Biodiversity and silvopastoral system use change in very acid soils

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ARTICLE INFO

Article history:
Received 6 August 2008
Received in revised form 11 February 2009
Accepted 17 February 2009
Available online 19 March 2009

Keywords:
Fertilisation
Liming
Silvopastoralism
Spatial and temporal scale
Biodiversity
Species richness

ABSTRACT

Most biodiversity studies endeavour to put forward strategies for its short-term enhancement, seeking to understand the spatial scale. However, biodiversity preservation strategies should also take into account temporal scales, in order to fulfil the main biodiversity preservation objectives. Biodiversity variability also depends on the structural heterogeneity of the land on which this strategy is developed. Agroforestry systems have a tree component that makes this heterogeneity more important than in exclusively agronomic systems. This paper aims to evaluate the effect of different soil fertility management (application of lime and fertiliser in both organic and inorganic nitrogen forms) on tree and pasture growth, as well as on the pasture richness in a silvopastoral systems developed on a 5-year-old Pinus radiata D. Don plantation over 6 years. Temporal scale, as well as spatial biodiversity scale, should be taken into account in biodiversity studies in forests. Tree development as well as fertility soil modifications modified species richness, the relative dominance between species and the type of species. The lack of management caused an undesirable development of shrubs, main resource of forest fires development in the region. Lower tree densities than those currently used combined with authochthonous breed grazing, to reduce shrub biomass is the best option to sustain biodiversity and productivity from the area.

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1. Introduction

Silvicultural practices management can modify understory biodiversity in forest. However, there are very few studies evaluating how management can modify understory vegetation diversity (Barbier et al., 2008) at a short- or long-term. An analyses of the principal causes of biodiversity changes in the major biomass on Earth suggests that land-use change will continue to have the largest global impact on biodiversity in the current century, followed by climate change, nitrogen deposition, species introductions and changing concentrations of atmospheric CO2 (Sala et al., 2000; Chapin, 2003). The promotion of afforestation has been an important issue of the European Union in the last few years, when around one million hectares has been afforested between 1994 and 1999 as a result of the implementation of the regulation EEC 2080/92. The plantation of forest has very important advantages from an environment point of view when compared with agronomic land (carbon sequestration, biodiversity and water quality), but adequate management should be implemented in order to enhance the benefits from an environ-
Silvopastoral systems, which are a sustainable way of land management (UN, 1992), can produce social benefits from forest areas, as the economic return is obtained earlier and, therefore, will tend to enhance stabilisation of the rural population (Rigueiro-Rodríguez et al., 2008). They can also promote biodiversity, through the creation of micro-sites within the plantation (shaded and unshaded areas) due to the presence of trees not found in purely agronomic land, as well as through the reduction of habitat fragmentation (Rois et al., 2006). The last EU Council regulation on support for rural development formulated by the European Agricultural Fund for Rural Development (EAFRD) establishes that “measures targeting the sustainable use of forestry land through the first establishment of agroforestry systems on agricultural land” should be taken.

Once trees are established, after selecting the species and an adequate density for socio-economic purposes, the best way to enhance productivity (understory and tree) in a silvopastoral system is through liming (due to the high acidity of Galician soils) and the use of inorganic or organic fertilisers. The use of fertilisers, as well as liming, can modify productivity of the different components of the system (pasture and trees) as well as its botanical composition (Mosquera-Losada et al., 2006).

Biodiversity conservation should take into account genetic species and ecosystem levels, as described by the Convention on Biological Diversity and the Pan-European Biological and Landscape Diversity Strategy. The best way for conserving biodiversity is through the knowledge of the effect of different land management techniques on the number of species (alpha-biodiversity like species richness) and the relative abundance of the different ecological types of the species present. Different studies have been carried out in grasslands, mainly in alpine (Buttler et al., 2008), calcareous and wetland grasslands (Plantureux et al., 2005), in order to see how biodiversity is affected by liming or fertilisers. However, very few studies have considered this aspect in temperate agroforestry systems developed in situations of natural stress (very acid soils) and dealing with recurrent disturbances (summer drought) over a long-term.

The objective of this experiment is to evaluate, over a period of 6 years, the effect of liming and fertilisation on tree and pasture growth, as well as on the pasture richness in a silvopastoral system that have been sown in very acid soils under 5-year-old Pinus radiata D. Don over 6 years, together with their growth under Atlantic Climate conditions with summer drought disturbances.

2. Materials and methods

The study was located in Pol (Lugo, NW Spain) at an altitude of 450 m asl. Mean long-term annual rainfall and temperature were around 1083 mm and 11.5 °C, respectively. The experiment was established in a sandy clay loam soil with a depth of 50 cm and initial soil water pH strongly acidic (4.97). The experiment was carried out from 1998 to 2003 in a 5-year-old P. radiata D Don plantation (1667 trees ha⁻¹), where plots of 96 m² were established in autumn 1997. Initial tree height was 2 m and tree diameter 5 cm. The experimental plots consisted of 25 trees distributed in a rectangle (5 × 5 trees tree distance 2 m × 3 m). The experiment design was of randomized blocks with three replicates and consisted of nine treatments: a combination of liming (two doses) and different sewage sludge doses (four doses, including no-fertiliser). A traditional control treatment was also established with mineral fertilisation.

Shrubs were mechanically cleared in autumn 1997. Lime was then applied at a rate of 2.5 t ha⁻¹ of CaCO₃ in one half of the plots and immediately afterwards sowing with ryegrass (25 kg Lolium perenne L. ha⁻¹), cocksfoot (10 kg Dactylis glomerata L. ha⁻¹), and white clover (4 kg Trifolium repens L. ha⁻¹) was done in October 1997.

Four different treatments were established in both the limed and unlimed plots, consisting of the surface application of four different dosages of urban sewage sludge involving doses of total nitrogen of 0 (NF), 160 (LB), 320 (LM) and 480 (LA) kg of total N ha⁻¹. It must be taken into account that approximately 25% of the total nitrogen will be mineralised in the first year (EPA, 1994), due to stabilisation by anaerobic digestion. In the case of the unlimed plots, an additional treatment consisting of the application of 500 kg/ha of complex 8:24:16 (MN), which is equivalent to the fertilisers traditionally applied in local agriculture. A summary of when were applied the treatments applied can be seen in Table 1.

| Treatment | t ha⁻¹ CaCO₃ | Year 1998 | Year 1999 | Year 2000 | Total inorganic N applied (kg N ha⁻¹ year⁻¹) | Year 2001 | Year 2002 | Year 2003 |
|-----------|-------------|-----------|-----------|-----------|----------------------------------------|-----------|-----------|-----------|
| NF        | 0.0         | 0         | 0         | 0         | 0                                      | 0         | 0         | 0         |
| LB        | 0.0         | 160       | 160       | 160       | 160                                    | 20        | 20        | 20        |
| LM        | 0.0         | 320       | 320       | 320       | 320                                    | 20        | 20        | 20        |
| LA        | 0.0         | 480       | 480       | 480       | 480                                    | 20        | 20        | 20        |
| NF + lime | 2.5         | 0         | 0         | 0         | 0                                      | 0         | 0         | 0         |
| LB + lime | 2.5         | 160       | 160       | 160       | 160                                    | 20        | 20        | 20        |
| LM + lime | 2.5         | 320       | 320       | 320       | 320                                    | 20        | 20        | 20        |
| LA + lime | 2.5         | 480       | 480       | 480       | 480                                    | 20        | 20        | 20        |
| Mn        | 0.0         | 40        | 40        | 40        | 40                                    | 40        | 40        | 40        |

NF: no-fertiliser treatment; LB: Low dose of sewage sludge; LM: medium dose of sewage sludge; LA: high dose of sewage sludge; Mn: mineral treatment.
also made, in which neither the percentage of senescent material nor percentage of needles were taken into account. ANOVA were performed between the different variables studied and Duncan test was used to separate means.

3. Results

3.1. Tree

In them, it can be seen that the treatment without fertiliser and without liming presents a significantly lower level of tree height and tree cover (Figs. 1 and 2) than those treated with mineral fertiliser or without fertiliser, but with liming in the final year.

3.2. Production of pasture

Annual pasture production (Fig. 3) was positively affected by fertilisers in the first 2 years of the experiment, but no effects from liming were observed. During the third year, no response was observed to the different treatments applied. During the fourth year, the importance of the senescent material and needles increased relative to their contribution to aboveground biomass. There were no significant differences in aboveground biomass production in the final 3 years, in either the limed or unlimed plots. However, senescent material and pasture production was significantly higher in the no-fertiliser treatments in 2002, 2003 and 2004, respectively.

3.3. Species richness

From the list of species (Table 2), it can be seen that 41 species were found, belonging to 14 different families, of which 16 (39%) belonged to the family Poaceae, 5 to the Fabaceae, 4 to the Polygonaceae, 4 to the Ericaceae, 2 to the Caryophyllaceae, 2 to the Asteraceae, leaving just one representative each of the families Cistaceae, Geraniaceae, Juncaceae, Lamiaceae, Onagraceae, Plantaginaceae, Ranunculaceae and Rosaceae. Of these, 83% are perennial species and 80% herbaceous (20% woody). The total number of species was 19, 23, 20, 24, 17 and 17, for the years 1998, 1999, 2000, 2001, 2002 and 2003, respectively. Of the total, only eight species were present throughout the whole period evaluated (20% of the total identified), coinciding 15 of 27 between the first and second year studied (55%) and 18 of 25 between the second and third (72%), 14 of 30 between the third and fourth (47%), 14 of 27 between the fourth and fifth (52%) and 12 of 21 species between the fifth and sixth year (57%). These eight species are all perennials and herbaceae with the exception of *U. europaeus* L. and *Erica umbellata* Loeﬂ.ex L. that are woody. Of the 41 species found, 30% (11) only appear in 1 year, 6 appear at the beginning of the experiment but disappear over time, and another 5 appear later, but are then present until the end.

During the first year, no significant differences in the alpha biodiversity (Fig. 4) were observed as a result of the treatments evaluated. However, apart from this moment, in general and systematically, it was observed that the no-fertiliser treatment — whether limed or not — showed a significantly higher number of species than in the treatments with organic fertiliser or with low doses of sewage sludge after 2000. Liming also negatively affected the alpha-biodiversity in the last year of the no-fertiliser treatment. When the ground was not limed, the treatments LB and LM in the fourth year and LA from the fifth year were significantly different to NF without liming. If we observe the mineral treatment, we can see that in the second year of the study its biodiversity was reduced considerably with respect to...
the no-fertiliser, but this difference is only maintained if compared with the no-liming and no-fertiliser treatments. The alpha-biodiversity is positively and significantly affected by the mineral fertiliser in 2000 and 2001, but this effect decreases afterwards.

From the richness (Fig. 4) and the abundance diagrams (Figs. 5 and 6) seems to be clear that liming and organic fertiliser appears to negatively affect the alpha-biodiversity when compared to the treatment without liming and fertiliser. However, when inorganic fertiliser is used without liming, this negative effect does not appear to be seen as clearly until after 2002.

The effect of organic fertiliser during the experiment caused, on one hand, a decrease in the number of species and, on the other, an alteration of the relationship between them, reducing codominance between the most important ones.

Of the two grasses sown, the perennial ryegrass was favoured by liming, as both establishment and persistence were greater in this treatment. Similarly, cocksfoot showed a higher percentage in

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**Fig. 3.** Total annual pasture production split on pasture, senescent material (SM) and needles in each treatment. NF: no-fertiliser treatment; LB: low dose of sewage sludge; LM: medium dose of sewage sludge; LA: high dose of sewage sludge; MN: mineral treatment. Different letters indicate significant differences between treatments at the 0.05 level according to Duncan’s multiple range test.

**Fig. 4.** Yearly and seasonal evolution of the number of species in the plots developed under pinewoods in the applied treatments. NF: no-fertiliser treatment; LB: low dose of sewage sludge; LM: medium dose of sewage sludge; LA: high dose of sewage sludge; MN: mineral treatment. Different letters imply significantly different averages in each year. Different letters indicate significant differences between treatments at the 0.05 level according to Duncan’s multiple range test.
the organic fertiliser treatments and always exceeded 50% if the soil had been limed. However, despite its excellent establishment with mineral fertiliser and NF, with or without liming, it eventually disappeared in these two treatments.

The genus Agrostis, with four species, is the most represented throughout the study. *A. curtisi* Kerguelen, which is found in all the years studied, shows high proportions in all the treatments during the first year. It even becomes a dominant species in the plots in the second year of the mineral treatment, which is also the only case when limed. There are species that associate with certain treatments throughout the study. One of these is *E. umbellata* Loefl., which is present in the no-fertiliser treatments and always exceeded 50% if the soil had been limed. However, despite its excellent establishment with mineral fertiliser and NF, with or without liming, it eventually disappeared in these two treatments.

The species of the genus Holcus are importantly represented in most of the treatments throughout the study. *Holcus lanatus* L. is the one that is better established initially. As time passes, when liming is not used, *Holcus mollis* L. persists more with low doses of nitrogenised fertiliser and *H. lanatus* L. with high doses, but in this case when limed.

There are species that associate with certain treatments throughout the study. One of these is *E. umbellata* Loefl. Ex L. that always appears in the NF and unlimed treatments and increases its representation over a period of time. The presence of this species was also associated with the NF treatment, when it was limed in the first 2 years and with the mineral treatment in the first 3 years, disappearing later in both cases. Something similar happened with *U. europaeus* L., which is present in the no-fertiliser treatments (whether limed or not), although it also appears sporadically in the sludge treatments, always appears with mineral fertilisers and never appears with high doses of sludge and liming.

Within the less important species, we could mention the dicotyledonous *Taraxacum officinale* Weber. This has a very low presence and never appears in the plots that have been limed together with high doses of sludge. It disappears from all the treatments that have not been limed during the final year of the study. *Juncus effusus* L. appears in the first year in practically all the treatments, although it only persists where no fertiliser is used,
Fig. 5. Abundance diagrams for the 6 years of study in the liming treatment. NF: no-fertiliser treatment; LB: low dose of sewage sludge; LM: medium dose of sewage sludge; LA: high dose of sewage sludge.
Fig. 6. Abundance diagrams for the 6 years of study in the no liming treatment. NF: no-fertiliser treatment; LB: low dose of sewage sludge; LM: medium dose of sewage sludge; LA: high dose of sewage sludge; MN: mineral treatment.
especially if limed and also in the treatments that are not limed, but receive medium doses of sludge. Finally, and regarding *Pseudorrenatherum longifolium* (Thore) Rouy, it is a species that appears in numerous treatments, but only achieves a certain importance when neither fertiliser nor lime is used. *Festuca arundinacea* Schreb is a species that only appears in the first 2 years of various treatments in which it also gains a certain importance.

4. Discussion

Tree growth is significantly limited when soil nutritive conditions are very poor. The resulting variable “cover” was more sensitive over time to fertiliser and liming than the variable “height”, probably due to the higher influence of this factor on leaf development comparative to wood development. The effect of the treatments on the growth of the tree is fundamentally associated with the competition established between the pasture and the woodland. If there is an increase in available nutrients (mineral fertiliser and liming without fertilisers) and the pasture is not capable of using it (reduced pH and low availability of N), the woodland will use the excess through deeper rooting, thus avoiding system losses and improving efficiency (Mosquera-Losada et al., 2006).

In the first 2 years of the study, a significant effect of liming and fertiliser on the production of pasture was found. However, this positive effect disappeared after 2000 due to the higher tree cover (Sibbald, 1996) and, therefore, the possible response to the fertilisation treatments, as pasture growth was limited due to light input reduction caused by tree growth.

The number of species found during the study is high compared with the richness of each year. This reflects the importance of evaluating biodiversity over a period of time for policy purposes and not just spatially as, despite the inclusion of all the species found in the three harvests carried out each year, in none of the years do they exceed 60% of the total number of species found during the whole 7 years of the study. Moreover, close to 30% of the species only appear in one of the later years and so cannot be associated with the tilling of the land that normally involves a notable change in the vegetation. This factor also highlights the necessity for increasing the length of the experiments from the viewpoint of biodiversity, something that is infrequent, as most of the published ecological studies are for periods of less than 3 years. In extensive studies developed in 186 plantations of between 1 and 1.5 years in Galicia, 191 different species were found, grouped in 55 families (Zas and Alonso, 2002). This means that in the year of highest biodiversity in our study, only 11% of the biodiversity present in the extensive study was found and this proportion only increased to 22% when the total period of our study was considered.

Some of the species found in this study are also found in areas with a higher pH (Mosquera-Losada et al., 2006), such as those characterising the cultivated pastures of Galicia that are traditionally limed, *e.g.* *D. glomerata* L., *Sonchus asper* (L.) Hill, *T. officinale* Weber, *Plantago lanceolata* L., *A. capillaris* L., *F. arundinacea* Schreb, *H. lanatus* L., *L. perenne* L., *Lolium multiflorum* Lam and *Poa pratensis* L. The rest of the species characterise the areas of uncultivated acid soils in Galicia, above all, the shrub species, which are not present in soils with a recent history of liming or uncultivated acid soils in Galicia, above all, the shrub species, *Erica L.* The rest of the species characterise the areas of woodland. If there is an increase in available nutrients (mineral fertiliser and liming without fertilisers) and the pasture is not capable of using it (reduced pH and low availability of N), the woodland will use the excess through deeper rooting, thus avoiding system losses and improving efficiency (Mosquera-Losada et al., 2006).

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In addition a predominance of perennial species was found in the undergrowth, which is present from the initial establishment of the pasture to the end of the study. In the Atlantic Zone, the greater presence of annual species is generally associated with spring sowing (Mosquera-Losada et al., 2005). In autumn sowing, as in our case, the capacity of sowing grasses, such as ryegrass, to establish themselves is very high, whilst cocksfoot appears somewhat later due to a slower establishment (Mosquera-Losada et al., 2006). The poor establishment of ryegrass in our study could be explained by its low tolerance to high percentages of aluminium saturation close to 55% (Lam et al., 1991). This scarcity of ryegrass or, equally, the presence of patches in the pasture should favour the proliferation of annual species, generally dicotyledonae, which show rapid-growth characteristics (abundant seed—rapid germination) (Grime et al., 2007) and normally have a higher level of cations in the biomass than the monocotyledonae. However, this did not happen under the conditions of our study, probably due to the reduced availability of these cations in the soil (fundamentally Ca and Mg) that limited the adaptation of this functional ecological type to these conditions. In fact, it has been found that in studies developed under experimental conditions, the short-term ecological regeneration strategies are associated with germination capacity and that the number of seeds produced is important after establishment, although it is the invaders associated with perennial pasture grasses that are more durable long-term (Grime et al., 2007). In our case, the non-development of the typical annual herbage species probably derives from poor edaphic conditions, which, on the other hand, accelerate the colonising process of the perennial species. The reduced presence of annual species in conditions of low essential cation levels in the exchange complex has been found by Zas and Alonso (2002) for species such as *T. pratense* L., *T. officinale* Weber or *P. lanceolata* L., all of which are species associated with liming in our case. These results are very different to those found by Calvo et al. (2003) in mountain soils with a pH of around 5.5 after fire, in which the important presence of annual species in pine groves (100% in the first year – 70% in the third) stands out. In this case, the development of ecological regeneration strategies or the frequency of mixtures could be linked, in the first place, to a higher pH (5.5) than in our soil (which was below 4.5 in NF and no liming treatment and in mineral treatment, between 4.5 and 4.9 in sludge fertilized without liming and between 5 and 5.4 when liming and sewage sludge was applied) that notably reduced the presence of reactive aluminium (Al III ) in the exchange complex and, in the second place, to the effect of the fire itself that increased the calcium concentrations in the soil and so allowed the development of these annual species.

The decreasing presence of annual-type species over the years in this study, could also be explained by the superior persistence of perennial species under our conditions, because they have root systems that persist during the summer drought periods (Barbier et al., 2008). This answer, however, differs to that found in more southern European areas belonging to the Mediterranean Climatic Regions, in which the predominating species are annual-types. This is because very few perennial species are capable of supporting the long summer drought and so must use regenerative strategies based on the production of seeds to guarantee persistence. In fact, in Galicia, it can be said that the average period of drought is between 2 and 2.5 months (Mosquera-Losada et al., 2008).
and González-Rodríguez, 1999), which can extend to 5 months in Mediterranean zones. In the last few years, the length of the summer drought in our region has increased, probably due to the climate change. We think that if this drought becomes more intense, it may cause the predominant functional type to change from perennial to annual, which could contribute to a latitudinal climate change. We think that if this drought becomes more summer drought in our region has increased, probably due to the Mediterranean zones. In the last few years, the length of the treatments and only be emphasised that the three latter species appear in low-fertiliser a more restricted range, only appear in Spain and Portugal. It should be emphasised that the three latter species appear in low-fertiliser use, perhaps due to its ability for fixing nitrogen. P. tridentatum Boiss. and Reut. Ex Wilk., Avenula sulcata (Gay ex Boiss) Dumort, P. longifolium (Thore) Rouy in Portugal, Spain and France and finally E. umbellata Loefl. Ex L., Cytisus striatus (Hill) Rothm., Pterospartum tridentatum (L.) Wilk. in Wilk. and Lange, which have a more restricted range, only appear in Spain and Portugal. It should be emphasised that the three latter species appear in low-fertiliser use, perhaps due to its ability for fixing nitrogen. P. tridentatum (L.) Wilk. in Wilk and Lange is a woody species that, despite belonging to the Legume family, shows a very low content in protein and other nutrients (Rego et al., 1988). In our case, it is associated with the more acid treatments (NF and MN), with less fertility, which coincides with its adaptation to oligotrophic soils (Pacheco-Marqués, 1991). These species can be considered as stress-tolerant according to the classification of Grime et al. (2007) and probably have a good capacity for growth in soils with an aluminium saturation of more than 65%, from which other species would be excluded. If we take into account the alpha biodiversity in each year of the study, we can see that there is an increase in the total number of species in 1998, 1999, 2000 and 2001 and a decrease in the total number beginning in 2002. This is probably due to the increase of shade, signified by the increased number of needles on the ground, which were killed by the absence of light on the lower part of the tree, which makes advisable to reduce tree density to allow better biodiversity preservation. The lack of species in these conditions could be because P. radiata D. Don (an exotic species in Galicia) retains more light than the other more habitual species of Pine (Pinus pinaster Aiton) below which biodiversity is higher.

In general, it has been found that although liming does not modify the alpha biodiversity initially, it does have a long-term effect depending on the dosage of organic fertiliser, such that beginning in the third year of the study, when medium doses of sludge are applied, liming presents a negative effect on the biodiversity. This effect was also observed in 2001, with the high dosage of sludge. Liming, whether improving or not production, increases the relative proportion of a few species in terms of pasture biomass, which limits the development of other species and so reduces pasture biodiversity. Liming and the resulting increase in pH increases the availability of nutrients, reducing the percentage of aluminium saturation, which is used competitively by D. glomerata L. (Grime et al., 2007). The highest levels of pH within our scope should increase the biodiversity since, as we move closer to neutrality, the less restrictive edaphic conditions should lead to an increase in the number of species. However, curiously, the history of the area could be the explanation for the existence of an important bank of seeds that develop on poor soils, in which other types are scarce, thus limiting the biodiversity of the system, allowing the species that are competitive in poor soils to develop adequately in more oligotrophic conditions. This aspect increases the importance of considering seeding policies that use species adapted to a higher pH if liming is to be used, in order to increase biodiversity.

On the other hand, and as found by authors such as Thompson et al. (2001), it should be pointed out that the increase in fertilisation reduces the invasion of weeds and therefore biodiversity. In our case, this is true with the organic fertiliser, which has an important limiting effect derived from the high pH of the sludge (close to neutral). However, the opposite situation is found in the case of inorganic fertiliser that causes an important decrease in the pH (actually in the final year of the study) (Rodríguez-Barreira, 2008) and does not harm the alpha biodiversity when compared to NF without liming, until the last 2 years. This delayed effect is probably due to the limitation of light, deriving from the development of woodland, which could be associated with the presence of the aforementioned bank of seeds adapted to acid soils. Different publications exist that mention the fact that nitrogen fertiliser favours (Tracy and Sanderson, 2000; Gross et al., 2005) or disfavours (Willems et al., 1993; Hyvonen and Salonen, 2002; Dise and Stevens, 2005) biodiversity. However, this effect depends in the first place on the initial situation (such as the existing pH and seed bank) and, in the second place, on the effect that this fertiliser will have on other important soil parameters that determine biodiversity, as in the case of acid soils and tolerance to aluminium and, finally, the capacity of adaptation of the species to perturbations (drought) in a determined edaphoclimatic context.

It is very important that the biodiversity conservation should not only be based on the total number of species, but should also take into account the specific species present in the pasture, above all, those that are considered to be rare or more sensible to large scale changes (Suding et al., 2005). In this sense it is important to highlight species from our area that appear in NF and do not appear in other treatments.

In addition to the effect of liming and fertiliser on the total number of species, these treatments also cause modifications in the soil that generate different levels of fertility and alter the distribution with regard to their relative proportion. The most representative species during the first year are D. glomerata L., F. arundinacea Schreb and A. curtisi Kerguemen. The first is more abundant when treated with fertiliser (limed or not), as it associates with high levels of Ca, Mg and P (Zas and Alonso, 2002), and the latter when fertiliser is not used. F. arundinacea has a higher tolerance to aluminium than ryegrass (Edmeades et al., 1991). In the second year A. capillaris L. is the dominant species, replacing A. curtisi Kerguemen when neither fertiliser nor liming is employed, which is fundamentally accompanied by the grasses H. mollis L. and D. glomerata L. when limed, but by E. ciliaris L. and A. curtisi Kerguemen when not limed. This fact appears to indicate the higher requirements in exchange cations of H. mollis L. and D. glomerata L. than of E. cinerea L. and A. curtisi Kerguemen. Liming together with the original fertilisation with sludge, whether continued or not after 2001, makes Cocksfoot the dominant species that is always accompanied by A. capillaris L. and H. mollis L., as also happened in the case of liming without fertiliser. Therefore, the phenomenon of a change in the relative distribution between A. capillaris L. and D. glomerata L. when limed and as a function of fertiliser use, can be observed. A similar pattern is detected in the last years of the study with low sludge doses that reflect a response similar to the NF treatment as, due to the low doses of sludge, the residual effect is limited over time compared to the other two higher doses. A. curtisi Kerguemen appears as a species that accompanies D. glomerata L. and A. capillaris L. in 2003, when LB was not limed or fertilised after 2001. When, from the beginning of the experiment annual treatments with mineral fertiliser were carried out, D. glomerata L. and A. capillaris L. ceased to be dominant species due to the important percentage of aluminium saturation in the exchange complex (pH of around 4.5) and so shrub species, such as U. europaeus L. and E. cinerea L. and herbaceous such as H. mollis L. and A. curtisi Kerguemen became important. The
competitive success of the species developed in the NF treatment are in consonance with the theory posed by Tilman (1999), in which he suggested that an important predictor of competitive success is the ability of a species to continue to extract resources down to low concentrations, adapted for the understanding of systems with low soil nutrient levels and over a longer time frame (Kemp and King, 2001).

5. Conclusions

Therefore, in the evaluated soils, the presence of woody species and determined herbaceous are linked to conditions of low edaphic fertility, which together with the persistence of summer drought also favours the establishment and later development of perennial type species. The demand for sunlight of these species, not associated with treatments in areas of high woodland coverage, require that the plantation density be reduced, which on the other hand, will contribute to the production of high size timber over shorter periods of time. The conservation of meadow species that are characteristic of oligotrophic soils in the Atlantic Zone should be united with the use of rustic authochthonous breeds of animals adapted to the low quality of these species derived directly from the poor soil, which will make these systems compatible with the maintenance of the vegetal and animal biodiversity.

Acknowledgements

We are grateful to Spanish Science Ministry and Xunta de Galicia for financial assistance, to Escuela Politécnica Superior for facilities, to Divina Vázquez Varela, Teresa Pálieiro López, José Javier Santiago-Freijanes, Antonio Rodríguez Rigueiro for helping in processing, laboratory, and field, and to Sheelagh (Interlingua traducciones) for helping with the translation.

References

Barbier, S., Gosselin, F., Balandier, P., 2008. Influence of tree species on understory vegetation diversity and mechanisms involved—a critical review for temperate and boreal forests. For. Ecol. Manage. 254, 1–15.

Butler, A., Kohler, F., Gillet, F., 2008. The Swiss mountain wooded pastures: patterns and processes. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R. (Eds.), Agroforestry in Europe Current Status and Future Prospects. Springer, Berlin, pp. 377–387.

Calvo, L., Santalla, S., Marcos, E., Valbuena, L., Tárrega, R., Luis, E., 2003. Regeneration after wildfire in communities dominated by Pinus pinaster, an obligate seeder, and in others dominated by Quercus pyrenaica, a typical resprouter. For. Ecol. Manage. 184, 209–223.

Chapin, F.S., 2003. Effects of plant traits on ecosystem and regional processes: a conceptual framework for predicting the consequences of global change. Ann. Bot. 91, 455–463.

Dise, N.B., Stevens, C.J., 2005. Nitrogen deposition and reduction of terrestrial biodiversity: evidence from temperate grasslands. Sci. China Ser. C-Life Sci. 48, 720–728.

Edmeades, D.C., Blarney, F.P.C., Acher, C.J., Edwards, D.G., 1991. Effects of pH and aluminium on the growth of temperate pasture species. 1. Temperate grasses and legumes supplied with inorganic nitrogen. Aust. J. Agric. Res. 42, 559–569.

Environment Protection Agency (EPA), 1994. Land Application of Sewage Sludge. A Guide for Land Applicators on the Requirements of the Federal Standards for the Use of Disposal of Sewage Sludge. 40 CFR Part 503.

European Union (E.U.), 2002. Forest fires in Europe 2001 fire campaign. http://www.firescanning.uni-freiburg.de/programmes/eu-comission/EUR-FIREREP-2001.pdf. EUNIS, 2008. http://eunis.eea.europa.eu/cited 20 July 2008.

Grime, J.P., Hodgson, J.G., Hunt, R., 2007. Comparative Plant Ecology, 2nd edn. Cambridge University Press, Cambridge.

Gross, K.L., Mittelbach, G.G., Reynolds, H.L., 2005. Grassland visibility and diversity: responses to nutrients, seed input and disturbance. Ecology 86 (2), 476–486.

Hoyosan, T., Salonen, J., 2002. Weed species diversity and community composition in cropping practices at two intensity levels—a six-year experiment. Plant Ecol. 159 (1), 73–81.

Keddy, D.E., Barrella, S.M.G., 2001. Plant competition in pastures—Implications for management. In: Lazenby, A. (Ed.), Competition and Succession in Pastures. CAB International, Wallingford, pp. 85–103.

Magurran, A.E., 1988. Ecological Diversity and its Measurement. Princeton University Press, London.

MMA (Spanish Environment Ministry), 2008. Los incendios forestales en España. Decreto 1996–2005. http://www.mma.es/secciones/biodiversidad/defensa_incen/estadisticas_incendios/pdf/estadisticas_decreto_1996–2005.pdf. cited 20 July 2008.

Mosquera-Losada, M.R., González-Rodríguez, A., 1999. Pasture production in North-west Spain. In: Sibbald, A., 1996. Silvopastoral systems on temperate sown pastures a personal perspective. In: Etienne, M. (Ed.), Western European Silvopastoral Systems. INRA, Paris, pp. 23–37.

Suding, K.N., Collins, S., Gough, L., Burke, M.J., Clark, C., Cleland, E.E., Gross, K.L., Milchunas, D.G., Pengins, S., 2005. Functional- and abundance-based mechanisms explain diversity loss due to fertilization. Proc. Natl. Acad. Sci. U.S.A. 22 (12), 4387–4392.

Thompson, K., Hodgson, J.G., Grime, J.P., Burke, M.J.W., 2001. Plant traits and temporal scale: evidence from a 5-year invasion experiment using native species. J. Ecol. 89, 1054–1060.

Tilman, D., 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80 (5), 1455–1474.

Tracy, B., Sanderson, M.A., 2000. Patterns of plant species richness in pasture lands of the northeast United States. Plant Ecol. 149, 169–180.

UN, 1992. Agenda 21. United Nations Conference on Environment and Development, Rio de Janeiro.

Willems, J.H., Peet, R.K., Bink, L., 1993. Changes in chalk-grassland structure and species richness resulting from selective nutrient additions. J. Veg. Sci. 4 (2), 203–212.

Zas, R., Alonso, M., 2002. Understory vegetation as indicators of soil characteristics in northwest Spain. For. Ecol. Manage. 171 (1–2), 101–111.