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Review

Below-ground biomass production and allometric relationships of eucalyptus coppice plantation in the central highlands of Madagascar

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ABSTRACT

Short rotations of *Eucalyptus* plantations under coppice regime are extensively managed for wood production in Madagascar. Nevertheless, little is known about their biomass production and partitioning and their potential in terms of carbon sequestration. If above-ground biomass (AGB) can be estimated based on established allometric relations, below-ground (BGB) estimates are much less common. The aim of this work was to develop allometric equations to estimate biomass of these plantations, mainly for the root components. Data from 9 *Eucalyptus robusta* stands (47–87 years of plantation age, 3–5 years of coppice-shoot age) were collected and analyzed. Biomass of 3 sampled trees per stand was determined destructively. Dry weight of AGB components (leaves, branches and stems) were estimated as a function of basal area of all shoots per stump and dry weight for BGB components (mainly stump, coarse root (CR) and medium root (MR)) were estimated as a function of stump circumference. Biomass was then computed using allometric equations from stand inventory data. Stand biomass ranged from 102 to 130 Mg ha^{-1} with more than 77% contained in the BGB components. The highest dry weight was allocated in the stump and in the CR (51% and 42% respectively) for BGB parts and in the stem (69%) for AGB part. Allometric relationships developed herein could be applied to other *Eucalyptus* plantations which present similar stand density and growing conditions; anyhow, more is needed to be investigated in understanding biomass production and partitioning over time for this kind of forest ecosystem.

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1. Introduction

Forests comprise the largest carbon pool of all terrestrial ecosystems thanks to the potential of to sequester carbon [1–3]. This important role in regulating carbon cycle is of major concern today in relation to the continuous increase of CO_2 in the atmosphere which contributes to global warming [1,4]. In fact, as incited by the Kyoto Protocol in relation with the United Nations Framework on Climate Change, reducing the release of carbon stored in vegetation (i.e. reduce deforestation and forest degradation) or establishing vegetation sinks (i.e. enhance afforestation and reforestation) are among the several methods for reducing the net emissions of CO_2 in the atmosphere [5]. The Clean Development Mechanism (CDM) in the Kyoto Protocol will allow afforestation and reforestation projects to be established and financed in the developing countries to assist industrialized countries reach their emission reduction targets. Thus, there is much interest in estimating biomass of forests and tree plantations and this implies a need to explore all biomass components.

As in many countries [6,7], short rotation forestry (SRF, especially under coppice regime) using fast growing exotic species such as Eucalyptus genus is a major forestry practice in the central highland of Madagascar for energy purposes. *Eucalyptus robusta* plantations are well known to the people who are living in the central highland of Madagascar. This practice contributes to alleviate the natural forests' decline which is mainly caused by increasing population and economic pressures [8]. These plantations have been in place since the beginning of the last century [9,10] and are pursued with the increased demand for wood and fuel wood but also for ecological services and future incomes from CDM projects.

In SRF a variety of established methods exists for estimating the biomass in above-ground tree components for not only a direct measure of productivity, but also for nutrient accumulation and distribution. For instance, Senelwa and Sims [11] with *Eucalyptus ovata*, *Eucalyptus saligna*, *Eucalyptus globulus* and *Eucalyptus nitens* in New Zealand, Nordh and Verwijst [12] with *Salix* sp. in Sweden and more recently Zewdie et al. [13] with *E. globulus* in Ethiopia assessed the relationship between above-ground biomass (AGB) production and tree dimensions (height and diameter) to determine a non-destructive sampling equation and demonstrated that a pooled equation could be applicable to a variety of eucalyptus.

Besides, a very limited part of the research was focused in root compartment because, as in any forest ecosystem, biomass of root systems is difficult to measure [14,15]. This is mainly because excavating root systems is a difficult task (measurements are tedious and very time-consuming) but also because there is a lack of adequate method to study the dynamics and functions of this part of the ecosystem [16,17]. Therefore, below-ground biomass (BGB) was generally assessed indirectly by using the Root:Shoot ratio (R:S) which corresponds to the relative biomass allocation between roots and above-ground parts [14]. For SRF, there are few investigations on below-ground biomass measurement such as those conducted by Misra et al. [18] and Wildy and Pate [19] in Australia when studying spatial distribution of below-ground biomass of *E. nitens* and describing the general biology of coppices respectively, and by Bouillet et al. [20], et Saint-André et al. [21] in Congo for their works on spatial distribution of root systems and eucalyptus biomass equations, respectively. But understanding root system is especially important for SRF of eucalyptus because these systems are often based on coppice regeneration, it is then necessary to provide an accurate below-ground biomass. The objective of the present study was therefore: (i) to assess the relationship between BGB production (and also the AGB) and tree dimension (stump circumference or basal area) and (ii) to estimate the biomass production and partitioning in different components of these old *E. robusta* coppices in the central highland of Madagascar.

2. Material and methods

2.1. Study area

The study was conducted at Sambaina-Manjakandriana, in Malagasy Highlands (47°45′–47°50′ East and 18°50′–18°56′ South and 1350–1750 m elevation). Average annual rainfall and temperature were 1600 mm and 14.5 °C respectively. The geological substratum is composed of granites, and soils are Ferralsols according to the FAO classification [22] with 1:1 clay content of a mean of 55%.

The eucalyptus plantation in this area shows the historical setting of eucalyptus plantations in the whole central highland of Madagascar. These plantations cover 150,000 ha that is to say 46.5% of all plantation forestry in Madagascar and where *E. robusta* is the most widespread species thanks to its aptitude in rough stony soil and bush fire conditions [23]. *E. robusta* shows the natural ability to sprout, so it could be adopted as a coppicing system of renewal as existing in our study area; actually, since their first plantation in 1900, most of all stools have not been renewed. Being planted first along the railway for locomotive fuel wood supply, eucalyptus plantations were used for landed property and mainly for energy purposes from now [8]. Stands have variable areas (from a few hundred of square meter to less than 10 ha) are privately managed and usually harvested at the age of 3–5 years and stumps cut on ground level are left to resprout. No silvicultural treatments are practiced, all stems (shoots) are left after coppicing for natural thinning.

2.2. Studied stands characteristics

Nine stands of *E. robusta* (Table 1) were identified and selected to study below-ground (BGB) and above-ground biomass (AGB) production and partitioning in relation to total plantation age which ranged from 47 to 87 years. Plantation age and coppice-shoot age were obtained by means of interviews with elderly and officials local people and of use of aerials photo interpretation. According to the small size of the stands, three plots (10 m × 10 m) were randomly located in each stand. Inventory was made in each plot where all stools (stocking 1) and shoots (stocking 2) density was counted and some variables directly measured: stump circumference of all stools (Cir), circumference at breast height (CBH) and height (H) of all shoots.