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Date of First Thinning in a Very High-Density Eucalyptus Plantation in the Pointe-Noire Region (Republic of Congo)

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Abstract

Management of the Pointe-Noire Forest requires high-performance tools for simulating tree and stand growth and assessing the sustainability of plantations. Modelling the dynamics of even-aged and mono-species stands is a very active research topic. The approaches adopted by researchers vary according to the objectives and species considered: dendrometrical, Eco physiological or architectural. Thanks to the particular nature of these plantations and the trial set-up, it will be possible to explore the various aspects of production, clearly separating the part linked to genetics (three clones tested) from the part linked to the environment (via fertilisation) and the part associated with competition between trees (via planting densities and thinning regimes). This study will make a major contribution to the applicability of the self-thinning line and the RDI (Reineke Density Index) (Reineke, 1933) to fast-growing plantations. This research work will contribute to two points: 1) product diversification, which is a way of coping with international variations in timber markets, and 2) understanding how ecosystems function in exceptionally poor conditions, which will then enable the environmental impacts of the various recommended silvicultural itineraries to be assessed. The results obtained show that competition between trees in a stand of eucalyptus at very high density (10,000 stems/ha) and in two environments of very contrasting fertility is different depending on the clone. The decision on the date of the first thinning with a view to silviculture for timber and energy wood, which aims to ensure sustained and sustainable production of eucalyptus wood in these soils, should be taken between 12 and 14 months. The competition band is strong between 14 and 17 months, when the RDI = 0.8 is double that observed at 12 months.

Keywords

Silviculture, Eucalyptus, Pointe-Noire, Thinning, RDI

1. Introduction

Tropical forests are at the heart of the international issues surrounding climate change and biodiversity conservation. As the second largest tropical forest ecosystem after Amazonia, the Congo Basin plays an important role in the continental climate system. These African forests provide a livelihood for 60 million people who live in or near them (medicines, food, fuel, fibre, non-wood products). They also fulfil social and cultural functions. More indirectly, these forests help to feed the 40 million people who live in urban centres close to these forest areas (Nasi et al., 2011).

Management of even-aged stands involves setting production objectives according to required forest products (Resquin et al., 2024). Thinning these stands to reduce mortality in the residual stems and reduce fuel risks has been proposed as a restoration approach (Matsushita et al., 2016). Although many considerations come into play, the feasibility and desirability of thinning programmes will depend, in part, on the costs of thinning, the quality of the material to be removed and the impact of potentially large volumes of thinned material on regional markets and market participants (Bachofen & Zingg, 2005; Chanthalath et al., 2017).

Understanding how thinning strategies impact wood quality and quantity for different purposes is of interest, given that plantation management is often based on parameters that require validation under varying growth conditions (Nogueira et al., 2014; Resquin et al., 2024; Alem & Pavlis, 2012; Gomat et al., 2011).

Between 2000 and 2014, the Congo Basin forest massif lost 16.6 million hectares, mainly due to the actions of small-scale loggers and large companies (https://www.adiac-congo.com/). It is estimated that more than 500,000 hectares of land are deforested each year in the Congo Basin (Marien & Mallet, 2004), although this represents a low rate of deforestation and degradation compared with other regions of the world. The rate of net deforestation rose from 0.09% between 1990 and 2000 to 0.17% between 2000 and 2005. (Tchatchou et al., 2015). In the Republic of Congo, a country with high forest cover (23.5 million hectares of forest, representing 69% of the national territory), the rate of deforestation and forest degradation is around 0.05% per year, or around 12,000 hectares/year (CNIAF, 2015).

With a surface area of 180 million hectares and a high level of production, forest plantations play a decisive role in world forestry (Bouvet et al., 1999). For several years now, forest plantations have been expanding rapidly around the world to meet the growing demand for wood for energy production and the paper industry, among other uses.

Global, regional and national demand for wood products (timber, industry and energy) and associated services (health, employment, etc.) raises the question of how to create a resource that is sufficient in quality and quantity, available and competitively priced. New societal demands are also helping to expand the role of forest plantations. The challenges posed by global change (climate, energy, water, agriculture, etc.) (Koutika, 2022), developments in processing technologies and international markets, and the privatisation of the forestry sector mean that forest plantations are playing an increasingly important role. The species and uses of these plantations are set to diversify, and they can be integrated into the various scales of intervention and production (individual, village, regional, industrial, etc.) (Marien et al., 2012).

Eucalyptus plantations in the Republic of Congo, particularly in the Pointe-Noire region, are established on sandy, highly draining soils. Short-rotation, fixed-density silviculture is aimed primarily at producing wood for paper pulp (Laclau et al., 2003; Bouillet et al., 2004). The development of suitable fertilisation regimes and plantation densities has been essential to achieving such sustained production from plantations (Bouillet et al., 2004; Curtis, 1970) with the possibility of adapting silvicultural techniques or itineraries (plantation density, fertilisation, thinning) for optimum production of trees with diameters of at least thirty cm and stands for use as service wood and timber within a reasonable timeframe and whose qualities are compatible with those for processing (Chanthalath et al., 2017).

Management of the Pointe-Noire Forest requires high-performance tools for simulating tree and stand growth and assessing the sustainability of plantations. Modelling the dynamics of even-aged and mono-species stands is a very active area of research. The approaches adopted by researchers vary according to the objectives and species considered: dendrometric, ecophysiological or architectural. Thanks to the particular nature of these plantations and the trial set-up, it will be possible to explore the various aspects of production, clearly separating the part linked to genetics (three clones tested) from the part linked to the environment (via fertilisation) and the part associated with competition between trees (via planting densities and thinning regimes). This study will make a major contribution to the applicability of the self-thinning line and the RDI (Reineke Density Index) (Reineke, 1933) to fast-growing plantations.

The general aim of this study is to define silviculture with thinning to further diversify wood production (pole, post, timber) in eucalyptus plantations in Congo. Knowledge of the date of the first thinning in the context of the soils of Pointe-Noire is essential to maintain the free growth of the stands.

2. Materials and Method

2.1. Presentation of the Study Aera

The experimental plot is located at Luvuiti in the department of Kouilou (latitude

4˚40'46" south and longitude 11˚55'29" east) on the coastal plain. The experiment was set up in 2007.

The climate is transitional equatorial (Samba Kimbata & Mpounza, 2001). Average annual rainfall was 1491 mm at the Luvuiti station, with a marked dry season from June to September. The average temperature is 25˚C, with small seasonal variations (<5˚C) and very few inter-annual variations. Relative humidity averages 80%, with very little variation over the year.

The soils have relatively homogeneous chemical characteristics down to 15 m (Laclau, 2001; Bikindou et al., 2012). The clay content is low, with less organic matter and deficiencies in N, P, K, Ca and Mg. In addition, the water content of the soil is low, often close to the point of permanent wilting in the dry season. Exchangeable cations (Ca, Mg, K) are rapidly leached. Acidic pH levels (3.5 to 5.5) slow down microbial activity.

The vegetation in the experimental plot consisted of the offshoots of eucalyptus stumps, savannah grasses (*Loudetia simplex* and *Hyparrhenia diplandra* predominating), *Annona senegalensis* bushes with a low density of stems per hectare, the nitrogen-fixing legume *Eriosema psoraleoides* and a few plants of *Anthocleista schweinfurthii*.

2.2. Plant Material

Three eucalyptus clones were studied: clone E. PF1 1-41 and two clones of the "urograndis" hybrid, namely clone 18-52 and clone 18-147 from a cross between *E. grandis* and *E. urophylla*.

The three clones were chosen because the first (1 - 41) is the reference clone in eucalyptus plantations in Congo (13 - 18 m^3/ha/year) and the other two (18 - 52 and 18 - 147) are artificial clones with high productivity (20 - 25 m^3/ha/year).

2.3. Experimental Set-Up

It consists of contrasting fertility zones to compare stands in a normal (control) fertility situation (corresponding to that achieved in the industrial plantations at Pointe-Noire, i.e. 500 kg/ha of ammonium nitrate at 27% applied foot by foot at replanting); to a situation of non-limiting fertility, with a complete supply of macro- and micro-elements, i.e. 1 ton/ha of limestone before planting (to obtain a minimum of 200 to 300 kg of Ca; 150 to 200 kg of K and 20 to 30 kg of Mg, and 5 kg per hectare of boron at planting. A further 500 kg/ha of combined NPK fertiliser (13-13-21) is added every six months.

A high planting density of 10,000 stems/ha (i.e., 1 m × 1 m spacing) was chosen to explore a range of possible growth conditions with thinning.

In each fertility zone, two blocks of 12 plots each were defined. That is four plots per block and per clone.

2.4. Reineke Density Index RDI (Reineke, 1933)

RDI is a density index that takes into account both stem density and basal area. It is, therefore, relatively independent of age: an RDI close to 1 corresponds to a maximum density level; an RDI of 0 corresponds to a very low level of competition, where the trees can be considered to be growing freely; an RDI of 0.5 corresponds to the low range of current recommendations in public forests.

It is the law of self-thinning which accounts for natural mortality due to the effect of competition, in regular and very dense pure stands by considering them in the framework:

[Ln(Dg), Ln(N)].

Reineke's reference curve (Reineke, 1933) is: Ln(N) = a − b Ln(Dg)

With b = −1.605, a = constant, varying with the species

$Dg = aN^{-0.625}$ (−0.625 is identical for all species) (**Figure 4**)

$N = aDg^{-1.605}$

lnN = 11,236 − 1428lnD

RDI = N × (11,236D)^1(−1428)

The stands were monitored using the self-thinning line adjusted for even-aged *E. delegatensis* and *E. regnans* forests (Borough et al., 1984), with a slope value equal to −0.66 et −0.70, very similar to that proposed by Curtis (1982) for Douglas but steeper than that suggested by Reineke (1933) with a constant slope for all species (−0.625).

2.5. Data Collection and Statistical Testing

There are 36 × 36 trees in each plot, and a central area has been set aside for measurements in order to avoid the border effect, which influences the shape of the trees and competition for light and nutrients between neighbouring plots of different densities and clones. This zone has 21 × 25 trees, giving a total of 525 trees, 60 of which are regularly distributed and marked, making up the permanent measurement trees.

The following data were observed or measured on the trees: diameter at the base, diameter at 1.30 m, total height and mortality was estimated on the 525 trees in the useful plot. These measurements were carried out on the 60 trees marked in each plot at 3, 7, 12, 14 and 17 months.

3. Results

3.1. Effect of Fertilisation on Mortality

Mortality increases with the age of the stand. Whatever the clone (**Figures 1(a)-(c)**), trees die more in stands located in areas of normal fertility, with a significant difference except for clones 18-52 after one year (**Figure 1(c)**).

3.2. Effect of Clone on Mortality

Mortality according to clones as a function of time shows a gradation in the sense that there is less mortality in populations of *E. urophylla* × *E. grandis* only for clones 1-41 in the two fertility regimes (**Figure 2**). There is a reversal of mortality between *E. urophylla* × *E. grandis* clones: mortality of clones 18-52 is high compared with clones 18-147 in the fertility zone and vice versa in the normal fertility zone (Figure 2(a), Figure 2(b)).

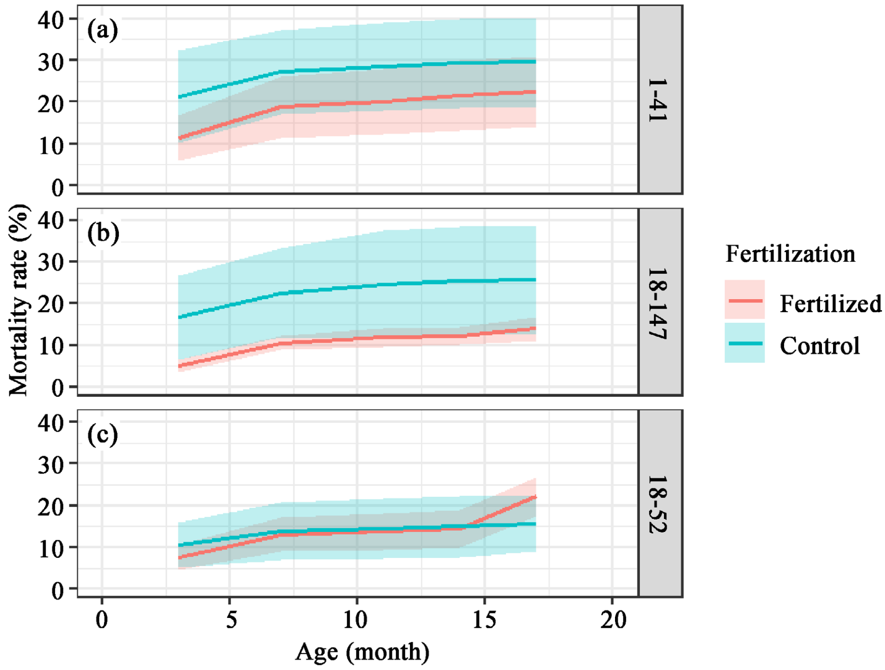

Figure 1. Effect of fertilisation on clone mortality.

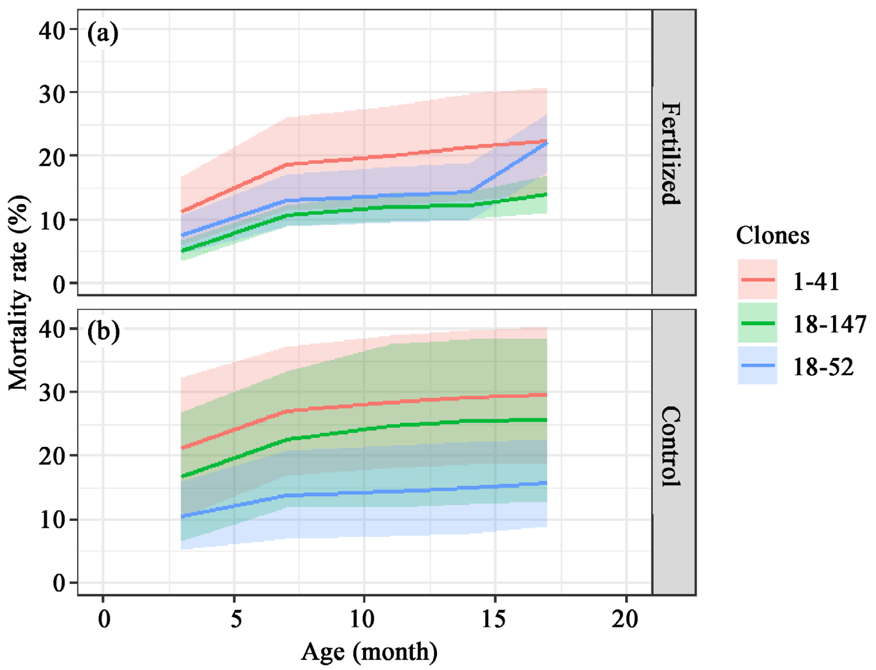

Figure 2. Clone effect on mortality.

3.3. Choice of Self-Thinning Curve

Whatever the clone and the fertilisation zone, the trees rather compete and align themselves around the curve of the *Eucalyptus regnans* literature (Figure 3).

3.4. Density/Diameter Relationship (RDI)

The RDI (Reneke density index) increases with age, regardless of the fertility of the site and, thus, for all clones (Figures 4(a)-(c)). This increase is relatively small before 12 months (Figure 4).

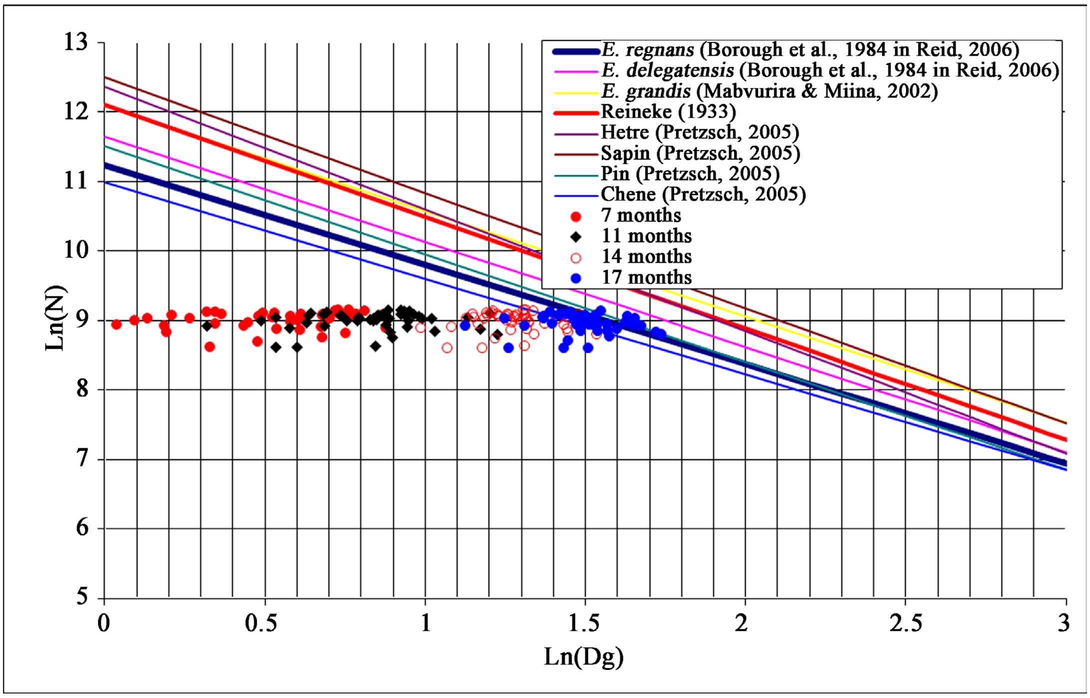

Figure 3. Self-thinning line of the literature and measurement data. (Mabvurira & Miina, 2002; Pretzsch & Biber, 2005)

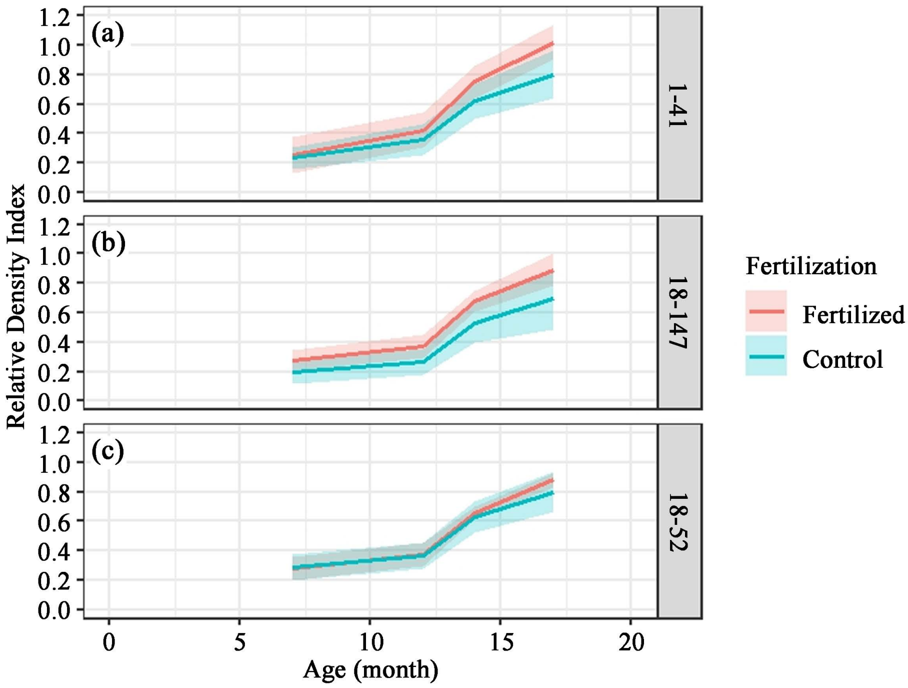

Figure 4. RDI as a function of age in high-density stands.

Between 12 and 14 months the band is strong; the trees are competing with each other, and at 17 months, we have an RDI = 0.8 with a small difference between the two fertilities for clones 18-52 (**Figure 4(c)**).

4. Discussion

4.1. Growth and Mortality

Mortality or dieback is a natural phenomenon of forest dynamics and occurs in all phases of development. Both the physiological processes and the causes that lead to increased mortality are not yet fully understood. However, for effective forest management and successful forest protection, it is essential to understand the driving factors that lead to tree mortality (Franklin et al., 1987). In general, mortality in a young stand is very high due to competition, decreases with increasing stand age through self-thinning, and finally increases when the stand is old (Korpel, 1995). To define a silvicultural itinerary, we used a stand density index constructed on the principle of the self-thinning law, and this RDI index varies between 0 (no trees) and 1 (the stand has maximum density and mortality due to competition is maximum). As a result, a comparison of natural mortality due to the effect of competition in stands by fertility zone (normal fertility and non-limiting fertility) shows that: whatever the fertility regime or the clone, the mortality rate is higher in the normal fertility zone and for clones 18-147 and 18-41 (urograndis) this difference is due to the supply of more mineral substances in one of the fertility zones.

In our case, death is more pronounced in areas of normal fertility; the more food there is, the more death sets in, and trees in areas of non-limiting fertility are more resistant. The mortality rate of clones 1-41 is higher than that of urograndis trees, which are more resistant whatever the fertilisation regime.

4.2. Decision on Thinning Date

From 17 months onwards, growth slows down and maximum competition sets in. The density must then fall sharply for all clones if the trees are to continue growing, following the *E. regnans* literature curve: Ln(N) = 11.236 Ln (Dbase) − 1.428 (Borough et al., 1984; Reid, 2006).

Thinning is triggered according to the level of competition set in relation to the RDI deduced from self-thinning curves in the literature. The self-thinning line selected is the one where the stands come closer together, bend significantly and, therefore, express a state of maximum competition (RDI = 1). The growth of the trees in relation to the self-thinning lines published in the literature (**Figure 1**) shows that as this growth progresses, the stands approach the state of maximum competition (RDI = 1). At 17 months, a clear inflection of points aligns, to a first approximation, with the self-thinning line for *Eucalyptus regnans* (Ln(N) = 11.236 Ln (Dbase) − 1.428) (Borough et al., 1984; Reid, 2006).

Between 12 and 14 months, the band is strong; the trees are competing with each other, and at 17 months, we have an RDI = 0.8. The ideal date for thinning in order to release the trees for free growth would be between 12 and 14 months in order to maintain the free growth of the trees since we should not wait for the competition to set in. We should act instead. Also, the mortality rate between trees between 12 and 14 months is high. After 14 months, there would be constraints (light, organic matter).

Thinning has an influence on the quality of forest production, because the greater the thinning, the greater the growth in tree diameter.

5. Conclusion

The study carried out for the definition of silviculture with thinning to diversify wood production in eucalyptus plantations in Congo highlighted a competition that starts very early at one year between trees, which slows down their growth. The possibility of diversifying products (poles, poles, timber) despite a very restrictive ecological environment for the growth of eucalyptus trees requires thinning fairly early in a stand with a high density (10,000 stems/ha).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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