Andean foothill the amount of N

fixed by four legumes (*T. subterraneum*, *O. compressus*, *T. vesiculosum* and *T. incarnatum*) ranged between 43 and 147 kg N/ha (Espinoza *et al.*, 2011). In legume mixtures of 2 to 4 legume species, the amount of N fixed varied between 97 and 214 kg N/ha (Espinoza *et al.*, 2011). There is a close relationship between shoot dry matter and the amounts of N₂ fixed by all legume species across sites; between 18 and 20 kg shoot D/ha were fixed on average for every ton of shoot DM accumulated (Fig. 2). These values are similar to those found in grain legumes in the same environments (Espinoza *et al.*, 2012).

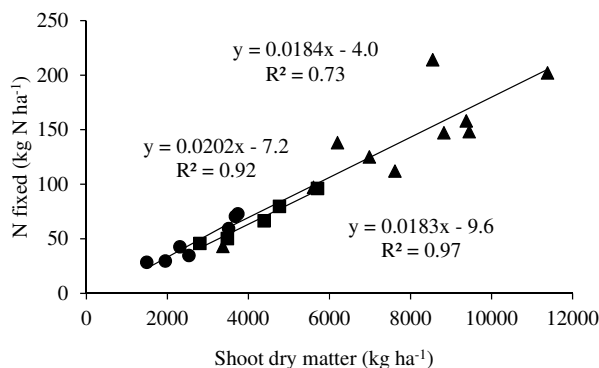


Fig. 2. Relationship between shoot dry matter (DM) and amounts of shoot N fixed by annual legumes in granitic (●) and clay (■) soils of the interior dryland, and in alfisols (▲) of the Andean foothill. Data from Ovalle *et al.* (2006) and Espinoza *et al.* (2011). In the Andean foothill the highest dry matter and N fixed by attained by legume mixtures.

VI – Cover crops

Cover cropping with nitrogen (N) fixing annual legumes is a technology increasingly being used in grapevine and orchards production systems in various Mediterranean regions. Among the benefits of using cover crops are the reduction of soil erosion, the enhancement of the soil biological activity, the increase of soil organic matter content and nutrient availability, and improvements in soil porosity and aggregate stability, and increase of soil water holding capacity. In grapevine, average inputs of annual legume N represented 112-161 kg shoot N/ha/y, respectively, grape dry matter production was increased significantly by 48-61% and the amount of N accumulated in grape bunches was enhanced by 74-105% after 2 years of legume cover crop (Ovalle *et al.*, 2010).

VII – Conclusions

The productivity and persistence of *B. pelecinus* in the interior dryland and *O. compressus* in the Andean foothill are clearly superior to other annual legumes (*M. polymorpha* or *T. subterraneum*) seeded in those areas. The use of legume mixture is also highly recommended due to their higher productivity and persistence compared to monospecific pastures. The amount of N₂ fixed by annual legumes is closely related to the shoot dry matter production of the pasture, and the rate is 18-20 shoot N fixed per tonne shoot DM accumulated. Finally, annual legumes contribute to the N nutrition of wheat or grapevines in a Mediterranean environment.

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