MODIFICATIONS OF THE BIOGEOCHEMICAL CYCLES OF NUTRIENTS IN SAVANNA AFTER AFFORESTATION WITH EUCALYPTS.

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INTRODUCTION

The genus ***Eucalyptus*** is nowadays the most represented in tropical plantation forests and cover approx. 15 millions ha. The replacement of large areas of native vegetation by monospecific eucalypt stands led to polemical discussions around the world about the ecological impact of these plantations (Cossalter & Pye-Smith, 2003). Many studies were carried out to quantify the water consumption of eucalypts at the tree and catchment levels (Whitehead & Beadle, 2004), as well as nutrient requirements by these plantations throughout the rotation (Grove et al., 1996). However, studies designed to gain insight into the global mineral functioning of the ecosystem and the effects of afforestation on water and nutrient fluxes throughout the development stages of eucalypt stands are scarce. Clonal plantations of eucalypts have been introduced for 30 years on savanna soils of the coastal plains of Congo. The biogeochemical cycles of nutrients have been compared in a clonal eucalypt stand and an adjacent savanna ecosystem (Laclau et al., 2005). The objective of the present paper was to provide an overview of the influence of afforestation with a eucalypt clone in an herbaceous savanna on the biogeochemical cycles of nutrients.

MATERIAL AND METHODS

The mean annual rainfall on the study site was 1200 mm, with a marked dry season, and the mean temperature was 25 °C, with low seasonal variations. The soils were Ferralic Arenosols, characterized by their textural homogeneity (sand content > 85 %), their great depth and their chemical poorness.

A lysimetry design was installed in a 6-year-old eucalypt stand (first rotation after afforestation) and an adjacent herbaceous savanna situated at 500 m apart on the same soil type. The graminaceae ***Loudetia arundinacea*** (Hochst.) Stend represented 80% of the total aerial biomass in the savanna, which reached about 5 t ha^{-1} of dry matter at the end of the rainy season. This savanna was burnt every dry season like most savannas in Congo. After 3 years of extensive monitoring of water and nutrient fluxes, the experimental savanna was planted with the same eucalypt clone and the fluxes were measured over 4 years after afforestation. The classical silviculture in Congo was applied: stocking of 530 trees per hectare, starter fertilization (150 g $plant^{-1}$ of NPK 13:13:21) and chemical weeding over the two first years after planting.

Atmospheric deposition of nutrients and throughfall were collected by funnels installed above the savanna and below the foliage in the native savanna and the eucalypt stands. Soil solutions were collected every week in both ecosystems by zero-tension lysimeters in the top soil and tension lysimeters on the whole rooting depth (6 m). Drainage fluxes at the depths where the lysimeters were installed were estimated from a mechanistic water transfer model (Hydrus 1D) calibrated from a TDR monitoring of soil water content down to a depth of 6 m over 7 years. Solutions were collected once a week, and after volume measurements and sampling, they were carried to the laboratory and kept at + 4 °C. Pooled volume weighted samples were made every 4 weeks for chemical analyses. Solutions were filtered (0.45 µm) and ionic balances were established. A complete description of the lysimetry design and the methods of calculation of the fluxes are given by Laclau et al. (2005). Measurements performed during seven successive years made it possible to quantify the nutrient and water fluxes in the native savanna and throughout the eucalypt rotation.

RESULTS AND DISCUSSION

The flux of deep drainage accounted for about 40% of the precipitation the first year after afforestation. For an annual rainfall of 1200 mm, corresponding to the long term mean in the region, the recharge of water table could be estimated to about 470 mm year^{-1} under savanna, 500 mm the first year after afforestation, then about 350 mm year^{-1} from age 2 years to the end of the rotation. A general characteristic of soil solutions collected in the eucalypt stands and the Guinean savanna was their exceptional poorness in solutes compared to most forest ecosystems in temperate regions. The low nutrient concentrations in drainage solutions show that silvicultural practices do not impair the quality of surface waters in that region. Little influence of *Eucalyptus* plantations on the chemistry of surface waters has also been reported in Brazil (Lima & Zakia, 2006). By contrast, comparisons of catchments in other pedo-climatic situations showed that eucalypt plantations can strongly reduce stream flow (Scott & Smith, 1997; Whitehead & Beadle, 2004).

The biogeochemical cycles of P, K, Ca and Mg were conservative in the two ecosystems. By contrast, the cycle of N was more opened in savanna, with losses of approx. 25 kg N ha^{-1} year^{-1} by volatilization during burnings. The main inputs of nutrients in savanna occurred through atmospheric deposition and biological nitrogen fixation by a leguminous species. After afforestation, weeding stopped the N_2 fixation but inputs of the other nutrients increased as a result of dry deposition of aerosols in the canopy. Internal nutrient cycling within the ecosystem also was deeply modified by afforestation. While ash production during burning and foliar leaching were the main processes of P, K, Ca and Mg return to the soil in the savanna (3-10 kg ha^{-1} year^{-1}), these fluxes were negligible after afforestation. By contrast in the plantation, 5-6 t ha^{-1} year^{-1} of litter fall led to an accumulation of large amounts of N, Ca and Mg quickly mineralized at the soil surface. Intense internal remobilization of nutrients within trees provided 30-50% of the total annual requirements of N, P and K from age 2 years. By contrast, tree growth was dependent on the availability of Ca and Mg in the soil throughout the whole rotation. Outputs of nutrients occurred mainly during the annual burnings in savanna and with biomass removal in the eucalypt stand. Losses by deep drainage were low in the two ecosystems, even during the early growth of eucalypts, owing to a fast root development.

The long-term sustainability of short rotation forests is greatly dependent on the reliability of fertilization practices, since atmospheric inputs and soil mineral weathering are unable to balance high nutrient outputs with biomass removal. Input-output budgets showed clearly in the present study that eucalypt plantations take advantage, during the first rotation after afforestation, of a N soil fertility inherited from the previous vegetation of savanna (Laclau et al., 2005). Unfavorable qualitative changes add further to the quantitative deficit of the N budget: savanna organic matter is progressively replaced by *Eucalyptus* organic matter poorer in N (Trouvé et al., 1994), and whose chemical composition (tannins, lignin, polyphenols) leads to a slower mineralization. For the other nutrients, the budgets were well balanced relative to the amounts of elements in the soil. This behavior was consistent with fertilizer field trials.

The high amounts of nutrients released during litter decay in these plantations also emphasize a quick adaptation of the biota present in this savanna soil to changes in OM characteristics, after introduction of this exotic species. Despite unfavourable chemical properties of *Eucalyptus* OM, the ability of soil biota to mineralise quickly the OM plays a basic role in the fast growth of the stands.

CONCLUSION

Eucalypts showed a remarkable strategy for using all the available resources in this nutrient poor environment, but by dint of a depletion of the N stock in the soil inherited from the previous savanna. Therefore, the sustainability of Congolese plantations will require an increase in N fertilizer inputs over successive rotations to balance the N budget. The influence of previous land uses on forest nutrition is an important point to look at in medium and long term research. The development of mixed-species plantations between eucalypts and leguminous tree species is a promising research issue to maintain the long term N availability in this soil, compensating by biological fixation a part of N outputs with biomass removal at the harvest.

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