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Importance of root system in total biomass for *Eucalyptus globulus* in northern Spain

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ABSTRACT

Biomass equations have become a vital estimation tool and a prerequisite for studies on forest productivity, nutrient cycling and carbon sequestration.

In this paper a new set of biomass equations were fitted for *Eucalyptus globulus* in Northern Spain. These equations allow us to estimate the total biomass and above- and below-ground fractions from the basal area and the height of the tree. A dummy variable was included in the model to calculate the root fraction of planted versus coppice stands.

A descriptive study of the root system was also carried out to complete the information about this component. Root fraction plays an important role in forest structure, but is often omitted in carbon sequestration estimates due to the difficulties and cost associated with measurement. Our results indicated that root biomass accounted for 15% and 35% of total biomass in planted and coppice stands, respectively, at a shoot age equal to 9 years. We also found that the stand type and plantation age influenced the number of roots per root system, the volume of the root system and root length.

This paper brings to light how coppice stands accumulate significant amounts of carbon in their root systems from the time a plantation is established. Such information makes it possible to orient ecosystem management towards potential for C fixation.

1. Introduction

Forests are considered to be mitigating elements against the predicted rise in atmospheric concentration of carbon dioxide, since trees sequester carbon efficiently [1–3]. Plantations can accumulate carbon at a very high rate, especially those composed of fast-growing tree species. In forest plantations, the capacity to sequester carbon is partially influenced by the forest management regime: the age of rotation, silviculture throughout the rotation, timber destination, the type and desired dimensions of the final products, etc.

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The *Eucalyptus* genus has been used in European forestation since the early 19th century because of its high productivity and plasticity. *Eucalyptus* plantations composed mainly of *Eucalyptus globulus*, with an increasing proportion of the frost-tolerant *Eucalyptus nitens*, cover approximately 14,000 km^2 of southern Europe.

E. globulus is a high-productivity crop in Northern Spain. This fast-growing species is managed according to a relatively simple production system based on its precocious, fast growth and ability to re-sprout after harvest. Most plantations are pure stands with a density of aerial trees between 1100 and 1400 ha^{-1}. Stands are normally harvested in three or four cutting cycles of 14–16 years and managed in a coppice system after the first cutting cycle. These plantations mainly produce raw material for the pulp and paper industries, which are important sectors of Spanish economic activity.

Biomass equations have been established for *Eucalyptus* spp. plantations in different parts of the world such as New Zealand [4], Portugal [5,6], Ethiopia [7] or Madagascar [8]. In Spain, Montero [9] fitted the first biomass equations using diameter at breast height as the unique regressor. Later, Pérez-Cruzado [10] and Ruiz-Peinado [11] fitted a set of equations for *E. globulus* that included the additivity property, with diameter at breast height and tree height as independent variables in some biomass fractions. Unfortunately, these equations are inadequate for coppice stands, where trees can be composed of two or more shoots. Furthermore, they only consider the aerial compartments of trees. Very few studies have developed equations for the root system because excavating root systems is difficult and measurements are tedious and very time-consuming. Some research has been done in Australia [12,13], in the Congo [14], in Ethiopia [7], or in Portugal [15].

Detailed knowledge of root system configurations will facilitate better estimation of below-ground biomass and understanding of the role of the root system in improving soil structure [16], in tree anchoring [17] and in nutrient cycles [18,19]. Diverse factors affect root formation and development from the moment a plantation is established, such as physiological functions, adaptability to environmental stresses, site factors, soil conditions and forest management. Until recently, belowground biomass was generally assessed indirectly using the root:shoot ratio (Wr/Wa), which corresponds to the relative biomass allocation between roots and above-ground fractions [15]. However, root biomass estimations using Wr/Wa ratio are prone to error in re-sprouting forests, especially for the youngest trees.

The objective of the present study was to determine the total biomass of *Eucalyptus globulus* plantations in Northern Spain. Our specific objectives were: (i) to fit a set of biomass equations that accounted for the above- and below-ground fractions and the stand regeneration type (planted or coppice stands) and (ii) to analyze the main characteristics of the root system.

2. Material and methods

2.1. The study area

The study area was located in the Cantabria region of northern Spain (between 43° 10′N-43° 30′N, and 3°10′W-4°34′W), which is classified as a Eurosiberian region. Altitudes in the plantations included in this study ranged from 110 to 317 m above sea level. Mean annual rainfall is 1146 mm (summer precipitation 190 mm) and the mean temperature is 14.5 °C. The mean temperatures for the coldest month [January] and the hottest month [August] are 10 °C and 22.9 °C, respectively. About 200,000 ha or 37.8% of the region is forested and *Eucalyptus* spp. plantations cover around 45,000 ha (21.5% of the total forested area). However, according to the Third Spanish National Forest Inventory [20], potential distribution of the species could be higher because 40.4% of the Cantabrian forestlands are not actually covered by forests. The soil is classified as Acrisols, Cambisols and Umbrisols [21], with some horizons of higher clay content; pH 4.3, 3.3% organic C and 0.22% total N in the upper horizon.

2.2. Data

Data from twelve plantations were used to fit dry biomass equations. In each stand, diameter at breast height (d [cm]), total height (ht [m]) and crown height (hc [m]) were measured for all trees in a 30*30 m square plot. Site quality, age and plot density were varied for maximum representativeness (Table 1).

Half of the plots were marked out in planted stands, which are defined as stands in the first rotation and characterized by the age (in years) since establishment. In planted stands, the trees were the original shoots. The remaining plots were marked out in coppice stands, in a forest structure that consisted of multiple shoots per stump following harvest. The coppice stands were characterized by the age of the coppice shoots [shoots that emerged after harvest], the coppice root age [the age of the root system since establishment] and by the number of cutting cycles [number of harvests carried out since establishment]. Four cutting cycles had transpired in the six plots analyzed.

Table 1 – Stand characteristics of the sampled plots.

	Shoot age (years)	N	dm (cm)	QMD (cm)	BA (m^2 ha^{-1})	Ho (m)
Planted stands	6	1222	11.9	11.2	12.1	14.2
	8	1289	11.4	10.7	11.6	17.7
	4	1322	7.4	6.8	4.8	11.7
	11	922	10.7	13.7	13.6	23.7
	10	1344	12.3	11.9	15.0	18.1
	9	1222	13.0	13.0	16.3	20.1
Coppice stands	7	2256	16.4	8.6	13.1	13.3
	6	1744	11.4	7.7	8.2	10.9
	7	1589	16.9	12.6	19.9	19.3
	9	1678	13.8	10.5	14.6	19.2
	16	1878	23.9	15.3	34.7	27.5
	16	2133	27.1	15.3	39.0	28.9

Note: *N* is the stand aerial shoots density per hectare; dm (cm) is the mean diameter of the shoots; QMD (cm) is the shoot quadratic mean diameter; BA (m^2 ha^{-1}) is the stand basal area; Ho (m) is the shoot dominant height; planted stands are the stands in the first rotation after establishment; coppice stands are harvested stands after rotation; shoot age (years) is the plantation age in planted stands and the shoot age in coppice stands.