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Fate of *Acacia mangium* in eucalypt mixed-species plantations during drought conditions in the Congolese coastal plains

Destino de *Acacia mangium* en plantaciones mixtas con especies de eucaliptos durante condiciones de sequía en las llanuras costeras congoleñas

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SUMMARY

A mixed-species plantation of *Acacia mangium* (acacia) and *Eucalyptus urophilla x grandis* (eucalypt) hybrid was established on the Arenosols of the coastal Congolese plains to improve soil fertility and sustain forest plantation productivity. At one year into the second rotation, some of the acacia started to exhibit yellowing and drying of leaves, resulting in the death of the whole tree. One-third of the pure acacias (100A) and the mixed, 50 % acacia and 50 % eucalypt (50A50E) hybrid, exhibited these characteristics five months later. To limit the damage, the acacias were pruned up to 1.30 meters. The acacias were threatened by a dry season that extended two months longer than during the previous year, probably triggered by sandy textured soils and poor soil fertility (nitrogen < 0.07 % in the 0.05 meters). Soil moisture to a depth of 0.15 meters was higher under eucalypt compared to acacia. It appears that the acacia root structure may have been less tolerant to drought conditions compared with the eucalypts, leading to damage of acacias, which was exacerbated by the acacia's young age, poor soil fertility and sandy soil texture. One year after pruning, acacias in both 100A and 50A50E presented a healthier tree structure. Furthermore, no negative impact on aboveground biomass -*i.e.*, wood, bark, leaves and branch- has been recorded at 12 and 24 months.

Key words: young plantation, dry season, arenosols, pruning.

RESUMEN

Plantaciones mixtas de *Acacia mangium* (acacia) y el híbrido de *Eucalyptus urophilla* x *grandis* (eucalipto) se establecieron en Arenosoles de las llanuras costeras congoleñas para mejorar la fertilidad del suelo y mantener la productividad de las plantaciones forestales. Un año después de la segunda rotación, parte de la acacia mostró un color amarillento y el secado de hojas, lo que provocó la muerte de todo el árbol. Un tercio de las acacias puras (100A) y el híbrido mixto, 50 % de acacia y 50 % de eucalipto (50A50E) exhibieron estas características cinco meses después. Para limitar el daño, las acacias fueron podadas hasta 1,3 m. Las acacias se vieron amenazadas por una estación seca que se extendió dos meses más que el año anterior, probablemente desencadenada por los suelos de textura arenosa, y la fertilidad del suelo (nitrógeno < 0,07 % en 0-5 cm). La humedad del suelo a una profundidad de 15 cm fue mayor bajo eucalipto en comparación con acacia. La estructura de la raíz de acacia pudo haber sido menos tolerante a las condiciones de sequía en comparación con los eucaliptos, lo que ha provocado daños en las acacias, que se han visto agravados por la juventud de la acacia, la fertilidad del suelo y la textura del suelo arenoso. Un año después de la poda, la acacia en 100A y 50A50E presentó estructura de árbol más saludable. Además, no se registró ningún impacto negativo en la biomasa aérea, es decir, madera, corteza, hojas y ramas a los 12 y 24 meses.

Palabras clave: plantación joven, estación seca, arenosoles, poda.

INTRODUCTION

Acacia mangium Willd. is a fast-growing tree mainly used in forestry for the production of paper and solid wood products and for ecological restoration (Eyles *et al.* 2008, Coetzee *et al.* 2011). Its taxonomic name is *A. mangium*, while its common name is black wattle (English) and brown salwood (Australian standard trade name). *Acacia mangium* is widely planted and has been cultivated out of its native environment of Australia. It has been introduced into humid tropical lowland plantations of Asia, and can also be found in Latin America (Brazil, Colombia, Costa Rica etc.) and in Central Africa (Republic of Congo, Cameroon, DR Congo etc.).

The natural distribution of *A. mangium* overlaps the warm and hot tropical climatic zones. In these areas, temperatures are high throughout the year, with the mean maximum hottest month between 31 and 34 °C and the mean minimum coolest month between 15 and 22 °C. The mean annual rainfall is from 1,500 to 3,000 mm, with summer (January to March) being the wettest period. It prefers well-drained, acidic soils (pH of less than 4.0) of moderate to low fertility and has a vigorous growth rate (Cole *et al.* 1996). *Acacia mangium* is able to grow reasonably well in nitrogen poor soil and in areas where competition with other plant species is severe. In part, because of its nitrogen-fixing ability. For example, *A. mangium* could survive in the *Imperata* grasslands (Yamashita *et al.* 2008) or in mixed-species plantations combined with fast growing trees such as eucalypts (Inagaki *et al.* 2011, Bouillet *et al.* 2013). Its extensive worldwide introduction in forest plantations established on infertile soils is due not only to the improvement in nitrogen (N) dynamics, but also to soil carbon accretion especially when combined with fast growing species (Binkley *et al*. 2000, Bouillet *et al.* 2013, Epron *et al.* 2013, Koutika *et al.* 2014). No regarding the beneficial effects cited above, *A. mangium* may have a negative impact on ecosystems and biodiversity outside its native environment (Aguiar *et al.* 2014). In the current study, we have tried to find out why, besides its successful introduction in Arenosols of the Congolese coastal plains, the acacia trees died in the beginning of the second rotation of mixed-species plantation of acacia and eucalypt. The following hypothesis is formulated: *A. mangium* tree in the juvenile age of the second rotation will be less tolerant to drought conditions than are *E. urophilla x grandis* trees.

METHODS

Studied site characteristics, trial history and soil analyses. The study site was a mixed plantation of acacia and eucalypt located approximately 35 km East of Pointe-Noire city on a plateau close to the Tchissoko village in the Republic of Congo (4°S, 12°E, 100 m Alt.). The soil is a deep Ferralic Arenosol, overlaying geological bedrock of thick detritic layers (continental origin from Plio-Pleistocene). Soil fertility is low, with a low CEC (< 0.5 cmol+ kg^{-1}), high sand content (> 90 % of mineral soil), very low clay and silt content (2 to 6 % according to depth, respectively) and low iron oxides content (< 1.5 % of the bulk soil, Mareschal et al. 2011). The climate is subequatorial with a cool dry season extending typically from May to September, with the mean annual rainfall of 1,250 mm and more than 85 % of atmospheric moisture. The studied area was afforested in 1984 with eucalypt hybrids. Before the trial establishment, vegetation was native tropical savanna dominated by the poaceae Loudetia arundinacea (Hochst.) Steud.

A complete randomized block design was established in May 2004 with five blocks (first rotation). The first rotation of mixed-species plantation was planted with *E. urophylla x grandis* hybrid and *A. mangium* with starter fertilization (ammonium nitrate, 43 kg ha^{-1} of nitrogen). A pure acacia plot (100A), a mixed-species plot with 50 % acacia and 50 % eucalypt trees (50A50E) and a pure eucalypt plot (100E) were established within each block at a stocking density of 800 trees per hectare. Each plot (1,250 m^2) consisted of an inner part of 36 trees (6×6) and two buffer rows (Epron *et al.* 2013). The second rotation was replanted under the same scheme as used in the previous rotation in March 2012 with *E. urophylla x grandis* hybrid and *A. mangium* with starter fertilization (KCl, 150 kg ha^{-1}) (figure 1). Monitoring equipment such as Campbell CR 1000 was installed to collect data on rainfall and soil moisture. Soil water content was monitored with CS616 Campbell probe buried at various distances from the trees.

Soil sampling (0-15 cm) was completed in December 2011 (end of the first rotation at age 7 years) and in March

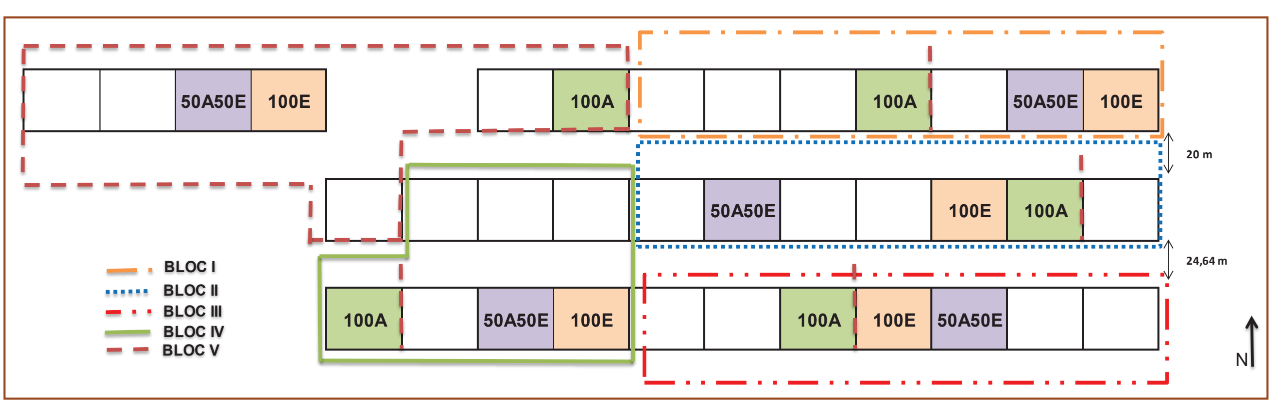

Figure 1. Tchissoko trial, total area: 4.375 ha. 100A: pure acacias; 50A50E: mixed, 50 % acacia and 50 % eucalypt hybrid.

Prueba de Tchissoko, área total: 4.375 ha. 100A: acacias puras; 50A50E: mezclado, 50 % de acacia y 50 % de híbrido de eucalipto.

2014 (at age two years of the second rotation) in three out of the five blocks in the inner part of the stands. A composite soil sample consisting of nine sub samples was collected for each of the three stands of the three blocks. The soil samples were air-dried and sieved at 2 mm. Total carbon and nitrogen concentrations were determined by combustion with an elemental analyzer (NCS 2500, Thermoquest, Italy). The soil samples were fused with $LiBO_2$ and dissolved in 1 N HNO_3. Mean total phosphorus (P), aluminium (Al), iron (Fe) and manganese (Mn) were analyzed using plasma atomic emission spectroscopy (ICP-AES, soil analyses laboratory, INRA, Arras, France).

RESULTS

Soil carbon and nitrogen concentrations at the end of this first rotation are summarized in table 1. The studied soil has low nitrogen concentrations (< 0.07 %) with a high C/N ratio mainly in the upper layer soil. Phosphorous and calcium concentrations are also low (table 2). The dry season during 2013 was five months longer than that of 2012 (figure 2), while the soil water content down to a depth of 0.15 meters was higher in the pure eucalypt 100E stands than in the pure 100A acacia stands (figure 3). The damage of acacia trees was observed in the acacia stands early in March 2013, one year after the planting of the second rotation. At the beginning, leaves became ye-

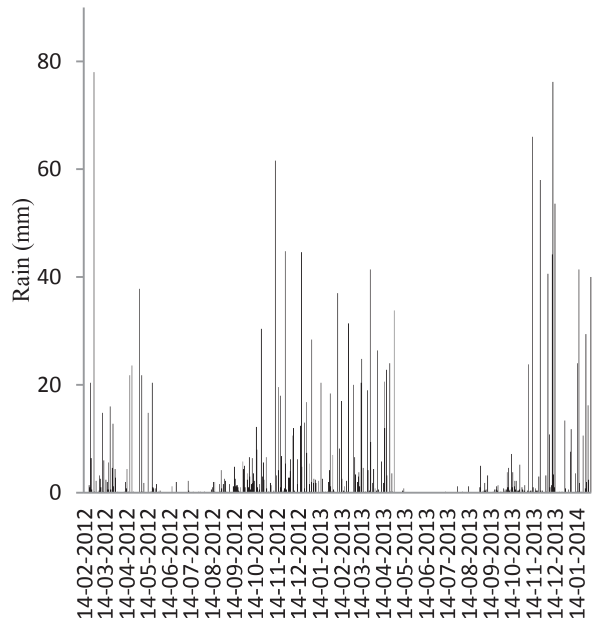

Figure 2. Precipitation at the studied site during two years and soil water contents down to 0.015 depth under 100A, 100E and 50A50E (Tchissoko, Republic of Congo).

Precipitación en el sitio estudiado durante dos años y contenido de agua del suelo hasta 0,015 m de profundidad bajo 100A, 100E y 50A50E (Tchissoko, República del Congo).

Table 1. Nitrogen (N), carbon (C) concentrations and C/N ratio to a depth of 0.15 m under the pure acacia (100A), 50 % acacia and 50% eucalypt (50A50E) and pure eucalypt (100E) stands of the mixed species plantation of acacia and eucalypt at the end of the first rotation (mean with standard error adapted from Koutika *et al.* 2014).

Concentraciones de nitrógeno (N), carbono (C) y relación C/N hasta una profundidad de 0,15 m bajo los rodales de acacia pura (100A), 50 % acacia y 50% eucalipto (50A50E) y eucalipto puro (100E) en las plantaciones de especies mixtas de acacia y eucalipto al final de la primera rotación (media con error estándar adaptado de Koutika *et al.* 2014).

Depth and soil properties (soil collected on December 2011)	N (%)	C (%)	C/N
100A – *A. mangium*			
0-0.05 m	0.058 (0.00)	0.99 (0.07)	16.9 (0.54)
0.05-0.10 m	0.041 (0.00)	0.59 (0.03)	14.2 (0.45)
0.10-0.15 m	0.038 (0.00)	0.40 (0.01)	10.6 (0.26)
50A50E-50 % acacia and 50 % eucalypt			
0-0.05 m	0.064 (0.00)	1.18 (0.08)	17.8 (0.48)
0.05-0.10 m	0.042 (0.00)	0.56 (0.02)	13.3 (0.35)
0.10-0.15 m	0.035 (0.00)	0.42 (0.01)	12.0 (0.23)
100E- eucalypt			
0-0.05 m	0.050 (0.00)	0.87 (0.09)	17.1 (0.51)
0.05-0.10 m	0.038 (0.00)	0.49 (0.03)	13.0 (0.56)
0.10-0.15 m	0.036 (0.00)	0.43 (0.02)	12.0 (0.26)

Table 2. Phosphorus (P), aluminium (Al), iron (Fe), calcium (Ca) and manganese (Mn) in 0-0.05 m layer of stands 100A, 50A50E and 100E.

Fósforo (P), aluminio (Al), hierro (Fe), calcio (Ca) y manganeso (Mn) en una capa de 0-0,05 m de los rodales 100A, 50A50E y 100E.

Treatments and stands	P g/100g	Al g/100g	Fe g/100g	Ca g/100g	Mn g/100g
			Year 1 – End of rotation 1		
100A	0.07	1.08	1.06	-	51
50A50E	0.04	1.04	0.99	-	47.
100E	0.07	0.99	1.03	-	45
			Year 2 – End of rotation 2		
100A	0.01	0.99	0.97	0.09	49
50A50E	0.06	1.02	0.94	0.06	45
100E	0.03	0.97	0.98	0.13	45

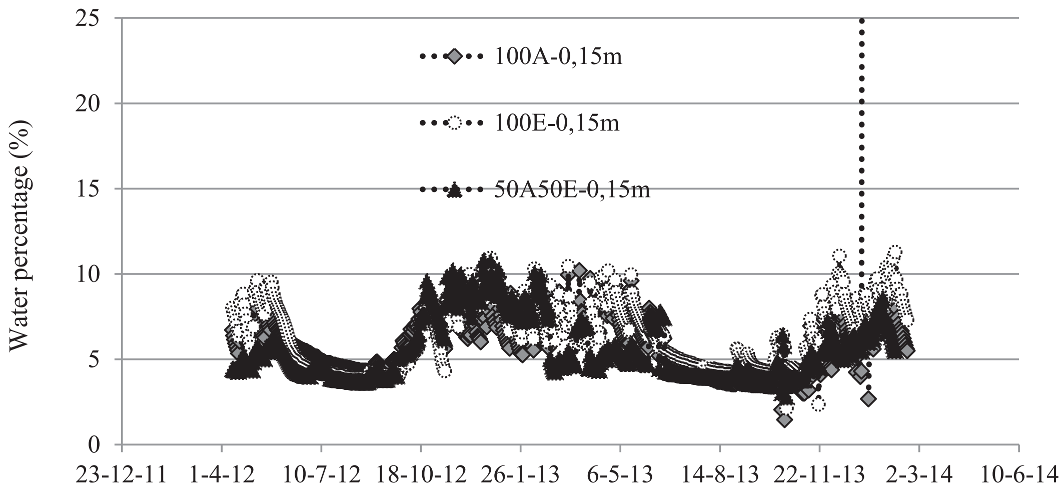

Figure 3. Soil water contents down to 0.015 cm depth under 100A, 100E and 50A50E.

Contenido de agua del suelo hasta una profundidad de 0,015 m bajo 100A, 100E y 50A50E.

llow followed by dark and brown stains on branches and stems. Around fifteen days later, the stem became black, followed by the drying up and death of the whole tree. The number of acacias impacted by the damage drastically increased during the subsequent five months, through August 2013.

Afterwards, branches were pruned up to 1.30 m, leaving the trees at a ground height around 4 m. Upper damaged branches were even pruned over 1.30 meters. After pruning, no sign of damage was further noticed and thereafter. The number and percentage of dead acacia trees in the pure acacia (100A) and 50 % acacia and 50 % eucalypt (50A50E) are reported in table 3. The biomass of wood, bark, leaves and branches of all stands at 12 and 24 months of plantation are presented in table 4.

Table 3. Number and percentage of dead acacia trees in the pure acacia (100A), 50 % acacia and 50 % eucalypt (50A50E) of the mixed-species stands in the Congolese coastal plains. Values in brackets are percentages. Total tree number in the stand =140.

Número y porcentaje de acacias muertas en los rodales de acacia pura (100A) y 50 % acacia y 50 % eucalipto (50A50E) en las llanuras costeras congoleñas. Los valores entre paréntesis son porcentajes. Número total de árboles en el rodsl = 140.

Blocks and stands	100A	50A50E
Block I	16 (11.4 %)	4 (2.9 %)
Block II	32 (22.9 %)	1 (0.7 %)
Block III	0 (0 %)	0 (0 %)
Block IV	1 (0.7 %)	3 (2.0 %)
Block V	0 (0 %)	1 (0.7 %)

Table 4. Biomass of wood, bark, leaves and branches at 12 and 24 months in the pure acacia (100A), eucalypt (100E) and mixed-species (50A50E) stands. There are means (± standard error) in five blocks. For each year and tree part, different letters indicate significant differences between stands (HSD-test of Turkey) and ANOVA at 5 % (*), 1 % (**) or 0.1 (***), (ns); adapted from Tchichelle (2016).

Biomasa de madera, corteza, hojas y rama a los 12 y 24 meses en rodales de acacia pura (100A), eucalipto (100E) y especies mixtas (50A50E). Medias (± error estándar) en cinco bloques. Para cada año y parte del árbol, diferentes letras indican diferencias significativas entre los rodales (prueba HSD de Turkey) y ANDEVA al 5 % (*), 1% (**) o 0,1 (***), (ns); adaptado de Tchichelle (2016).

Months	Component	Aboveground biomass (kg m^{-2})			
		100A	50A50E	100E	Significance
12	Wood	0.15 ± 0.01a	0.12 ± 0.02ab	0.08 ± 0.01b	**
	Bark	0.06 ± 0.00a	0.04 ± 0.01b	0.02 ± 0.00c	***
	Leaves	0.30 ± 0.01a	0.18 ± 0.02b	0.08 ± 0.00c	***
	Branch	0.20 ± 0.01a	0.14 ± 0.02b	0.08 ± 0.01c	***
	All	0.70 ± 0.04a	0.48 ± 0.05b	0.25 ± 0.02c	***
24	Wood	0.82 ± 0.08	0.99 ± 0.06	0.87 ± 0.09	ns
	Bark	0.23 ± 0.02	0.23 ± 0.01	0.18 ± 0.02	ns
	Leaves	0.67 ± 0.06a	0.54 ± 0.03a	0.19 ± 0.01b	***
	Branch	0.91 ± 0.08a	0.77 ± 0.05a	0.36 ± 0.07b	***
	All	2.63 ± 0.25a	2.54 ± 0.15a	1.60 ± 0.19b	**

DISCUSSION

Even though pruning acacia trees may sometimes contribute to fungi wound infection, careful pruning reduces this risk in young *A. mangium* plantations (Tarigan *et al.* 2011). Therefore, to stop the damage of acacia trees in the mixed species plantation with eucalypts located in the Congolese coastal plains and based on the findings of Beadle *et al.* (2007), it was decided to make the pruning of acacia trees in both 100A and mixed-species 50A50E stands, where the damaged trees have been first observed. After pruning, the damaged acacias performed better and no further damage was identified in any additional trees during the following weeks. This result confirmed the hypothesis i.e., acacia tree is less tolerant to drought conditions than are *E. urophilla x grandis* trees at the juvenile age of the second rotation of the mixed species plantation. It appears that the rain season, which began in October 2013, may have stabilized the outbreak of the acacia tree damage. It also appears that the damage of acacia tree was not due to any fungal pathogens as observed in other parts of the world (Maguias *et al.* 2011), as no additional outbreak has been observed after pruning.

It may be assumed that acacia tree damage, observed in the pure 100A and mixed-species 50A50E stands of the plantation, may have been due to the extended dry season occurring from May to September 2013 compared with the previous shorter 2012 season (July-September), which lasted only from June to September. The impact of drought on the young plantation can also be observed through the measured precipitation and soil water content to a depth of 0.15 meters (with the lower soil water content in the pure 100A and the higher in the pure eucalypt 100E). It is important to notice that the higher percentage of damaged acacia trees observed in the 100A stands at the juvenile age of mixed-species plantation located in the Congolese coastal plains (table 3) did not negatively impact the aboveground biomass. As a nitrogen fixing species, *A. mangium* did positively affect aboveground biomass as revealed by its higher estimated wood and bark biomass in 100A (0.15 kg m^{-2} and 0.06 kg m^{-2}, respectively) relative to 100E (0.08 kg m^{-2} and 0.02 kg m^{-2}, respectively) (table 4, Tchichelle 2016).

The drought may have triggered the damage of the acacia trees in the young plantation in the beginning of the second rotation, enhanced by the poor-nutrient status and coarse texture of soil. These observations are supported by Laclau et al. (2013) who found at the Itatinga Experimental Station, state of Sao Paulo in Brazil, that the pure *A. mangium* stand 100A developed a higher number of fine roots in the first two meters than those developed by the mixed species stand 50A50E. The shallow superficial root system may also explain why the *A. mangium* is prone to drought, which further involves tree damage in the juvenile age of acacia and eucalypt plantation at the second rotation. Fortunately, the damage of acacia trees occurred in the juvenile age of the plantation did not have a negative impact on the biomass of the wood, bark, leaves and branches (table 4).

CONCLUSIONS

Tree acacia damage due to an extended dry season, and enhanced by a shallow root system in a sandy soil, may be alleviated through gentle pruning. The observed acacia damage was more pronounced in the pure acacia (100A) and less in the mixed eucalypt stands (50A50E), and may suggest that *A. mangium* is less tolerant to drought conditions than are eucalypt trees in the juvenile age of the rotation. This damage of acacia trees occurred at the juvenile age of the mixed-species plantations of acacia and eucalypt, and did not have, however, a negative effect on aboveground biomass at 12 and 24 months. This observation is critical for the establishment of acacia plantations in the coastal plains of Congo and surrounding regions, where annual precipitation can be 750 mm lower than it is in their native ecosystem and the dry season may be longer. However, more elaborated studies must be conducted to confirm this observation.

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