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Deciduous plantations established on former agricultural land in northwest of Spain as silvopastoralism: Tree growth; pasture production and vascular plant biodiversity

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A B S T R A C T

The *Betula* genus is distributed throughout most of Europe, where it is mainly represented by two stand-forming tree species, *Betula pubescens* Ehrh. and *Betula pendula* Roth. Despite the many advantages of birch as a commercial timber tree, ease establishment, high value timber and a short rotation, it has a poor reputation in Spain where this study was carried out. In the past, *Betula* sp. has often been treated by foresters as a woody weed, being under-valued, under-utilised and under-managed. In the present, the interest shown in it by foresters and private owners is still low. The recognition of the many advantages that this genus offers, especially from afforestation is needed to change gradually. This study aims to evaluate the effects of afforestation with *Betula pubescens* Ehrh. established at two different densities (2500 and 833 trees ha^{-1}), fertilizer with mineral and no fertilizer, and sown with two different pasture mixtures (*Dactylis glomerata* L. + *Trifolium repens* L. + *Trifolium pratense* L. and *Lolium perenne* L. + *Trifolium repens* L. + *Trifolium pratense* L.), on tree growth, tree survival, slenderness ratio, pasture production and vascular plant biodiversity over a period of 13 years. Mineral fertilization increased pasture production and reduced vascular plant biodiversity but it does not seem to be effective in order to improve downy birch growth. The higher planting density promoted on one hand, a lower percentage of survival and less resistance to damage of downy birch; and on the other hand, less pasture production.

1. Introduction

Betula genus is distributed throughout most of Europe, where it is mainly represented by two stand-forming tree species, *Betula pubescens* Ehrh. (downy birch) and *Betula pendula* Roth. (silver birch) (Rendle, 2001). Downy birch is found on damper soils than silver birch, and can even tolerate waterlogged or peaty conditions. Downy birch range is more northerly and western than silver birch, and it can grow at higher elevations. On the other hand, downy birch tolerates damper soils and poorly drained, is not particularly wind resistant, and do not tolerate summer drought. In Spain, downy birch is distributed throughout the northwest quarter of the Iberian Peninsula and the western half of the Pyrenees. Downy birch stands currently cover 49,000 ha in northwest Spain, with 32,000 ha in Galicia where the present study was carried out (Xunta de Galicia, 2011), In Galicia, downy birch grows at 0–1700 m above sea level (asl), although it is more abundant in the north eastern area of this region at altitudes above 400–500 m asl. In the past, birch has often been treated by foresters as a weed. However, it is currently recognized that the timber of downy birch is excellent to make furniture and also as raw material for the pulp and paper industry. It also delivers positive changes in soil chemical, biological and physical properties (Mitchell et al., 1997, 2010). However, the interest shown in this tree species by foresters and private owners is still low in Europe. Consequently, the presence of downy birch is much less common than it could be in Galicia as an integral part of the climax vegetation in the area, as a potentially useful species for colonising part of the approximately 635,000 ha (almost one third of the area in Galicia) that is at nowadays abandoned, unproductive or colonised by scrubs (Gómez-García et al., 2010).

Agroforestry is a sustainable form of land management integrating woody vegetation and crops and/or livestock that has been both politically and economically promoted at world and European level (CAP 2014–2020) as a tool to increase carbon sequestration in soils (Fernández-Núñez et al., 2010) among other benefits that agroforestry provide. These systems allow landowners to obtain additional and earlier financial returns if the understorey pasture is used as fodder for livestock compared with exclusive forest systems. However, the presence of trees may have positive or negative impacts on pasture production and biodiversity through shelter effects and may cause competition for light, water and nutrients (Sinclair et al., 2000; Rigueiro-

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Rodríguez et al., 2012). The balance among these components and their time course may be manipulated by the choice of tree species, planting density and distribution as well as fertilization techniques and pasture mixture sown (Mosquera-Losada et al., 2009; Fernández-Núñez et al., 2014). Downy birch is known as a shade intolerant species and pasture competition for light is probably of primary importance in agroforestry practices established with downy birch. Previous research showed that the crown development and stem growth of birch are retarded when growing at high densities (Hynynen et al., 2010; Fernández-Núñez et al., 2014), On the other hand, tree planting density affects light availability to the understory vegetation; as the tree are developed and consequently pasture production (Burner and MacKown, 2006; Rigueiro-Rodríguez et al., 2007); and species composition (Rigueiro-Rodríguez et al., 2012). As opposed to pines (Rigueiro-Rodríguez et al., 2012)., winter deciduous species, such as downy birch, could leave a temporal window for herbaceous growth during the cool season, if there are no other restrictions (e.g. low temperatures), which allow the maintenance of a pasture production even under high plantation densities in those areas with cool winters. However, it is essential to choose adequate sown pasture species, among which *Dactylis glomerata* L. and *Lolium perenne* are the most extensively used in such systems *Dactylis glomerata* is well known as a shade and drought tolerant species and has been successfully used in agroforestry systems in Galicia (Rigueiro, 1985), as well as having high productivity and nutritional quality (Mosquera-Losada et al., 2006). However, nurse species such as *Lolium perenne* with only a slight shade tolerance and normally included in mixtures to provide quick cover, and shelter for slower growing plants are more recommended for using during the tree planting, in low-density tree plantations, or to accompany tree species with open canopy structures (Lin et al., 1999). Although *Lolium perenne* may interfere with native species, it may not threaten the long-term functionality of certain ecosystems since it leaves within 3–5 years of initial sowing in environments with a summer water shortage (Mosquera-Losada and González-Rodríguez, 1998).

Fertilization is the simplest management practice that a farmer has to enhance pasture production when no other factors like light, temperature or humidity limits growth. Studies carried out in coniferous silvopastoral systems in the NW Spain have shown that inorganic fertilization enhances pasture production as well as tree growth in very acidic soils (López-Díaz et al., 2007), but reduces the production of both components in neutral soils (Mosquera-Losada et al., 2006). However, fertilization is not a common practice in the management of birch stands, usually managed as exclusive forest systems. A few empirical fertilization trials carried out in Finland have shown only a weak birch growth response to fertilization (Oikarinen and Pyykkönen, 1981), that may be different in areas with highest growth potential like Galicia. On the other hand, fertilization also affects diversity due to the modification of the relationship of species (presence of monocots vs. dicots), different functional ecological traits (presence of annual vs. perennial species) or richness (Fernández-Núñez et al., 2014).

The objective of this research was to evaluate the effects of canopy density (833 vs 2500 trees ha^{-1}), sown pasture (*Dactylis glomerata* + clovers vs. *Lolium perenne* + clovers) and fertilizer treatment (mineral fertilization vs. no fertilization) on tree growth, pasture production and vascular plant biodiversity along thirteen years of study in silvopastoral systems established with *Betula pubescens*.

2. Materials and methods

2.1. Study area

The experiment was established in Castro Riberas de Lea (Lugo, NW Spain, 43°01′N; 7°40′W) at an altitude of 439 m above sea level. Fig. 1a shows the monthly average temperatures (°C) and the average monthly rainfall (mm) registered in the zone for the 13th years of the study (1995 to 2007), as well as the average monthly temperatures and rainfall of the last 30 years. The annual mean temperature was mild (12–13 °C). Years 1995, 1997, 2003 and 2006 were the years with the highest average temperature, while 2002 was the year with the lowest. The lowest average monthly temperatures registered during the 13th years of the study were obtained in January 2000 and throughout the whole winter period in 2005 and 2006 (4.1 °C), which in some cases, limited the growth of pasture ($T < 6$ °C) (Mosquera-Losada and González-Rodríguez, 1998). Regarding rainfall, the highest values were registered in 1999, 2000, 2001 and 2002 (1239, 1341, 1269 and 1296 mm, respectively) with all values above the average total of the last thirty years (1083 mm). The years with the lowest rainfall were 1998 (942 mm), 2004 (823 mm), 2005 (824 mm) and 2007 (738 mm). On the other hand, the rainfall registered during the summer period, which mainly determines the inter-annual variation in terms of pasture production in the study area (Mosquera-Losada and González-Rodríguez, 1998) was high in 1995 (211 mm), 1999 (279 mm) and 2001 (238); and low in 2005 (84 mm) and 2007 (90 mm). In general, the zone of the study was affected by a period of summer drought that limited pasture growth and, to a lesser degree, trees development. The duration of this period varied according to the year of the study. Thus, during the years 1995, 1998, 2002 and 2005 it was concentrated in June, July and August. However, the period of drought was only registered in a month in six of the 13th years of the study (June: 1996, 2000, 2001; July: 1999 and 2004; August: 2003). It is important to highlight that 2006 and 2007 were the most atypical years because the period of drought was registered from May to July in the first case; and from August to October in the second case.

2.2. Experimental design

At the beginning of the experiment in April 1995, the soil was ploughed, and the pasture was sown with two mixtures: a) mixture Dg: *Dactylis glomerata* L. var. Saborto (25 kg ha^{-1}) + *Trifolium repens* L. var. Ladino (4 kg ha^{-1}) + *Trifolium pratense* L. var. Marino (1 kg ha^{-1}) and b) mixture Lp: *Lolium perenne* L. var. Tove (25 kg ha^{-1}) + *Trifolium repens* L. var. Ladino (4 kg ha^{-1}) + *Trifolium pratense* L. var. Marino (1 kg ha^{-1}). *Betula pubescens* Ehrh. (from bared root) plants were planted at two densities: a) high density (H): 2500 trees ha^{-1}, with 2 m × 2 m between rows (64 m^2 per experimental unit); and b) low density (L): 833 trees ha^{-1}, with 3 m × 4 m between rows (192 m^2 per experimental unit). In each experimental unit, 25 trees were planted with in a frame of 5 × 5 stems. The experimental design was a completely randomized block with three replicates (8 treatments). The treatments consisted of a) no fertilization (NF); b) annual mineral fertilization (M) following a standard procedure for the 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. At the end of 2002, formation pruning was carried out on the birch trees, with the purpose of producing quality timber.

2.3. Field samplings

2.3.1. Tree

Based and diameter breast height (DBH) was measured with calliper from 1995 to 1998 and 1999 to 2007, respectively, while tree height was measured with a ruler and hypsometer for the same periods, respectively. DBH was determined as the average of two values measured in N-S and E-W directions. All measurements were taken from the inner nine trees of the plots, to avoid a border effect. The survival of trees was also determined.

It is well known that a straight relationship exists between the slenderness coefficient (SC) of the stands and the risk of stem breakage or tree fall due to the effect of abiotic factors such as the wind or snow. For this reason, from the data of height and DBH the slenderness coefficient was determined (height: DBH ratio).