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Pure stands *vs* four-species mixtures: Agronomic and ecological implications in Mediterranean rainfed conditions

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SUMMARY – Seasonal and annual patterns of species contribution to yield and unsown species control of different grass-legume mixtures in a four-year experiment were investigated. Thirty plots were sown in October 2002 with pure stands and 4-species mixtures of grass/legume and fast/slow establishing species (*Lolium rigidum*, *Dactylis glomerata*, *Medicago polymorpha* and *Medicago sativa*) in different proportions and at two sowing densities. In terms of sown species biomass along the years, mixtures outperformed pure stands, apart from *M. sativa* pure stand. Along the years there was a complete shift in the contribution of sown species, from fast establishing species contributing up to 80% in the first year to their complete disappearance and perennial species dominance in the last year. In most seasons increasing evenness in the mixture reduces unsown species biomass. Results suggest that the use of mixtures of different functional types may increase productivity and its seasonal distribution and decrease unsown species growth.

Keywords: Functional groups, simplex design, evenness, overyielding.

RESUME – *"Plantation pure ou mélange de quatre espèces : implications agronomiques et écologiques en conditions pluviales méditerranéennes". Des modèles saisonniers et annuels concernant la contribution des espèces à la production et le contrôle des espèces non semées, pour différents mélanges de graminées-légumineuses dans une expérimentation de 4 années, ont été étudiés. Trente parcelles ont été semées en octobre 2002 en stands purs et en mélanges de 4 espèces de graminées-légumineuses et d'espèces à instauration rapide/lente (*Lolium rigidum*,* Dactylis glomerata*,* Medicago polymorpha *et* Medicago sativa*). En termes de biomasse des espèces semées le long des années, les mélanges ont surpassé les stands purs, à l'exception du stand pur de* M. sativa*. Au fil des années il y avait une variation complète dans la contribution des espèces semées, les espèces à instauration rapide contribuant à plus de 80% dans la première année jusqu'à leur disparition complète et la dominance d'espèces pérennes au cours de la dernière année. Les résultats suggèrent que l'utilisation de mélanges de différents types fonctionnels peut augmenter la productivité et diminuer la croissance des espèces non semées.*

Mots-clés : *Groupes fonctionnels, simplex design, uniformité, surproduction.*

Introduction

Grass-legume mixtures may have the advantage of stabilizing yield over the growing season, which may be more important than achieving high yields, especially in Mediterranean rainfed conditions characterized by strong inter- and intra-annual meteorological fluctuations and the extremely high heterogeneity of environmental and farming system situations. Enhancing sward productivity by exploiting the synergies existing among plant functional groups as an alternative to high artificial inputs is one of the challenges faced by agricultural research. An optimal proportion of grass/legumes and annual self-reseeding/perennials, can favour species' establishment and persistence. A species-rich mixture may not necessarily meet the objective of producing high yields in a stable environment, whereas it may be advantageous in heterogeneous environments. In the former case the diversity effect could be obtained with a mixture of few species well adapted to the appropriate environmental conditions. We have recently developed a modelling framework which allows us to separately estimate contributions of interactions in species mixtures by manipulating relative abundance (Kirwan *et al.*, 2007). The present paper investigates the seasonal and annual patterns of species contribution to yield and unsown species control in grass-legume mixtures within the common activity of COST Action 852.

Materials and methods

Thirty plots (3 x 3 m) were sown in October 2002 at the Ottava Research Station (40°44' N, 8°32' E), 80 m a.s.l., on calcareous soil (pH = 7.5) in a typically Mediterranean climate with an average annual rainfall of 550 mm and 16.2°C mean annual temperatures. The species used in the experiment represent four functional groups: grass (G), legume (L), fast-establishing (subscript 1) and slow-establishing (subscript 2) species. The sown species were *L. rigidum* cv. Nurra (G_1), *Dactylis glomerata* cv. Currie (G_2), *M. polymorpha* cv. Anglona (L_1) and *M. sativa* cv. Mamuntanas (L_2). The plots include four pure stands and 11 mixtures with 4-species combinations, ranging from dominance by one (0.7; 0.1; 0.1; 0.1) or by two species (0.4; 0.4; 0.1, 0.1) to total evenness (centroid = equal contribution of all mixture components = 0.25), following a 'simplex design' (Cornell, 2002) duplicated at two sowing densities (high density = 35 kg ha^{-1}, low density = 60% of high density). Plots were fertilized at sowing with 54 kg ha^{-1} of N and 60 kg ha^{-1} of P and then with 60 and 46 kg ha^{-1} $year^{-1}$ of N and P, respectively. No irrigation and weeding were applied. Herbage samples were taken from 4 fixed quadrats (50 x 50 cm) per plot along the 4 years. Cutting frequency was based on local practice. The sward was cut to a height of 5 cm at each harvest. Plant material was separated into the five basic fractions: G_1, G_2, L_1, L_2 and unsown species. Fresh and dry weight (65°C for 18 hours) of the five fractions were determined. Total dry matter yield and the contribution of each component of the mixture to total yield were computed. The effect of mixing functional groups was tested by comparing the yield and resistance to unsown species at the centroid with that at the pure stands. Overyielding and transgressive overyielding for biomass production and unsown species control were determined (Trenbath, 1974). The same responses were also studied through multiple regression in a model-based approach, in order to detect synergisms between the components of the mixture (Kirwan *et al*., 2007).

Results and discussion

Plot establishment in the first year was regular thanks to high autumn rainfalls, though a long winter and spring drought negatively affected total annual forage production (3000 kg ha^{-1}), especially of perennials. Since the second year, total annual biomass has been quite stable ranging between 7100 and 7500 kg ha^{-1} $year^{-1}$ but with marked between-year variations in terms of seasonal distribution (Fig. 1). Along the 4 years biomass production was generally characterized by spring peaks of production although autumn production represented on average 20% of total annual DMY.

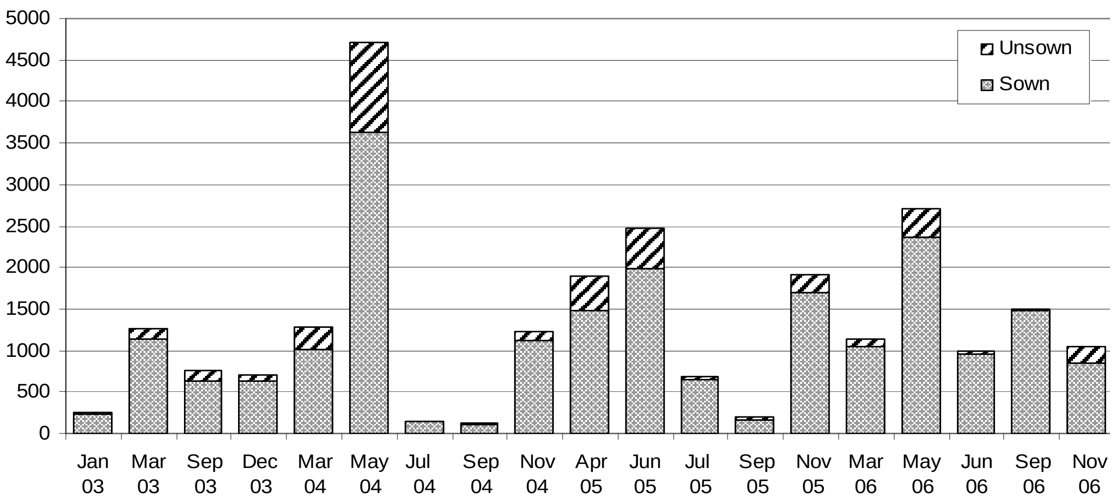

Fig. 1. Total dry matter (kg ha^{-1}) of sown and unsown species in each cut during the trial (2003-2006) as an average of all treatments.

As expected the contribution of L1 and G1 was high in the first year and then decreased progressively (Fig. 2).

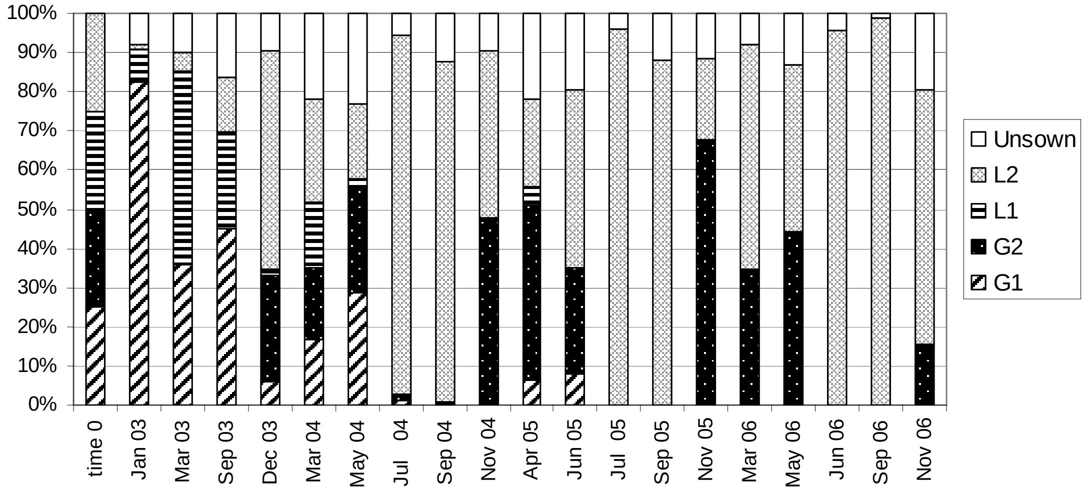

Fig. 2. Species contribution to yield (%) in each cut during the trial (2003-2006) as an average composition of all treatments.

Since the second year, plots dominated by perennials have controlled unsown species better. Regarding seasonal distribution the highest contribution in summer was made by L_2 and in autumn by G_2. Sown species biomass of mixtures outperformed pure stands, apart from L_2 pure stand (Fig. 3).

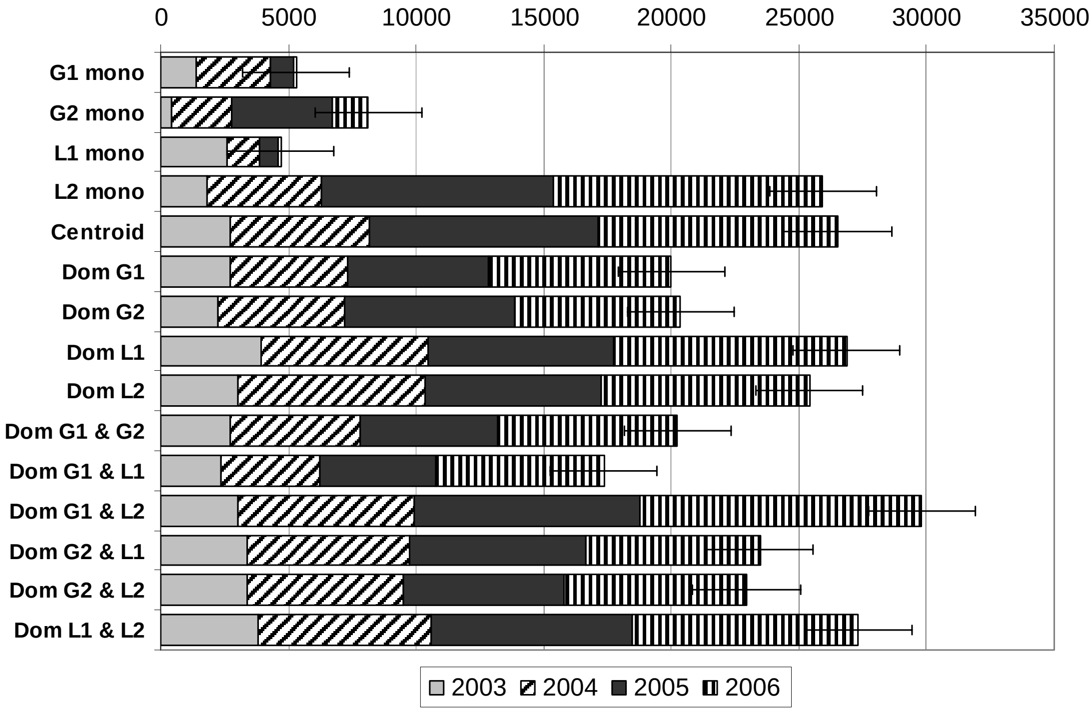

Fig. 3. Dry matter yield of sown species (kg ha^{-1}) of each mixture type in each year of trial.

In most seasons increasing evenness, expressed as a measure of the distribution of the relative abundance of species in a community (Kirwan *et al.*, 2007)**,** reduces unsown species biomass in the mixture. The performance of centroid plots exceeded that of pure stands leading to overyielding and transgressive overyielding for biomass production and unsown species control, the only exception being transgressive overyielding for sown yield in the last year (Table 1).

Table 1. Percent change of sown and unsown species of the centroid *vs*: the average of pure stands (overyielding) and the best pure stand L_2 (transgressive overyielding)

Year	Overyielding		Transgressive overyielding	
	Sown yield	Unsown yield	Sown yield	Unsown yield
2003	56	-35	8	-47
2004	107	-87	7	-87
2005	151	-99	9	-95
2006	221	-95	-8	-89

The preliminary application of the diversity model on the results of the first three years showed that for both response variables (total yield and unsown species yield), sowing density was never significant. Total yield was affected in 2004 and 2005 by synergistic interaction effects between G_2 and L_1, possibly due to the positive effect of L_1 nitrogen fixation in the first year on the subsequent biomass production of G_2. The asynchrony of growth cycles of G_1 and G_2 in the first year may explain their positive individual interaction effect on unsown species control. In the second and third year, $G_2 x L_1$ and $G_2 x L_2$ interactions reflect the importance of G_2 in unsown species control and the positive grass-legume and inter fast-slow functional group interactions also detected during the same years.

Conclusions

In Mediterranean conditions, grass-legume mixtures of species belonging to different functional groups compared to pure stands proved to: increase productivity and unsown species control and improve seasonal distribution of biomass. Perennial species in association with annuals may play a fundamental role in Mediterranean low input rainfed farming systems. The asynchrony of the growth cycles of fast/slow establishing species and grasses/legumes reduces between-year and within-year biomass variations. The compatibility between perennial and annual species when grown in mixtures, and in particular the effect of perennials on the re-establishment and seed set of annuals, need further studies to improve spring and autumn sward management aimed to extend the persistence of annual self-reseeding species. The new methodology for the design and analysis this kind of experiments seems useful to quantify diversity-function relationships and to develop optimised mixtures with the corresponding relative species' abundances.

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