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Nutrient cycling in a clonal stand of *Eucalyptus* and an adjacent savanna ecosystem in Congo 3. Input–output budgets and consequences for the sustainability of the plantations

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Abstract

Clonal plantations of *Eucalyptus* have been introduced since 1978 on savanna soils of the coastal plains of Congo. Atmospheric deposition, canopy exchange and transfer through the soil were estimated on the whole rooting depth (6 m) over 3 years, in an experimental design installed in a native savanna and an adjacent 6-year-old *Eucalyptus* plantation. Complementary measurements after planting the experimental savanna made it possible to establish input–output budgets of nutrients for the whole *Eucalyptus* rotation and to compare them with the native savanna ecosystem.

In this highly-weathered soil, atmospheric deposits and symbiotic N fixation by a legume species balanced the nutrient budgets in savanna, despite large losses during annual burnings. After afforestation, weeding in the *Eucalyptus* stands eliminated the leguminous species responsible for a N input by symbiotic fixation of about 20 kg ha^{-1} $year^{-1}$. Whereas the budgets of P, K, Ca and Mg were roughly balanced, the current silviculture led to a deficit of about 140 kg N ha^{-1} in the soil, throughout a 7-year rotation. This deficit was large relative to the pool of total N in the upper soil layer (0–50 cm), which was about 2 t ha^{-1}. Therefore, the sustainability of Congolese plantations will require an increase in N fertilizer inputs over successive rotations to balance the N budget. These results were consistent with field trials of fertilization. Practical consequences of these budgets were

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identified, in order to: (i) direct field trials of fertilization, (ii) select appropriate methods of soil preparation, weed control and harvest, (iii) highlight the importance of fire prevention in this area, and (iv) support the implementation of field trials aiming at introducing a biological nitrogen fixing understorey in *Eucalyptus* stands.

Keywords: *Eucalyptus*; Savanna; Biogeochemical cycles; Nutrient; Budgets; Sustainability; Congo

1. Introduction

Eucalyptus species have been planted extensively in tropical regions for a few decades and this genus is nowadays the most represented in tropical plantation forests (Nambiar and Brown, 1997). Owing to the replacement of great areas of native vegetation by monospecific *Eucalyptus* stands, the ecological impact of these plantations has been widely discussed around the world (Cossalter and Pye-Smith, 2003). Although most intensively-managed *Eucalyptus* plantations have been established on soils with low nutrient reserves, few studies quantify the effect of silvicultural practices using complete nutrient budgets, which can be considered as a reference method to assess the changes in forest soil fertility (Ranger and Turpault, 1999). Calculating such budgets requires quantifying the main nutrient fluxes and their variability associated with the development stage of stands and with the climate.

Several studies dealing with the ecological effects of *Eucalyptus* plantations have been carried out in Congo. The influence of afforestation in a native savanna on soil macrofauna was investigated (Mboukou-Kimbatsa et al., 1998), as well as changes with time in understorey floristic composition (Loumeto and Huttel, 1997), soil organic matter characteristics (Trouvé et al., 1994; Bernhard-Reversat et al., 2001), and nitrogen mineralization (Nzila et al., 2002). The biogeochemical cycles of nutrients have been compared in a clonal *Eucalyptus* stand and an adjacent savanna ecosystem over 3 years: modifications of the chemical composition of solutions throughout their transfer were investigated in the two ecosystems (Laclau et al., 2003a,b), as well as the dynamics of biomass and nutrient accumulation in the plants (Laclau et al., 2000, 2002).

The objective of the present study was to quantify the main input–output fluxes of water and nutrients in the soils of these two ecosystems, in order to calculate current nutrient budgets, as well as budgets for the whole *Eucalyptus* rotation. These budgets will make it possible to assess the effects of silvicultural practices on soil fertility and to formulate practical recommendations for foresters to maintain production of these commercial plantations, and to elaborate sustainable management practices.

2. Material and methods

2.1. Site characteristics

The ecological situation has been described previously (Laclau et al., 2003a). In brief, the study site is located on a plateau at an elevation of about 80 m and a distance from the sea of 10 km (4°S 12°E). The mean annual pluviometry over the last 50 years is 1200 mm, with a dry season between May and September, and the mean temperature is 25 °C with seasonal variations around 5 °C. The area is flat and the distance between the experimental designs in the *Eucalyptus* stand and the savanna is about 500 m.

The geological bedrock is composed of thick detritic formations of continental origin, dated from plio-pleistocene. The soils are ferralic arenosols (FAO classification), characterized by their homogeneity in the landscape in texture (sand content >85%), their great depth and their chemical poorness (Laclau et al., 2000).

2.2. Plant material

The *Eucalyptus* clone studied here comes from natural crosses in Congo between a few individuals of *Eucalyptus alba* Reinw. ex Blume (mother tree) and a group of poorly identified *Eucalyptus* hybrids (father tree). The stand was planted in January 1992 on savanna, at a stocking of 530 trees per hectare. It was 6 years old at the onset of the study, with a mean height