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## **Review article**

# **Functional diversity in low-input grassland farming systems: characterisation, effect and management**

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**Abstract.** High biodiversity in grasslands is widely perceived to have a major role in maintaining or enhancing the amenity and cultural value of landscapes in Europe. In this paper, we focus mainly at community level, evaluating factors that appear to influence biodiversity at farm and landscape levels. In order to establish generic principles we examine the maintenance of biodiversity in terms of maintaining or enhancing functional diversity (FD). We define plant functional types (PFTs), groups of species having the same function and/or the same effect in the grassland ecosystem, species identified on the basis of plant traits. These traits reflect ecological responses to nutrient input and/or defoliation frequency, and they can also have an effect on ecosystem properties. We reviewed the literature, examining the relationship between several leaf and plant traits and principal ecological factors and, in turn, how these traits could influence the feed value of the grassland vegetation for herbivores. FD was determining as the range of relevant PFTs at community, farm and landscape levels. We propose a practical method of assessing agronomic value of semi-natural grasslands based on the determination of dominant PFTs by measuring traits *in situ*, or through using a trait database coupled to species abundance records. We then assess the relevance of the method for semi-natural grasslands subjected to several management practices.

**Key words:** biodiversity, grassland, defoliation, fertilisation

## **INTRODUCTION**

At the livestock farm scale, specific and functional diversity of the vegetation depends greatly on how farmers manage grasslands and meadows, and how they are spatially arranged in the landscape. Adoption by livestock farmers of management practices that enhance biodiversity depends on subsidies they receive and on their objectives for animal performance, production costs and labour. Biodiversity has a range of functional roles within agroecosystems at a range of scales (Altieri, 2002). However, most studies have been done at just one scale, the plant community (plot level) or landscape level (Freckleton, 2004).

High grassland biodiversity is generally associated with low-input livestock systems that support less than 1 LU per ha (Duru & Hubert, 2003). Today biodiverse grasslands only survive where economic drivers towards intensification can not operate

or where there is adequate compensation against intensification via agri environment subsidies (Hodgson et al., 2005). Biodiversity rich areas are often characterized by marked differences in management between fields that reflect topographic and environmental differences. Although grassland biodiversity may provide a diversity of potential utilitarian functions (Swift et al., 2004) at an ecosystem or landscape level such as sequestration of carbon, purification and filtration of surface water, provision of amenity facilities for society, to the livestock farmer the essential function is to feed herbivores (Guérin & Bellon, 1990).

In this paper, we use plant functional traits, to characterize the functional diversity of grasslands at different spatial scales. We hypothesize that this approach could be a bridge linking management practices to the vegetation structure and to their productivity and quality. We exclude sown grasslands and we consider only ecological factors on which farmers could act upon through management of nutrient inputs and defoliation regime (mowing and/or grazing). These are the most important environmental factors that drive the structure and the composition of plant communities (Grime, 1988; Kleyer, 1999).

We define functional diversity (FD) of a grassland community using a combination of plant functional traits which reflect the influence of ecological factors on functional diversity and on the ecosystem properties. We examined a range of plant and/or leaf traits in order to identify ones that were specific to particular ecological factors. Two approaches were used, one based on plant functional types (PFTs) and a database of species having the same strategy for resource acquisition and use, and the second based on plant trait measurement *in situ*. We review the advantages and limitations of a functional-trait based approach to the categorisation of grasslands examining issues relating to the plant plasticity, and the comparison of plant growth forms. We also evaluate the relevance of both approaches to assess grassland functional diversity at farm and landscape scales.

## **From plant functional traits to functional diversity at plant community level: some methodological aspects**

### ***A functional classification of species based on plant traits***

It has been recognized that predicting the response of species and neighbour relationships to variations in resources and climatic change requires a functional classification of species (McIntyre, 1999). It could be based on traits directly linked to growth and development functions of plants, or strongly correlated to other variables describing these functions (Weiher et al., 1999). A short list of key plant functional traits has been identified (Diaz & Cabido, 1997), which has led to the development of the concept of plant functional type (PFT). PFTs are defined as non-phylogenetic groupings of species exhibiting common biological traits that enable them to fulfil specific functions in a similar way within an ecosystem (Gitay & Noble, 1997). PFTs are regarded as a concept enabling the identification of general principles for the functioning of organisms which can be used for making predictions, but also as a practical tool to reduce a wide diversity of species to a small number of entities. The basis of PFT rests on an analysis of the traits developed by plants growing in communities. One distinguishes traits of response, which are those whose values change in response to factors applied to the community, and traits of effect that act on

the processes of the ecosystem (productivity and nutrient cycling among others) (Lavorel & Garnier, 2002).

***Plant traits as indicators of environmental factors (response traits)***

Land management acts upon the composition and the dynamics of plant communities through changes in nutrient availability and defoliation regime. Nutrient availability depends on fertilizer supplied, amount and kind (quality) of litter and excreta through grazing. Defoliation regime could have an indirect effect modifying the light incoming at different heights of the canopy, and also direct effects making gaps, or removing vegetative or reproductive plant components (Bullock & Marriott, 2000).

Prediction of community or ecosystem response to changes in land management has driven a search for key traits that take account of: (i) the capacity to exploit resource-rich or -poor environments; (ii) the capacity for competitive dominance; (iii) the response to disturbance (Wilson et al., 1999). Modelling vegetation dynamics for predicting the rate at which the vegetation changes needs extensive studies on plant strategy for regeneration, avoidance, and tolerance, and most often the interaction with the climatic circumstances that are not considered here.

Certain leaf traits can be used to indicate the morphogenetic strategies of species to exploit resource-rich or -poor environments. For example, fast growing species have low tissue density and short organ lifespan (Ryser, 1996). Slow growing species have low area per leaf mass (SLA) and long leaf lifespan (LLS) indicative of slow turnover of plant parts, long nutrient residence times, and slow response to favourable growth conditions (Westoby et al., 2002). Wilson et al., (1999) showed that leaf dry matter content (LDMC) was much less variable than the other leaf traits, being largely independent of leaf thickness and a better predictor of location on the resource capture/use-availability axis (Garnier et al., 2001). High correlation was found between LDMC and the density of tissues, which is the key variable to distinguish the strategies of morphogenetic development of species.

Managing or knowing the response of plants within a community to nutrient availability needs to take into account the capacity of individual species to exploit the resources, but also their capacity for competitive dominance. Ryser and Urbas (2000) showed that a nutrient-conserving strategy with long LLS is of advantage in nutrient rich environments when no external disturbance removes the conserved nutrient.

Analysing the response of plant species within a community to a defoliation regime needs to take account of their individual capacities for competitive dominance. Specific shoot height (SSH) is considered to be the most relevant trait indicating capacity for competitive dominance (Hodgson et al., 1999), because it expresses an ability to capture light (Vesk et al., 2004). However, in cut or grazed grasslands this trait alone can not predict a species' capacity for competitive dominance. Others plant traits are related to meristem position (Bonser et al., 1996), resprouting and branching abilities (Lavorel et al., 1999). The timing of managements such as mowing, if imposed at the same time each year, will eventually lead to selection of phenological traits such as start of flowering and timing of seed set that are adapted to the particular management regime. After abandonment of any fixed agricultural management regime,

seed production is no longer time-limited, which appears to explain the increase in late flowering species (Kahmen & Poschlod, 2004).

### ***Plant traits determining effects of plants on vegetation characteristics influencing feed value for domestic herbivores***

Porter and Remkes (1990) showed that species with low relative growth rate (RGR), longer LLS, lower SLA and higher leaf tissue density (Reich et al., 1992), also contained proportionally more cell wall material (lignin, hemicelluloses, cellulose) than species with higher RGR. The latter contained proportionally more cytoplasmic elements such as protein and sterols (i.e. compounds in solution) (Ryser, 1996). Species with high RGR have high leaf water content, low leaf specific mass, low proportion of cell wall per unit of leaf area, high proportion of mesophyll protoplast per unit volume and high organic nitrogen concentration. Different proportions of leaf mesophyll (highly digestible tissue) among herbaceous species result in a large range of nutritive values (Van Arendonk & Poorter, 1994). Differences in tissue anatomy and chemical composition have a major influence on the digestibility of plant components (Wilson, 1993). Leaves having long LLS tend to have a high fibre/crude protein ratio, high lignin concentration and low nitrogen and phosphorous concentration (Nelson, Moser, 1994). Long LLS is very important for storing nutrients (Escudero et al., 1992). Low specific leaf area is also often associated with increasing concentrations of secondary compounds and starch (Aerts & Chapin, 2000).

During the reproductive period, herbage growth pattern depends greatly on the rate and duration of stem growth, whereas during vegetative regrowth, it depends mostly on the leaf lifespan (Duru et al. 2002). Over the vegetative period, the herbage bulk density is also highly correlated with leaf plant traits (Duru et al., 2004), species having higher LDMC also have higher bulk density.

### ***From plant traits to functional diversity***

The nutrient factor shows considerable overlap between response and effect traits. Leaf traits that are indicators for resources capture and utilization are also predictors for herbage growth rate, herbage nutritive value and leaf toughness. Timing of initiation and of flowering that determines the beginning and the end of stem elongation act upon the herbage growth pattern over the reproductive period. Specific shoot height which depends on defoliation management acts upon sward structure. On the other hand, demographic and regeneration traits, associated with response to disturbance, are known to have little connection with adult traits involved in plant ecophysiology (Lavorel & Garnier, 2002). They would be of little relevance to assess vegetation characteristics.

Functional diversity characterizes the extent of complementarity among species' trait value by estimating the dispersion of species in trait space (Mason et al., 2003). When the number of species is small, they generally present a high level of similarity in their plant features and could be related to the same functional group.

### ***Some key questions for functional diversity assessment***

Comparison of leaf traits in a set of species growing in pure stand showed that LDMC values separated the species into three life form classes (grasses, rosette forbs and upright forbs,  $P \leq 0.001$ ) while this is not the case for SLA and LLS. Rosettes and

upright forbs are respectively defined as dicotyledonous having, at the vegetative stage, entire wide leaves without stems and not entire leaves with stems or/and large petioles (Cruz et al., 2002). This result was confirmed when comparing SLA and LDMC for grass and rosette life forms growing in the same community (Viegas et al., 2005): the average values for LDMC were, respectively, 160 and 270 g kg<sup>-1</sup> for rosette forbs and grasses, whereas the SLA was the same (26 m<sup>2</sup> kg<sup>-1</sup>) for both plant life form. Consequently, LDMC should not be measured without considering separately plant life forms, unless the study is only on grasses. The choice of grasses is also justified by their high abundance in natural grasslands and their similar morphology (one botanical family) which avoid changes or adaptations in the procedure of trait measurements. Furthermore, when measuring only grass populations, the loss of information is low with respect to the whole community (Ansquer et al., 2005).

Evidence that species ranking for plant traits is strongly influenced by environmental conditions was shown in pot studies on *Dactylis glomerata* and *Brachypodium pinnatum* grown in different environmental conditions: 3 nitrogen x 3 phosphorus nutrient levels (Ryser & Lambers 1995). LDMC varied from 160 to 220 g kg<sup>-1</sup> for *D. glomerata*, and from 260 to 320 for *B. pinnatum*. For SLA, it was 28 to 42, and from 23 to 28, respectively. Therefore, under these controlled experimental conditions although plant traits appear to be environment dependent, the species ranking was not affected (Cruz et al., 2005; Poozesh et al., 2005). Species ranking was also compared at the plant population and plant community levels (Table 1). It is apparent that for these species the plant traits showed great variability reflecting therefore considerable phenotypic plasticity. Nevertheless the species ranking remained consistent.

**Table 1.** Comparison of average values of LDMC (g kg<sup>-1</sup>) for some grasses growing in pure stand (Toulouse : 150m asl, with or no N application) or in plant communities having great differences in P and N herbage nutrient status (Ariège, Central Pyrenees (1°17'E, 42°51'N, 600-900m asl), data 2001, P. Cruz, unpublished data).

| Species                    | LDMC of species in pure species stands: mean and (SD) for 3 growing seasons |          | LDMC of species in grassland communities (1 to 4 spring seasons): mean and (SD); n=number of plots |                             |
|----------------------------|---|----------|--|-----------------------------|
|                            | N+  | N-       | different N and P plant status   | min and max measured values |
| <i>Holcus lanatus</i>      | 208 (24)  | 219 (20) | 235 (26) n = 28  | 173–280                     |
| <i>Lolium perenne</i>      | 220 (42)  | 246 (31) | 246 (25) n = 18  | 193–269                     |
| <i>Dactylis glomerata</i>  | 237 (35)  | 250 (24) | 270 (22) n = 29  | 249–329                     |
| <i>Agrostis capillaris</i> | 256 (30)  | 270 (28) | 283 (26) n = 11  | 263–355                     |
| <i>Festuca rubra</i>       | 273 (48)  | 302 (42) | 304 (38) n = 9   | 272–335                     |

### ***Use of plant trait measurement for plant functional diversity assessment and management***

A plant functional approach to grassland community classification could be developed from a database of plant functional types, or directly in the field through measurement of plant traits.

A database, containing a list of relevant response and effect plant traits for a large range of grassland species, needs to be developed to show groups of species that have close similarity in plant trait values. The database would then be used to position different grasslands on an ecological gradient and classify them in terms of their agronomic characteristics. It would, however, be necessary to assess variation in FD within and between plant communities by comparing the abundance of different functional types (Petchey & Gaston, 2002). The agronomic characteristics of the pasture can then be deduced from those of the dominant functional type. This is the case of communities growing in nutrient-rich environments where competition for light lead to elimination of slow growing species. By contrast, under lower competition levels, several functional types can coexist (Lavorel & McIntyre, 1999). An example of database is given in Appendix 1.

Plant traits that are easy to measure in the field could be used to assess the position of a plant community on an ecological gradient, and to measure FD. An index proposed by Mason et al. (2003) allows for the inclusion of small functional differences between species, which might be ignored by the database approach. It should be possible to quantify functional diversity and functional richness with this approach. FD index reflects the range of character values present in a given area, so it does not have the same significance for all plant traits. To assess the potential (maximum) FD index in a given area, we used the minimum and the maximum recorded values.

Advantages and limitations to characterizing grassland communities using either the plant functional type method, in which a database on individual species is required, or the plant functional trait approach are summarized in Table 2.

**Table 2.** Comparison of two methods that could be used to characterized the functional diversity within and between grassland plant communities.

|             | Plant functional type  | Plant functional trait  |
|-------------|--|---|
| Advantages  | Opportunity to study correlations between a set of plant traits (leaf, phenological; some of them being hard to measure)<br>Species typology based on several plant traits<br>Linking with ecological factor and vegetation properties inside the database | Takes account of trait plasticity<br>Low botanical knowledge needed   |
| Limitations | Trait plasticity<br>Some botanical knowledge needed<br>Number of species in the database   | Only a limited number of plant traits easily measurable at field level<br>Requires knowledge on the relevance of plant traits for a given ecological factor and for the vegetation properties |

## Assessment and management of grassland functional diversity: some examples from natural grasslands used for cutting and grazing

### *Within plant community*

To assess FD within plant community, we used a long-term trial (17 years), conducted on a natural grassland in Rio Grande do Sul (Brazil), where the grazing pressure by cattle was maintained at four levels of intensity (Table 3). The vegetation structure of the most intensively grazed treatment (4% dry matter allowance) was homogeneous. The productivity of the grassland in this treatment was very low, in some extent due to low light interception. Grassland production and animal performance were higher in the 12 and 16% intensity treatments. These lenient grazing treatments allowed the cattle to select preferred forage species, which created structural heterogeneity with tall grass patches dominated by ungrazed or only lightly grazed species and tightly grazed short sward areas containing preferred species. Increasing grazing pressure reduced the FD. FD was higher when analysed using SLA values compared with LDMC values in all the treatments. There was, however, a tendency for LDMC to increase and SLA to decrease at lower grazing pressures.

The animal performances per animal or per ha were the lowest for the highest stocking rate treatment that coincide to the lower FD. In contrast, the lenient grazing treatments that allowed a better spread of forage over the year coincide with a higher FD.

Defoliation regime introduces changes of species either directly (via mortality following removal of apices) or indirectly (via change in competitive relations between species), which will result in differences in the dynamics of accumulation of herbage mass during regrowth. In the case of pastures that are exclusively grazed, these dynamics can result in substantial heterogeneity of the vegetation. Low grazing pressure conditions will favour several types of vegetation structures, each with species belonging to a different functional group.

Considering the minimum and the maximum LDMC and SLA observed at field level in the studied area, we computed the FD for a community having 50% of species of each leaf traits; it give respectively 0.50 and 0.75. It means that results shown in Table 3 express only a small fraction of the maximum diversity, respectively 20 and 28%.

**Table 3.** Average SLA ( $\text{m}^2 \text{kg}^{-1}$ ) and LDMC ( $\text{g kg}^{-1}$ ) values for 4 plant communities (data for grasses only which constituted more than 45% of the total herbage mass) that had developed under different grazing intensities, Cruz and Theau (unpublished data).

| Grazing intensity * | Number of species | SLA  |      | LDMC |      | Live weight gain**              |                     |
|---------------------|-------------------|------|------|------|------|---------------------------------|---------------------|
|                     |                   | Mean | FD   | mean | FD   | kg per animal day <sup>-1</sup> | kg ha <sup>-1</sup> |
| 4%                  | 10                | 16.3 | 0.12 | 307  | 0.03 | 0.2                             | 80                  |
| 8%                  | 13                | 15.7 | 0.21 | 313  | 0.06 | 0.4                             | 125                 |
| 12%                 | 10                | 13.2 | 0.21 | 350  | 0.10 | 0.5                             | 145                 |
| 16%                 | 11                | 13.3 | 0.18 | 337  | 0.09 | 0.5                             | 110                 |

\* in kg of DM per 100 kg of live weight per day (grazing pressure adjusted monthly during seventeen years)

\*\* from Nabinger et al., 1999



### Between plant communities

For these illustrations, we focused on natural grasslands that were cut for hay and grazed most often heavily in spring or in autumn, in such a way that there was only little effect of dietary choices of animals. Consequently, diversity is expected to be greater between plant communities than within.

To illustrate the relationship between management, measured functional diversity and agronomic characteristics, we used grassland communities located high in the central Pyrenees. There were large differences in herbage N and P status and defoliation regimes (Table 4).

**Table 4.** Leaf plant traits (average value and FD) for some upland grassland communities differing in their defoliation regime and nutrient status (grasses only). Proportion of the different functional types: A, B, C (see appendix 1).

| Defoliation regime<br>C: cut;<br>G grazing<br>(l: lax; s: severe)<br>(defoliation score) | Sward nutrient<br>status |            | SLA (m <sup>2</sup> kg <sup>-1</sup> ) |      | LDMC (g kg <sup>-1</sup> ) |      | functional<br>types<br>(A, B, C) |    |    |
|--|--------------------------|------------|--|------|----------------------------|------|----------------------------------|----|----|
|  | N<br>index               | P<br>index | average                                | FD   | average                    | FD   |                                  |    |    |
| C – C – G (1)  | 82                       | 63         | 24.4                                   | 0.10 | 245                        | 0.03 | 41                               | 42 | 7  |
|  | 61                       | 100        | 24.9                                   | 0.10 | 261                        | 0.03 | 39                               | 45 | 6  |
| Gs – C – G (2)   | 81                       | 86         | 24.7                                   | 0.09 | 250                        | 0.03 | 56                               | 43 | 3  |
|  | 66                       | 70         | 21.6                                   | 0.04 | 264                        | 0.01 | 35                               | 65 | 5  |
| Gl – C – G (3)   | 70                       | 76         | 24.2                                   | 0.18 | 260                        | 0.03 | 28                               | 41 | 31 |
|  | 68                       | 49         | 14.6                                   | 0.15 | 287                        | 0.03 | 4                                | 3  | 93 |
| G – G – G (4)  | 76                       | 69         | 23.7                                   | 0.14 | 267                        | 0.02 | 25                               | 13 | 62 |
|  | 66                       | 44         | 18.9                                   | 0.16 | 270                        | 0.03 | 15                               | 20 | 75 |

Measured and computed (see appendix 1) plant traits were highly correlated, respectively 0.67 ( $P < 0.01$ ) with SSH (Specific Shoot Height), 0.65 ( $P < 0.01$ ) for LDMC, and 0.82 ( $P < 0.001$ ) for SLA. There was also significant correlation between plant traits: SSH vs LDMC: 0.76\*\*\*, SSH vs SLA: 0.61\*, SLA vs LDMC: 0.75\*\*\*, indicating that a single one could not be a specific response trait.

FD is low for LDMC and higher for SLA, and there is a trend to have higher FD for SLA when there was no cut or a lax spring grazing. Considering the minimum and the maximum LDMC and SLA observed at field level in the studied area (respectively 175 and 350 g kg<sup>-1</sup>, and 12 and 36 m<sup>2</sup> kg<sup>-1</sup>), we computed the FD for a community having 50% of species of each leaf trait value; it gave respectively 0.34 and 0.63. It means that results shown in Table 5 express only a small fraction of the maximum diversity, respectively 8 and 29%.

We found that the plant trait LDMC was highly correlated with spring forwardness (date at which herbage mass reach 200g m<sup>-2</sup>), the daily herbage growth rate over the linear phase, and the date at which herbage ceiling yield for reproductive spring growth was reached (correlation coefficients were, respectively: 0.93 ( $P < 0.001$ ), -0.82 ( $P < 0.01$ ) and -0.82 ( $P < 0.01$ ). SLA and flowering date were the plant traits best correlated with the maximum standing herbage (0.84,  $P < 0.01$ ) and the date at which it occurred ( $r = 0.65$ ,  $P < 0.10$ ).

The relevance of plant functional approach to assess an ecological factor was assessed first using plant trait measurements. Given data from Table 4, we show that LDMC and SLA were both well correlated to the herbage nutrient index ( $r^2 = 0.75$ ;  $P < 0.001$ ), and that SSH was the trait which was best correlated with the defoliation regime ( $r^2 = 0.71$ ;  $P < 0.001$ ). When using computed plant traits instead of measured ones, coefficients of correlation were significant but at lower levels. There was not a plant trait specific to nutrient availability and defoliation regime. Finally, LDMC assessed both factors according to the following equation  $LDMC = 332 - 1.3 NPi + 3.79 \text{ defoliation}$ ,  $r^2 = 0.81$  (NPi: sward nutrient index; defoliation: defoliation score).

However, in a sample of 80 meadows and grasslands, we observed that plant functional types based on the LDMC database responded to defoliation regime and nutrient availability (Table 5), which meant that LDMC was not specific to an ecological factor. Furthermore, the proportion of plant functional types established on the LDMC basis depended on both nutrient availability and defoliation regime. There was a trend for a more even distribution of plant functional types in plant communities that had a lower nutrient herbage status, and those that were only grazed. The number of species was greatest when the proportion of the different functional types was more evenly distributed; i.e. when the competition for light was lowest (low nutrient, and/or early defoliation in spring).

**Table 5.** Functional diversity assessed at grassland community level through the proportion of different functional groups of grasses (A, B, C: see appendix), and species diversity of 80 grasslands differing in defoliation regime and nutrient herbage status (from Ansquer et al., 2004).

| Criteria             | Defoliation regime: | Herbage nutrient status |          |         |
|----------------------|---------------------|-------------------------|----------|---------|
|                      | C = cut; G = grazed | low                     | medium   | high    |
| Functional diversity | C C G               |                         | 52-40- 8 |         |
|                      | G C G               | 28-31-41                | 48-34-18 | 65-28-7 |
|                      | G G G               |                         | 25-28-47 |         |
| Number of species    | C C G               |                         | 21       |         |
|                      | G C G               | 32                      | 28       | 21      |
|                      | G G G               |                         | 30       |         |

### *At farm and landscape levels*

Surveys conducted on four commercial farms showed that each of them had grasslands dominated by one of the three PFT. This diversity between grasslands allows farmers to fulfil a set of functions (Guérin, Bellon, 1990). However, the proportion of each vegetation type varied greatly according to farm (Table 6). For example, type C occupied from 6 to 28% of the grassland area.

Farms 1 and 3 with the higher stocking rates had the highest proportion of grasslands in which the type A functional group was dominant. (Table 6). However, the proportion of *Chaerophyllum aureum*, an undesirable invasive species growing in nutrient-rich habitat and particularly when there is no spring grazing (Magda et al., 2003), was also more abundant on vegetation type A. This species was most abundant in grasslands in the valley bottom, due probably to more favourable soil conditions compared with the slopes.

**Table 6.** Functional diversity assessed at farm and landscape levels in terms of the proportion of different functional groups of grasses (A, B, C); the computed averages over three years are shown. Values with different superscript letters are significantly different ( $P < 0.05$ ).

| Level            | Percentage of grasslands where the functional groups A, B, C are dominant |    |    | Production system characteristics      |                                   |
|------------------|---|----|----|--|-----------------------------------|
|                  | A   | B  | C  | stocking rate (cow ha <sup>-1</sup> )* | proportion of undesirable species |
| <b>Farms</b>     |   |    |    |  |                                   |
| 1                | 60 <sup>a</sup>   | 34 | 6  | 1.20 <sup>a</sup>                      | 0.75 <sup>a</sup>                 |
| 2                | 37 <sup>b</sup>   | 39 | 23 | 1.05 <sup>b</sup>                      | 0.35 <sup>b</sup>                 |
| 3                | 47 <sup>a</sup>   | 33 | 19 | 1.22 <sup>a</sup>                      | 0.40 <sup>b</sup>                 |
| 4                | 43 <sup>a</sup>   | 28 | 28 | 0.95 <sup>b</sup>                      | 0.27 <sup>b</sup>                 |
| <b>Landscape</b> |   |    |    |  |                                   |
| Valley bottom    | 57 <sup>a</sup>   | 39 | 4  |  | 0.70 <sup>a</sup>                 |
| Slope            | 30 <sup>b</sup>   | 27 | 40 |  | 0.14 <sup>b</sup>                 |

At landscape level there was clustering of the landscape units, for example the valley bottoms being mainly occupied by type A, which corresponds to grasslands having the higher nutrient level, and/or being not heavily grazed in spring.

In areas where most of the grasslands were cut for hay at least once per year the plant functional diversity was higher at farm and landscape levels than at community level. Differences in the timing of hay harvest between fields due to topographic and edaphic reasons, for example, probably had a major influence on grassland FD at the farm/landscape level. Greater functional diversity in grasslands at the farm/landscape levels probably also reflected the needs of individual farmers, such as the ability to maximise the duration of the grazing season and thus vary the management regime at the field level between years depending on between year variations in weather.

## CONCLUSIONS

Management practices implemented to fulfil different functions in livestock feeding systems generate functional diversity in plant communities between fields within a given farm. Furthermore, topographic field characteristics determine the spatial distribution of the management practices within the farmland. Unfavourable field characteristics, such as steep slope, poor drainage or distance from the farm, determine the management practices of paddocks and consequently the vegetation types. As spatial and temporal scales increase (from field to farmland; from a season to a year or years) particularly where there is considerable variability in soil type, slope, elevation, aspect and climatic conditions, these factors drive an increase in vegetation diversity (White et al., 2004). In other words, grassland community diversity has a functional role in farmland management, and this role of diversity can only be assessed over the entire managed area at farm level. White et al. (2004) argue that a functionally diverse plant community over the entire managed area should be promoted in terms of potential for livestock farming sustainability, as well as for the biodiversity benefits of localized species diversity within grasslands. The farmland area could be a field used in continuous grazing (with high functional diversity) or a set of fields used in rotation grazing or for grazing and hay, leading to high diversity at farm level, but each of them

having low functional diversity. The maintenance of a range of grazing intensities at the landscape level can allow the conservation of a wide diversity of herbaceous plants (McIntyre et al., 2003).

Plant traits derived from measurements or databases are useful to assess grassland community characteristics, but they are not specific to a single management practice. There is a challenge to use them for growth modelling (Viegas et al., 2005). On the other hand, further researches should be done on linking planned and associated diversity (Altieri, 1999). Indeed, in less favoured areas, one role of grazing animal is maintenance or enhancement of sward structural heterogeneity, and thus botanical and faunal diversity, by selective defoliation due to dietary choices, treading, nutrient cycling and propagule dispersal (Rook & Tallowin, 2003).

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**Appendix 1:** Database used for designation of plant functional types (PFT).

Seed of 17 grass species collected from meadows in the Pyrenees were sown in pure stands at Toulouse and grown with two N application rates. Measurements were taken once for time of flowering and SSH) or three (LDMC, SLA) growing seasons.

We show that LDMC was a reliable plant trait measure because it was well correlated to flowering time, plant digestibility, and herbage growth rate. Four significant groups were determined (from Ansquer et al., 2004).

| Species                      | Date of flowering<br>(Julian days) | SSH<br>(cm g <sup>-0,33</sup> ) | LDMC<br>(g kg <sup>-1</sup> ) | LDMC classes* | SLA<br>(m <sup>2</sup> kg <sup>-1</sup> ) |
|------------------------------|------------------------------------|---------------------------------|-------------------------------|---------------|---|
| <i>Lolium perenne</i>        | 141                                | 44                              | 196                           | A             | 28.2                                      |
| <i>Holcus lanatus</i>        | 131                                | 41                              | 198                           | A             | 32.6                                      |
| <i>Arrhenatherum elatius</i> | 138                                | 43                              | 218                           | B             | 32.5                                      |
| <i>Festuca arundinacea</i>   | 150                                | 51                              | 222                           | B             | 18.7                                      |
| <i>Anthoxanthum odoratum</i> | 96                                 | 20                              | 222                           | B             | 28  |
| <i>Dactylis glomerata</i>    | 134                                | 41                              | 225                           | B             | 25.2                                      |
| <i>Poa trivialis</i>         | 143                                |                                 | 238                           | B             | 34.2                                      |
| <i>Trisetum flavescens</i>   | 158                                | 37                              | 240                           | C             | 26.5                                      |
| <i>Agrostis capillaris</i>   | 176                                | 31                              | 242                           | C             | 31.4                                      |
| <i>Phleum pratense</i>       | 175                                | 26                              | 247                           | C             | 30.8                                      |
| <i>Festuca rubra</i>         | 134                                | 29                              | 249                           | C             | 21.8                                      |
| <i>Avena pubesens</i>        | 162                                | 41                              | 250                           | C             | 20.5                                      |
| <i>Festuca ovina</i>         | 150                                | 34                              | 257                           | D             | 16.9                                      |
| <i>Cynosurus cristatus</i>   | 121                                |                                 | 262                           | D             | 19  |
| <i>Deschampsia cespitosa</i> | 176                                | 32                              | 266                           | D             | 14.2                                      |
| <i>Briza media</i>           | 146                                | 37                              | 274                           | D             | 18.9                                      |
| <i>Molinia caerulea</i>      | 172                                |                                 | 302                           | D             | 19.9                                      |
| <i>Brachypodium pinnatum</i> | 162                                | 41                              | 313                           | D             | 22.3                                      |