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Pasture, tree and soil evolution in silvopastoral systems of Atlantic Europe

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Abstract

Increased forest area and wood production is a key goal for the European Union, together with avoidance of hazards that damage forests. Galicia is a region of northwest Spain that belongs to the Atlantic biogeographic region with very high wood production, but due to climate fire has a major negative impact on forest productivity (i.e. it represents 16% of the fires of Europe). Silvopastoral systems offer the potential to enhance forest productivity as well as to obtain income from newly afforested areas in the short term. Herbaceous pasture production within such systems can be optimized through species selection and through fertilization. The aim of the present study was to evaluate effect of three types of fertilization on two sward mixtures established under *Pinus radiata* D. Don cover on abandoned agricultural land over an initial period of 7 years. Tree and pasture growth were enhanced with organic fertilization, tree growth rate not being limited by summer drought, and compared with mineral treatment, trees growing up on sludge treatment had around 35 and 30% more height and diameter, respectively. Acidity tendency of Galician soils was reduced with mineral treatment. Soil pH was positively affected by mineral fertilization as it was reduced in less extent in this treatment (pH 6) than in organic (pH 5.3) or no fertilization treatment (pH 5.6), as crop cation extractions were reduced. The proportion of Na and Mg in the effective CEC was higher in fertilization with dairy sludge and no fertilization plots due to better tree canopy development. The interchangeable potassium content in ryegrass sown plots was reduced when no fertilization was applied due to dicot extractions, which can explain lower tree growth than in non-fertilized cocksfoot plots. Correct tree and pasture management, using appropriate sowing mixtures and fertilization types, makes it possible to improve the productivity of both components of the silvopastoral system. Our present results indicate that it is better to use organic fertilizers in the establishment of cocksfoot or ryegrass on sandy soils for tree and pasture growth enhancement.

Keywords: Agroforestry; *Pinus radiata*; Dactylis; Dicots

1. Introduction

It is described in Chapter 11 of Agenda 21 (UN, 1992) that agroforestry, and therefore silvopasture, can be one of the management activities to promote and provide intermediate yields and to improve the rate of returns on investments in planted forests, through interplanting and underplanting valuable crops. In this context, it is important to highlight that about 1 million ha of agricultural land was afforested in the EU Member States during the period 1994–1999 (EC, 2004) thanks to Regulation No. 2080/92.

Just very recently (15/09/2005) a COUNCIL REGULATION on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) was released (15 September 2005), which establishes that ‘‘measures targeting the sustainable use of forestry land through the first establishment of agroforestry systems on agricultural land’’ should be taken.

From an environmental and productive point of view, one of the main advantages of silvopastoral systems is to fulfil multipurpose land use objective through the increase of resource use efficiency at spatial and temporal scales, the reduction of hazards and risks, the enhancement of system stability (multiple species) and the promotion of the social and recreational use of rural land as mentioned in the Silvopastoralism Declaration (Mosquera-Losada et al., 2005a). Atlantic region of Spain produces 70% of the Spain’s total forestry products output though it occupies just 10% of total surface area (MAPA, 2000). About 35% of the total area of the Atlantic region is made up of conifers, in pure stands, and a further 35% is made up of mixed stands with broadleaved species (MAPA,

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2000). Of the conifers, *Pinus radiata* D. Don represents 25% of the total area, and is currently one of the most widely used afforestation trees in this region (Rigueiro-Rodríguez et al., 2005). Plantation densities or number of trees per hectare are often high, the aim being to maximise wood production in terms of volume per hectare; the wood obtained is often pulp production.

Within our region of Galicia (northwest Spain), large amounts of money are invested annually in systems for the prevention, detection and extinction of forest fires. Fire prevention, detection and extinction account for about 40% of the total number of fires in Spain as a whole and, about 16% of the total number of fires in Europe (MAPA, 2000; Schmuck et al., 2005). But, in spite of these investments large areas of forestland are lost to fire, as in 1989, when 192,000 ha was burned. The high fire risk in the Spanish Atlantic region reflects climate (mild temperatures and abundant rainfall in the spring, followed by a summer drought), which favours development of flammable undergrowth and a subsequently high combustion risk.

Fire prevention techniques often aim to reduce plant fuel, for example, via clearing, which is a costly operation. In the Spanish Atlantic region the establishment of conifer plantations on abandoned agricultural land is usually associated with a decrease in soil fertility due to a pH reduction (Adams et al., 2001) (high precipitation rate and nutrient extraction), which leads to a change in the type of ground-cover vegetation, initially herbaceous with low fire risk, but eventually evolving towards shrub communities, characterized by the presence of species such as *Rubus* sp., *Ulex europaeus* L., *Ulex minor* Roth, *Ulex gallii* Planchon, *Erica cinerea* L., *Erica umbellata* Loefl. Ex L., *Erica arborea* L., *Erica australis* L., *Pterospartum tridentatum* L., *Cytisus multiflorus* (L'Hér.) Sweet, *Cytisus scoparius* L., *Cytisus striatus* Hill and *Genista florida* L. (Rigueiro-Rodríguez et al., 2005), which generally have higher rate of inflammability than herbaceous species.

From the point of view of forest protection, then, it is of interest to maintain a herbaceous stratum under tree stands, thus reducing fire risk. This can be done with silvopastoral systems, which allow us to optimize forestry and forage production in a compatible way, greatly reducing the risk of fire. The herbaceous cover can be created artificially and maintained by periodic clearing and by appropriate fertilization of the soil (Rigueiro-Rodríguez et al., 2000; Mosquera-Losada et al., 2005b), which may also favour tree growth. If the plant cover is used as fodder for livestock, income will be obtained in the short term in areas, whereas no income would be earned if only forest activities were carried out, at least until clearing and final cutting had taken place.

Grazing in tree-covered areas makes forestry management more complicated, however, and it will be necessary to carry out specific studies if we are to find out exactly which management practices are the most suitable for the development of the different elements involved in a silvopastoral system: pasture, trees and animals, as well as soil fertility and reduced fire risk. It is important, for instance, to ensure that grazing animals do not damage trees during the early stages of their development. The aim of this study was to evaluate the effects of three types of fertilization (no fertilization, mineral fertilization or fertilization with dairy-plant sludge) on two pasture mixtures (*Dactylis glomerata* L. plus *Trifolium repens* L. plus *Trifolium pratense* or Lp: *Lolium perenne* L. plus *T. repens* plus *T. pratense*) established at the same time as a *P. radiata* plantation on abandoned agricultural land, over an initial period of 7 years.

2. Methods

The silvopastoral system was introduced in 1995 in Castro Riberas de Lea (43.01 N; 7.40 O) (Lugo, Galicia). The study area is situated 439 m above sea level: average annual temperature is 12 °C and average annual rainfall 1350 mm. Rainfall is highest in the autumn and winter, and the highest temperatures are registered in the months of July and August. All years have a summer drought which limits plant growth. The determination of soil texture at the start of the experiment indicated that it has a sandy-loam texture (61.14% sand, 33.79% loam and 5.07% clay) with initial water pH close to neutral (pH 6.8). It is a sedimentary soil, classified as Umbrisol (FAO, 1998). Soil was previously used for potato crop.

The experimental design was a randomised complete block design with six treatments and three replicas. The aim of the study was to evaluate the effect of two pasture mixtures (Dg: *D. glomerata* L. var Saborto plus *T. repens* L. var Ladino plus *T. pratense* L. var. Marino, or Lp: *L. perenne* L. var. Tove plus *T. repens* L. var Ladino plus *T. pratense* L. var. Marino) and three fertilizer treatments (NF: no fertilization, M: mineral fertilization or D: fertilization with dairy-plant sludge) on tree, pasture and soil parameters throughout the first 7 years of establishment of the system. At the beginning of the experiment, the land was tilled, the fertilizer treatments were applied, and sowing and planting took place. Each experimental block was made up of 25 trees of the *P. radiata* grown in a greenhouse in a container to height of 18 cm (150 ml) at a plantation density of 2500 trees ha^{-1} (2 m × 2 m). Each plot was 64 m^2. The pasture mixtures evaluated were—Dg: *D. glomerata* L. var Saborto (25 kg ha^{-1}) + *T. repens* L. var Ladino (4 kg ha^{-1}) + *T. pratense* L. var Marino (1 kg ha^{-1}) and Lp: *L. perenne* L. var Tove (25 kg ha^{-1}) + *T. repens* L. var Ladino (4 kg ha^{-1}) + *T. pratense* L. var Marino (1 kg ha^{-1}). The fertilizer treatments applied in the plots were as follows—(a) no fertilization throughout the entire period the experiment lasted; (b) mineral fertilization every year throughout the experiment, following a standard procedure for our region: 500 kg ha^{-1} of 8:24:16 (N:P_2O_5:K_2O) fertilizer complex in March and 40 kg of N (calcium ammonium nitrate 26% N) ha^{-1} in May; (c) fertilization with dairy sludge (D) in the first year (1995) at 154 m^3 ha^{-1}, i.e. 160 kg of total N, 85.9 kg of total P_2O_5 and 23.4 kg of total K_2O ha^{-1}, values determined based on total sludge of N, P and K. Also added were 265.6 kg ha^{-1} of CaO and 32.8 kg ha^{-1} of MgO with D treatment in 2005. The 2 following years (1996 and 1997), the plots to which the sludge was applied were not fertilized, but they were fertilized again since 1998 to the end of the study with 500 kg ha^{-1} of the mineral fertilizer 8:24:16 (in March) and

40 kg of N ha^{-1} (in May). Milk sewage sludge applied in the plots with milk sewage fertilization has 2% DM, 1.3 kg m^{-3}, 0.55 kg P_2O_5 m^{-3}, 0.15 kg K_2O m^{-3}, 1.7 kg CaO m^{-3} and 0.21 MgO kg m^{-3}, values determined in the laboratory.

2.1. Soil chemistry determinations

In each of the 7 years of the experiment, soil samples were taken from the 18 experimental plots. Samples were taken randomly from each plot using a sampler which penetrated to a depth of 25 cm (in accordance with current Spanish legislation, Real Decreto 1340/90). Subsequently, in the laboratory, the samples were sieved (2 mm mesh) and allowed to dry, after which we determined pH in water (1:2.5), and exchangeable elements in BaCl (Guitián and Carballás, 1976). Ca, Mg and Na contents were determined using an atomic absorption spectrophotometer, and the K concentration using an emission spectrophotometer. Al content was determined by a colorimetric method using 0.01N NaOH phenolphtalein (1%) in an alcohol-based solution (Guitián and Carballás, 1976).

2.2. Tree measurements

Three measurements were taken each year of diameter at the base of the trunk (using calipers and forcipule) and height (telescopic height stick) of each of the nine trees in the centre of each experimental unit (in order to avoid edge effects). In January of the last year of the study (2001), all trees were pruned to a height of 2 m as it is usually made in the area in order to improve the forest transitability and silvicultural operations.

2.3. Pasture determinations

Each year, except the year in which the system was established (1995), the pasture was harvested four times, May (1), June (2), July (3) and December (4). At each harvesting in each experimental unit, the entire surface area delimited by four trees, of the nine trees in the centre of the plot, was cleared, the fresh forage was weighed in situ, and a representative subsample was taken to the laboratory for species separation and drying (48 h at 60 °C).

2.4. Statistical analysis

The results obtained were analysed by ANOVA (randomised block design, following the model: $Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}$, where Y_{ij} is the studied variable; μ the variable mean; T_i the treatment i; B_j the block j; ε_{ij} is the error), with the Duncan test for subsequent pair wise comparisons ($P < 0.05$; $\alpha = 0.05$). The statistical software package SAS (2001) was used for all analyses.

3. Results

3.1. Climate

Fig. 1 shows monthly average temperature, t (°C), and average monthly precipitation, p (mm), in the study area during the 7 years of the experiment, as well as the averages of these variables for the 30 years leading up to the final year of the experiment, t_{30} (°C) and p_{30} (mm). All climate data are from the nearby Rozas Aerodrome weather station (Lugo). As can be seen, the study area shows temperatures lower than 7 °C during the winter period (when plant growth is limited), with mild temperatures and abundant rainfall during the period with the highest level of plant growth, and with a summer period when drought is frequent (limiting plant growth). Only in 2 of the years studied were climatic conditions markedly different from the general pattern: in 1997, the low spring rainfall meant that plant growth was slower, while the high summer rainfall levels of 1997 and 2001 favoured plant growth.

3.2. Soil

3.2.1. pH

pH was 6.8 at the beginning of the experiment, and gradually decreased (Fig. 2), almost certainly as a result of: (a) new organic matter deposition (acidic compounds' inputs); (b) removal of cations by above-ground biomass and harvesting; (c) nitrogen mineralisation (the step from ammonia to nitrate happens and hydrogen protons are released into the soil solution media) and leaching of the nitrate by rainfall (Bremen, 1990). In 1997 and 2001 (Table 1), the pH of the plots studied varied between 5.12 and 6.34, and 5.28 and 6.02, respectively, within the normal range for acid soils in our region.

In both years we observed that no fertilization and fertilization with dairy sludge caused the pH level to drop significantly by comparison with mineral fertilization, which may be attributable to the lower tree growth rate in this latter treatment, which implies slower nutrient extraction. Similarly, Giddens et al. (1997) and Adams et al. (2001) found that the soil pH was lower in fields with *P. radiata* cover than in fields with no tree cover.

3.2.2. Cationic exchange capacity

The results of ANOVA for effective CEC revealed significant effects of the fertilization treatments on this parameter (Fig. 2). The values obtained in the plots sown with the *D. glomerata* mix were 2.0, 2.6 and 1.7 cmol(+) kg^{-1} of soil in the sludge fertilization (S), mineral fertilization and no fertilization plots, respectively. These values are similar to those for the plots sown with the *L. perenne* mix: 1.4 (D), 3.2 (M) and 1.8 (NF) cmol(+) kg^{-1} of soil. These results indicate

Table 1
Relationship of the pH measured in water, obtained 2 and 6 years after the experiment was initiated, in the two types of swards implemented (Dg and Lp) and for the three types of fertilization applied (fertilization with sludge (S), mineral fertilization (M) and no fertilization (NF))

Treatment	Year 1997		Year 2001	
	Dg	Lp	Dg	Lp
L	5.87ab	5.63bc	5.32bc	5.28c
M	6.13ab	6.34a	5.87ab	6.02a
NF	5.12c	5.73abc	5.42bc	5.64abc

Different letters indicate significant differences between treatments for each year.

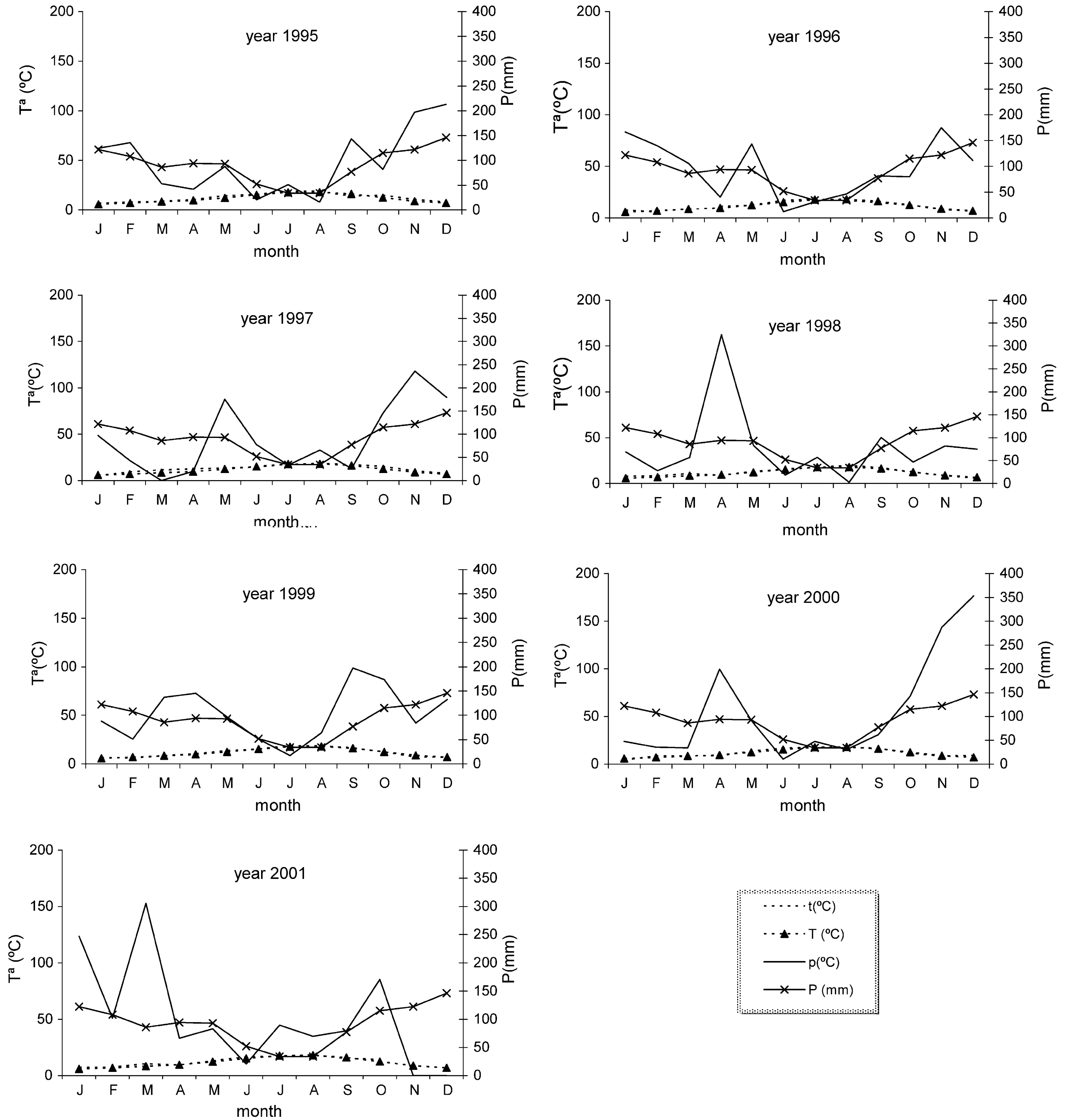

Fig. 1. Monthly mean rainfall and temperature in the study area, Castro Riberas de Lea (Spain), where *t* is average monthly temperature (°C), *p* is average monthly precipitation (mm) during the study (1995–2001) and p_{30} is average monthly precipitation for the 30 years leading up to the end of the experiment (mm). *Source*: Ministry of the Environment.

that the soil of the study plots is not very fertile, as expected for a sandy texture on a siliceous substrate. In general, higher effective CEC values were found in the mineral fertilization plots, which may be related to the higher pH values in these plots (López-Díaz, 2004). Fig. 3 shows the proportion of the different major cations in the effective CEC. Proportions varied between 54 and 66% for Ca, 11 and 22% for Na, 7 and 18% for K, 4 and 9% for Mg, and 3 and 8% for Al, indicating that the soil studied shows adequate calcium and potassium content, low content of magnesium and other elements, and excessive sodium content compared with reference values in ammonium acetate (Fuentes-Yagüe, 1989). In no case were symptoms of nutrient deficiency observed in the trees or pasture.

The sodium content was significantly lower in the mineral fertilization plots than in the other two plot types. In plots sown

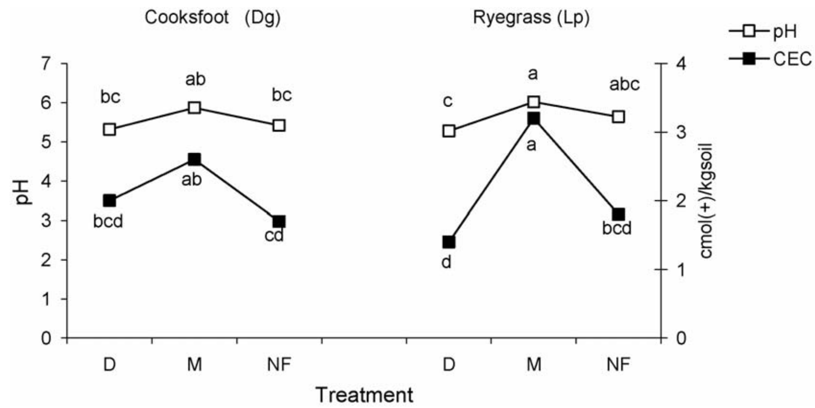

Fig. 2. Effective CEC (cmol(+) kg^{-1} soil) and soil pH in the plots sown with cocksfoot (Dg) or ryegrass (Lp) and sludge (D), mineral fertilized (M) or not fertilized (NF). Means with the same letter do not differ significantly at the 5% level ($P < 0.05$).

with the ryegrass (*L. perenne*) mixture, potassium content was significantly higher in the sludge-fertilized plot than in other plot types. In plots planted with the cocksfoot (*D. glomerata*) mix, both sodium and potassium contents were significantly higher in the sludge-fertilized and non-fertilized plots than in the mineral-fertilized plots. The aluminium and magnesium levels were significantly higher when mineral fertilizer was used in plots sown with pasture mixtures.

3.3. Trees

The height of the trees in the final year of the experiment ranged from 4 to 6.5 m, and basal trunk diameter from 6.5 to 10.5 cm, depending on treatments (Fig. 4). These values are higher than usual for low-fertility land in this region (Mosquera-Losada et al., 2004). In general, growth rates were higher in the years when it rained significantly during the summer period, as in 1997 and 2001. From the beginning of the experiment, the pines growing in the mineral fertilization plots showed a slower growth rate, both in terms of height and diameter, and both in plots sown with cocksfoot and in those sown with ryegrass, with the exception of height at the beginning of the experiment (1996) in the plots sown with ryegrass.

If we compare growth over the 7 year study period, in the different treatments, we can see that both sludge and no fertilization favoured development in terms of both height and diameter over all 7 years in the plots sown with cocksfoot, and over the first 4 years in the plots sown with ryegrass. After the fourth year in the plots sown with ryegrass, growth in the non-fertilized plots slowed, and at the end of the experiment diameter growth in these plots was no different from that seen in the mineral fertilization plots.

3.4. Pasture

3.4.1. Production

Fig. 5 shows the time-course of annual pasture production in the pastures sown with cocksfoot and ryegrass, and the effect of the fertilization treatments applied. Total pasture production over the 7 year study period was 3400, 3200 and 2100 kg ha^{-1} for the M, D and NF plots, respectively, and 2900 and 3100 kg ha^{-1} for the cocksfoot and ryegrass plots, respectively. In fertilized plots, annual production generally exceeded 4500 kg ha^{-1}, while in non-fertilized plots annual production was generally around 3000 kg ha^{-1}; however, pasture production in 1997 was very low, in view of the severe March/April drought in that year. The usual productivity in this area for treeless pastures with fertilization doses similar to those used in this study ranges from about 8000 to 12,000 kg ha^{-1} (Mosquera-Losada and González-Rodríguez, 1998).

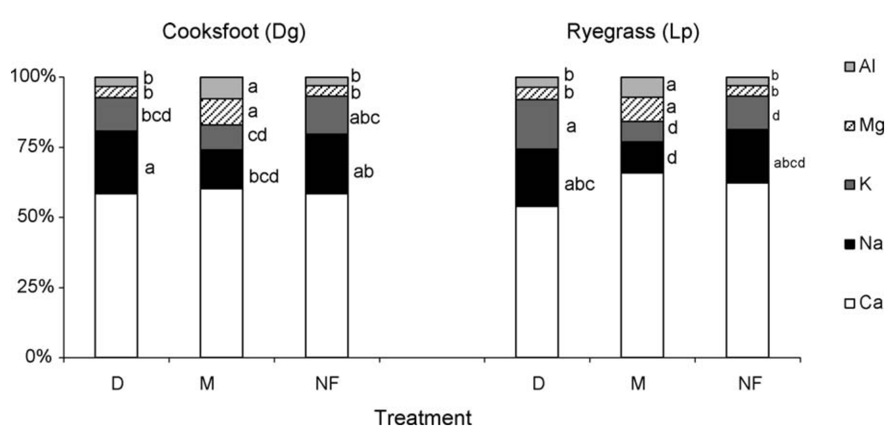

Fig. 3. Percentage contributions of the major exchangeable cations to effective CEC in the plots sown with cocksfoot (Dg) or ryegrass (Lp) and sludge (D), mineral fertilized (M) or not fertilized (NF). Treatment means of the same single element with the same letter do not significantly differ at the 5% level ($P < 0.05$).

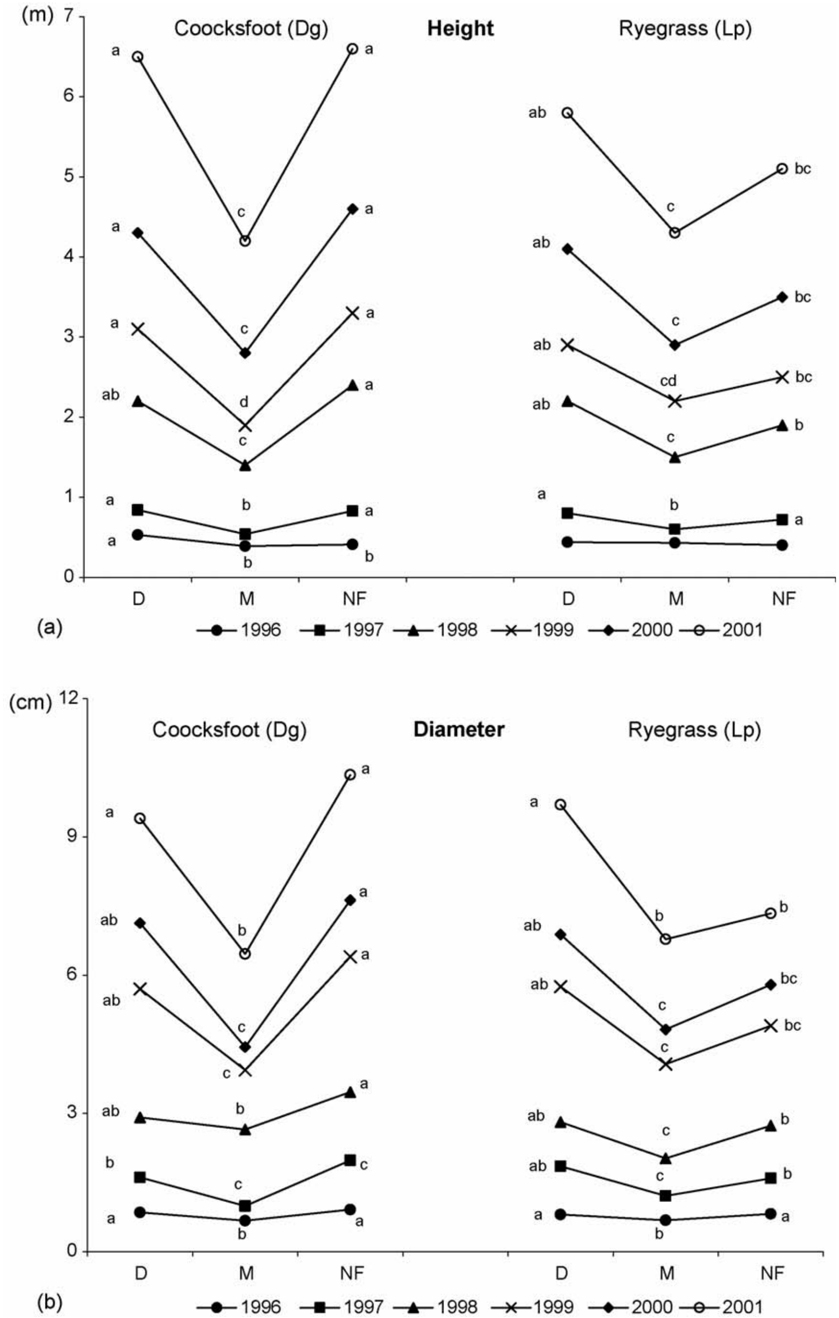

Fig. 4. (a) Growth in terms of height (m) of *Pinus radiata* in the two types of pasture under the three treatments: sludge (D), mineral fertilization (M) or no fertilization (NF). (b) Growth in terms of basal trunk diameter (cm) of *P. radiata* in two types of pasture under the three fertilization treatments. Treatment means for the same year with the same letter do not significantly differ at the 5% level ($P < 0.05$).

There is no evidence of significant reductions in pasture productivity between the first and the seventh years, which could be attributable to the fact that sowing took place in the spring (which tends to reduce first year productivity because the growth period is reduced), and to gradual lengthening of the growth season during the summer period, as shading by the trees increasingly protects against soil moisture loss. At the beginning of the last year of the study, the plots were pruned, which allowed more light onto the pasture, favouring its growth and inverting the general negative trend in the productivity of the land (Sibbald, 1996).

Pasture productivity in fact showed greater dependence on rainfall than on the treatments applied. Insofar as the effect of the treatments is concerned, is should be underlined that annual pasture production in the non-fertilized plots was significantly lower than in the mineral fertilized plots, in 1995 (year 1), 1997 and 1998 in the cocksfoot plots, and in 1996 and 1997 in the ryegrass plots. Comparing the organic fertilization treatment with the no-fertilization treatment, the response of the fertilized plot was positive during the first year after sowing with cocksfoot but not in the first year after sowing with ryegrass. In the following 2 years, a residual effect of the sludge was not

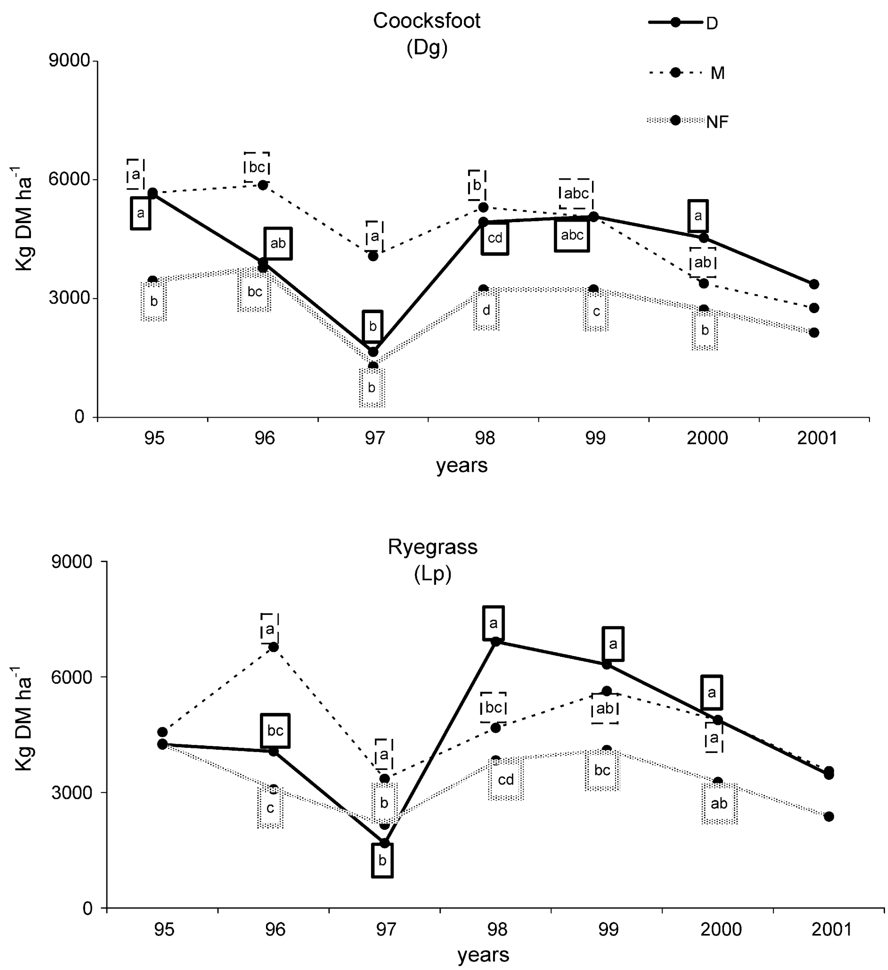

Fig. 5. Annual pasture production (kg dry matter (DM) ha^{-1}) in pasture sown with the cocksfoot (Dg) and ryegrass (Lp) mixtures and fertilized with sludge (D) or mineral fertilizer (M) or not fertilized (NF). Means with the same letter do not differ significantly at the 5% level ($P < 0.05$).

noticed, insofar as annual production was concerned, for either of the two sowing mixtures; after 1998, there was a significant increase in pasture production up until the penultimate year of the study in the ryegrass plots, and up until the antepenultimate year, in the cocksfoot plots. Note that the best pasture productivity in the final years of the study was in the sludge-fertilized ryegrass plots.

3.4.2. Botanical composition

Fig. 6 summarizes cocksfoot and ryegrass production (percentage of dry forage weight) over the study period. Information on clover is not shown because its presence was, in general, scarce, since it does not tolerate shade well (Mosquera-Losada et al., 2001). Evidently, in the early part of the experimental period cocksfoot was most abundant in the cocksfoot-seeded plots and ryegrass more abundant in the cocksfoot-seeded plots. Marked intra-annual variation was observed, and it can be seen that the proportion of cocksfoot was highest in the autumn period in the early years, while the proportion of ryegrass was highest in the spring period. Ryegrass initially grew well but declined over time, and eventually accounted for less than 30% of weight even in the plots in which it had been sown. By contrast, in the final year of the study in the plots sown with cocksfoot, this species represented 60% of forage weight regardless of fertilization treatment, and its contribution to the pasture was significantly higher in these plots than the contribution of ryegrass in the ryegrass-seeded plots throughout practically the entire study period, especially in the fertilized plots. Even in the plots in which ryegrass was sown, when the ryegrass declined there was a gradual increase in the proportion of cocksfoot, which partially occupied the space left by the ryegrass, as seen in 1998 and 1999, especially in the fertilized plots. The main adventitious species found in the plots sown with ryegrass were the dicotyledons *Taraxacum officinale* and *Plantago lanceolata*, and monocotyledons *Holcus lanatus* y *Agrostis* sp., the dicots mainly in the non-fertilized plots and the monocots mainly in the mineral or sludge-fertilized plots.

4. Discussion

Pine growth rates in our region are lower than in other regions of the world. The highest growth rates during the study period correspond to the years in which the summer drought was shortest. However, tree growth rates in our plots were in the high part of the range reported for this species in Galicia (Sánchez et al., 2002): in fact, tree heights at the end of the experiment were twice those reported for trees of the same age in another highly acid soil (initial pH 5) in our region (López-Díaz, 2004).

The negative effect of the summer drought on tree growth is especially important in sandy soils with a low organic matter content, and can be alleviated by adding organic amendments (such as dairy sludge) which favour the development of trees in periods of drought due to the increment of soil moisture holding capacity and limit competition from herbaceous vegetation in the months following planting (Rigueiro-Rodríguez et al., 2000). The high initial rate of growth of the trees is maintained, in general, throughout the life of the stand, but is not always associated with a reduction in initial pasture production. On the other hand, although no residual effect of the sludge on annual pasture production was detected in this study, there is a significant effect on some of the spring harvests in the second year of the study, although this effect disappears in the third year (Rigueiro-Rodríguez et al., 2000).

After the fourth year of the experiment, inorganic fertilizer was applied in the mineral and sludge-fertilized plots, and pasture production was increased without affecting tree growth, probably due to the different root depths, which reduce competition between pasture and tree growth, as had not happened in the first year of this experiment, when an important competition between tree and pasture was detected in M treatment. Moreover, it has been described that different root depths increase the sustainability and efficiency of use fertilizers (Nair and Kalmbacher, 2005), which used to be lower than 40% in agronomic soils (Jarvis and Menzi, 2004). Above-ground competition seems to have been less important, as pasture production in both fertilized plot types was similar, although tree growth was higher in the plots which received sludge initially (around 35% higher in height and 30% higher in diameter).

The results obtained show that the application of dairy sludge to the soil increased acidity, which contrasts with the results of other studies carried out in this region with sludges of this type (López-Mosquera et al., 2000) and with sludges from an urban wastewater treatment plant (López-Díaz et al., 2005). However, it should be borne in mind that in these previous studies the initial soil pH (4.5–5) was lower than in our plots, and sludge was applied in each year of the study, while in our case the initial pH was closer to neutral and the application of sludge only took place in the year in which the silvopastoral system was established. Reductions in soil pH are linked,

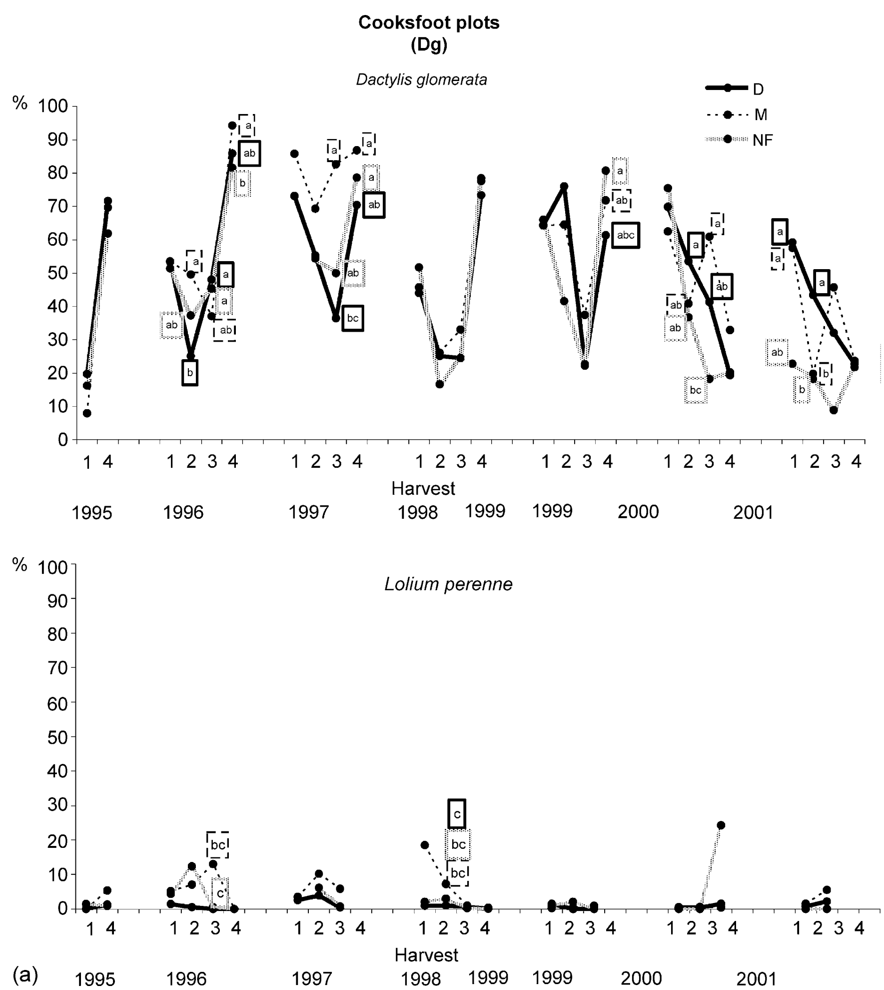

Fig. 6. Time-courses of the percentage contributions of the sown species (cocksfoot or ryegrass) to total dry forage weight, for each mowing over the 7 year study period. Data are shown for each fertilization treatment (sludge (D), mineral fertilizer (M) or no fertilization (NF)). Treatment means for the same harvest with the same letter do not differ significantly at the 5% level ($P < 0.05$). Letter border boxes are similar to the lines of the means they distinguish.

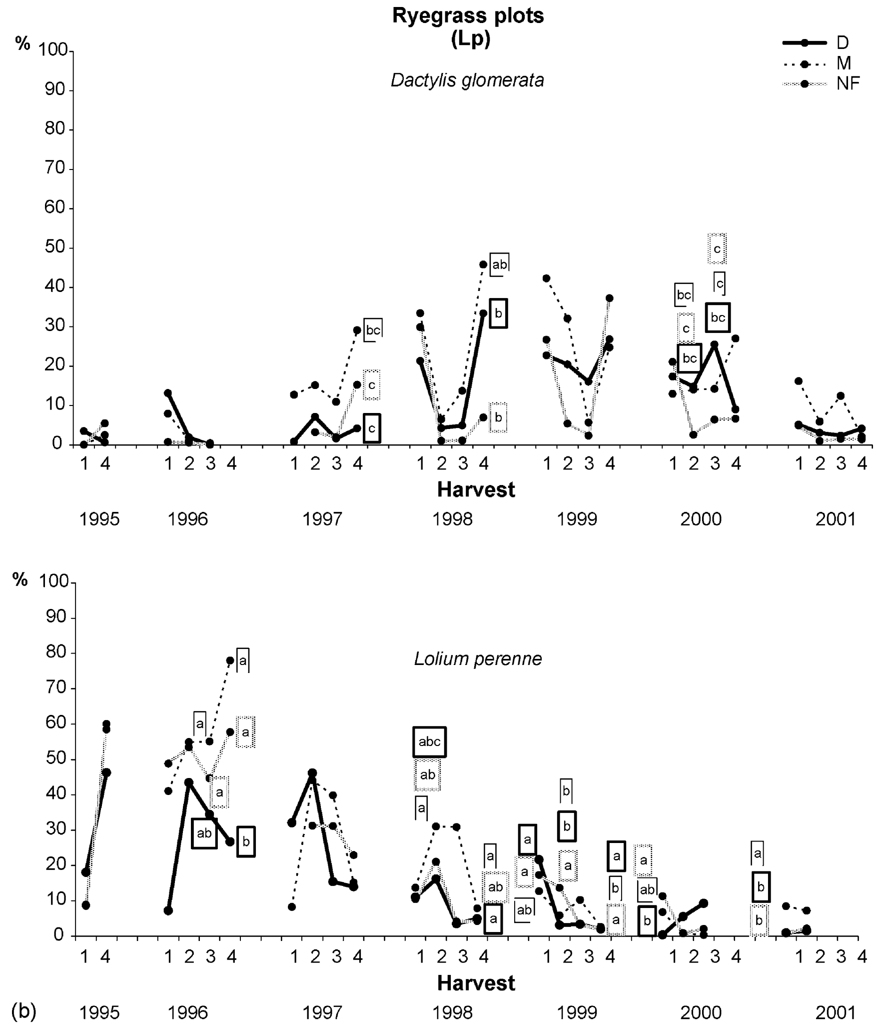

Fig. 6. (*Continued*).

among other factors, to rainfall (Porta et al., 1999) (in our case, the heavy rainfall favoured acidification of the soils within just a few years), although nutrient extraction by plants may also be relevant. It is no doubt for this reason that soil pH was reduced to a lesser extent in our study when nitrogen was applied in inorganic form, since with this fertilization treatment tree growth was notably lower than with the other two treatments, which implies that nutrient extraction was reduced and that the soil will maintain a greater cation exchange capacity (Mombiela and Mateo, 1984; Porta et al., 1999).

It should be emphasised that, regardless of the seeding mixture (cocksfoot or ryegrass) and the fertilization treatment applied (D, M and NF), the element making the most important contribution to CEC was calcium. As Giddens et al. (1997) and Noble et al. (1999) point out, calcium levels are well conserved in *P. radiata* ecosystems. In our region calcium is not usually the main component of the exchange complex, since soils are characterized by the high A1 content in our case; however, the liming that took place in the years before the experiment was started (in association with potato cultivation) meant that the initial pH was high and the percentage of aluminium saturation low.

In regard to other, such as sodium and magnesium, it is important to point out that they were present at significantly lower levels in the mineral fertilization plots, in comparison with the other fertilization treatments. Exchangeable sodium and magnesium levels were usually higher under *P. radiata* than under pasture; this probably resulted from the interception of airborne sea-salt by the *P. radiata* canopy, and subsequent transfer to the soil (Giddens et al., 1997). This could also be explained in our case by the presence of these cations in the soil in the no-fertilization plots and sludge-fertilized plots, in which the tree canopy was more developed. The high sodium levels could mitigate possible magnesium deficiencies (Osbert et al., 2001), that can be found in the region (Mosquera-Losada et al., 2004). Potassium levels were higher in the sludge-fertilized plots, in spite of the fact that this element was added at a higher rate with the mineral fertilization; this could be explained by the higher rate of leaching of the inorganic fertilizer, which would enable aluminium to occupy soil exchange positions. If we compare the interchangeable potassium content of the plots fertilized with sludge and the control, we can see that they are different in terms of the initial sowing mixture. In plots sown with cocksfoot there were no differences between the fertilization treatments; however, ryegrass plots initially fertilized with sludge showed significantly higher exchangeable potassium concentrations than those non-fertilized ryegrass plots. This could be due to the fact that the ryegrass performed badly in these plots, allowing other adventitious species to grow, specifically gramineae (*Agrostis* sp. and *Holcus* sp.) in fertilized plots, and dicotyledons (*Plantago* sp. or *Taraxacum* sp.) in non-fertilized plots. However, cocksfoot made a major contribution to pasture production in the plots in which it was sown. *D. glomerata* has significantly lower potassium levels than most other grasses and dicotyledons (Rodríguez-Barreira, 2000), which reduces its K requirement and thus makes more K available for consumption by the trees. By contrast, when the pasture is made up of K-rich species, this can contribute towards a reduction in K availability for the trees. Interference between the herbaceous cover and tree growth was evident after the third year of the study, in which the diameter and height of the trees growing in the non-fertilized ryegrass plots were, respectively, 25 and 30% less than in the sludge-fertilized ryegrass plots (these differences being statistically significant), as well as non-significantly less than in the non-fertilized or sludge-fertilized cocksfoot plots. In acid forest land soils dicot herbaceous species development like *Taraxacum* or *Plantago* is not important, and therefore NF treatment does not have the same effect showed in the present experiment.

This result is of great practical importance, since it indicates that once a *P. radiata* plantation has been established on abandoned agricultural land fertilization should be applied; this will reduce competition from herbaceous species, thus reducing invasion by dicotyledons undergrowth species which may limit the development of the tree species by potassium depletion. Silvopastoral management with fertilization can also reduce herbicide use to enhance tree and pasture growth in some conditions.

Correct tree and pasture management, using appropriate sowing mixtures and fertilization types, makes possible to improve the productivity of both components of the silvopastoral system. Our present results indicate that, unless under the climatic conditions of this study, it is better to use organic fertilizers in the establishment of cocksfoot or ryegrass on sandy soils for tree and pasture growth enhancement.

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