Diversity–ecosystem function relationship in mixed forage crops

Llurba R.[1], Ribas A.[1,2], Ventura D.[1], Connolly J.[3] and Sebastià M.T.[1,4]
[1] *Centre Tecnològic Forestal de Catalunya*
[2] *BABVE, Universitat Autònoma of Barcelona*
[3] *UCD, University College Dublin, School of Mathematical Sciences*
[4] *ETSEA-Universitat de Lleida*
Corresponding author: rosa.llurba@ctfc.es

Abstract

Monocultures and three species mixtures containing a grass (*Festuca arundinacea*), a legume (*Medicago sativa*) and a forb (*Cichorium intybus*) were sown in order to test the effects of diversity on forage swards. Yield, LAI (Leaf Area Index), leaching and stability indicators were determined as a function of sown species identity and diversity effects. Yield and LAI were higher in mixed swards than in monocultures. A diversity effect was found for both variables, with values in mixtures above that expected from the proportions of the sown species. There was a seasonal substitution of species dominance, thus maintaining overall total yield. As a result, mixtures showed higher stability than monocultures. On the other hand, we found a negative effect of total biomass on leaching, but this trend was not consistent across the 6 studied harvests.

Keywords: diversity effect, mixtures, *Cichorium intybus*, forage crops, LAI, leaching

Introduction

In the current context of global change and energy scenarios it is essential to test agricultural strategies which may sustain agroecosystem function and derived goods and services. Mixed forage crops have been shown to provide enhanced ecosystem function (Kirwan *et al.* 2007; Nyfeler *et al.* 2009); nevertheless, their use is still relatively scarce, in part because of a lack of sward stability (Nyfeler *et al.*, 2009). The inclusion of forbs in the mixtures, such as chicory (*Cichorium intybus*), may affect species composition shifts and thus stability (Hogh-Jensen *et al.,* 2006). Further, a multifunctional approach is required to assess the tradeoffs of different societal demands that mixed forage crops may provide, including environmental issues. We manipulated sown diversity of forage swards to assess compositional (identity) and diversity (through the evenness component) effects on: 1) yield; 2) Leaf Area Index (LAI); 3) sward stability; and 4) leaching.

Materials and methods

Monocultures and 3-species mixtures containing a grass (*Festuca arundinacea*), a legume (*Medicago sativa*) and a forb (*Cichorium intybus*) were sown following a *simplex* design (Kirwan *et al.*, 2007; 2009) in a semi-arid irrigated agricultural area in Catalonia. Mixtures included swards dominated by each of the components (80% sown proportion) and a centroid with an equal proportion of each of the sown species. This design was repeated at two densities, and replicated three times yielding a total of 42 plots measuring 12 x 12 m^2. Total yield was determined through the harvesting of 9.36 m^2; prior to that 0.5 x 0.5 m^2 samples were cut to 5 cm, separated into species, dried at 60 ºC and weighed. LAI was measured using a ceptometer (AccuPAR, Decagon Devices). The solution leaching for the different diversity treatments was assessed using lysimeters consisting of 1 m^3 containers placed in each plot, which allowed the natural drainage of the soil solution across an isolated block of soil located on top of three layers of gravel and sand, with decreasing particle size. Leachate was collected

periodically so that the sum of several leaching assessments corresponded to plant development between two consecutive harvests. The response variables were modelled (GLM, SAS) as a linear function of initial sown species proportions (P_i) and evenness (E), thus allowing the separation of identity and diversity (evenness) effects (Kirwan *et al.*2007; 2009). Evenness (E) was given by the expression $E = \frac{2S}{S-1}\sum_{i<j} P_i P_j$, where S is the community maximum plant species number and P_iP_j the species pairwise interactions. As no density effects were detected the models presented below are the average for the two density levels.

Results and discussion

In general, yield was higher in mixtures than in monocultures (Figure 1A) with total annual yield (average for 2008 and 2009) being significantly higher in mixtures ($P < 0.0001$). A diversity effect was found with values in mixtures above those expected from the proportions of the sown species (Figure 2A). This diversity effect increased with time, as found by Frankow *et al.* (2009), while the yield predicted from the monoculture performance decreased across the six studied harvests (Figure 1B); nevertheless, both identity and diversity effects decreased sharply in the last two harvests because of a water shortage. These results suggest a contribution of the species interactions to the stability of harvested biomass. Furthermore, we found a shift in the individual contribution of each species, or individual identity effects, across the six harvests, with a decrease in time of the chicory harvested biomass and an increase in the other two species, as reflected by the shift in the coefficients and the monoculture yields across the six harvests (Figure 1A). The same trends were found for LAI, with both yield and LAI showing predicted values above those expected from the monoculture performances (Figure 2A and 2B), due to the diversity effect.

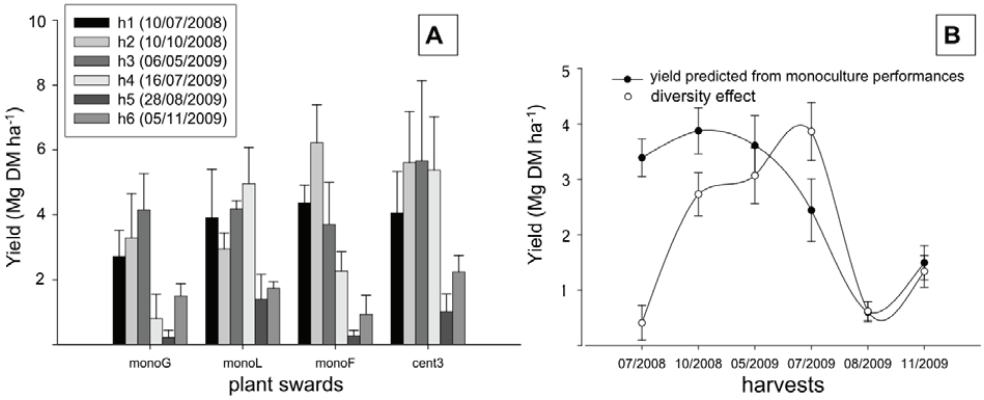

Figure 1. (A) Yield per harvest for each monoculture (monoG: *Festuca arundinacea*; monoL: *Medicago sativa*; monoF: *Cichorium intybus*) and the centroid mixture (cent3). (B) Yield per harvest predicted for the centroid from the monoculture performances and predicted diversity effect in equation $y = \sum_{i=1}^{3} \beta_i P_i + \delta E$. DM: dry matter.

The total harvested biomass in harvest 4 had a small but significant negative effect ($P < 0.0001$) on the amount of solution leached since the previous harvest. Nevertheless, this trend was not found for the rest of the leachate associated to the biomass collected between two consecutive harvests. A water shortage in 2009 and the variability in total drainage in the lysimeters may have hampered the correct assessment of leaching dynamics that were associated with diversity. Indeed, we found no diversity effects on total leached solution.

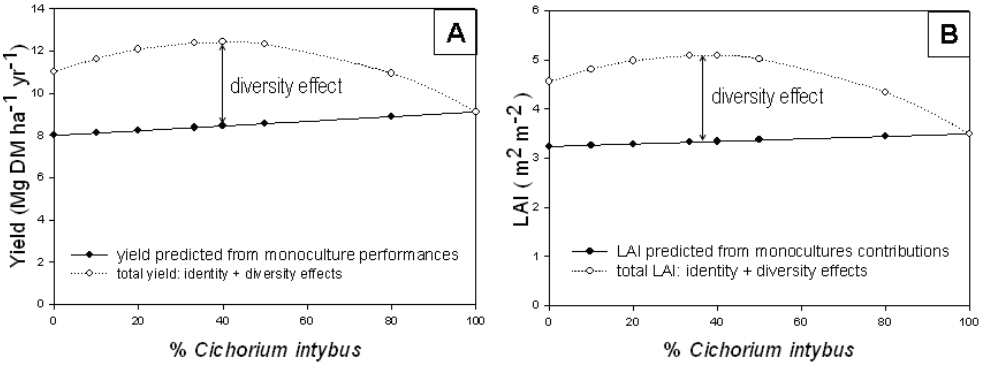

Figure 2. Annual yield (A) (mean from 2008 and 2009) and LAI (B) predicted for mixtures where the sown percentage of chicory is increased from 0 to 100% and the ratio among the other two sown species is held constant.

Conclusions

Forage mixed crops have the potential to increase forage production and supply stability, through the shift in the contribution of their components across time. This agronomical advantage could be paralleled by a decrease in leaching, with a clear environmental interest.

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