*A partnership project on:*
*SITE MANAGEMENT AND PRODUCTIVITY IN TROPICAL FOREST PLANTATIONS*
*- Impact on soils and options for management over successive rotations -*

# STUDY OF THE SUSTAINABILITY OF EUCALYPTUS COMMERCIAL PLANTATIONS IN THE CONGO

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## I INTRODUCTION

Since 1978, 43,000 ha of plantations have been set up on the savannah around Pointe Noire. The vast majority are planted with hybrid clones of *Eucalyptus*. They have been found to be well suited to the conditions and, given an adequate silviculture of maintenance and fertilization, they perform well (20-25 $m^3$/ha/year). However, little is known about the durability of production concerning the nutrient needs of the plantations, nor about the effect this intensive culture has on the variation in soil fertility. This question is particularly relevant to the 25,000 ha on their second and third rotation and those planted on sandy, acidic and chemically very poor soil (Nzila, 1996). The sustainability of the plantations has therefore been identified as a priority for research.

## II SCOPE OF WORK

The sustainable management of an ecosystem should aim for a number of objectives. It should not only try to conserve the level of production, soil fertility and the biodiversity or quality of the surface water, but also to meet the economic and social needs of the inhabitants of the area (Near and Hornbeck, 1994 ; Olbrich *et al.*, 1997). In our case, the focus will be to attain a level of production as close as possible to the optimum for the climatic conditions, both today and in the long term (Manichon, 1996). This system must also lead to maximum profitability in the long term. It should use the most appropriate clones and optimize inputs and manpower. It is therefore necessary to understand and define some elements concerning production during a cycle and sustainable production.

*Production during a cycle*

Three points are apparent:

- The objectives of production in relation to potential production controlled by the climate (light energy and rainfall), taking into account the annual variability of these factors.
- The amount of nutritional factors needed to bring about these objectives, taking into account environmental inputs and losses.
- The conditions of the uptake of these factors and, thus, the installation mode of the root system in relation to implantation techniques (plantation, replantation,...).

Research work over the last 20 years has provided a number of results that are used (plantation spacing, fertilizing elements and doses,...).

*Sustainable Production*

Four points appear:

- The variation of water and nutrient resources and their sources in the medium and long term.
- The variation in the availability of water and nutrients.
- The consequences of these variations with regard to input needs.
- The consequences on the environment (fauna and flora, erosion,...).

Together, these different elements make the base for the research to be conducted on the sustainability of the production systems, *sensu stricto*.

## III SCIENTIFIC PROBLEMS

The research will be structured around a number of scientific problems.

1) The establishment of a production model on biomass potential.
It will be necessary to establish (perhaps by using groups of clones) a production model on biomass potential in relation to the climate (solar energy and pluviometry). It will also be possible to analyze the differences with this potential of the various production systems and to propose solutions (such as the use of fertilizers,...). Moreover, it should be possible to test the strength of the systems towards climatic variations. This is a medium-term objective (5 to 10 years).

2) A study on the nutrient cycle and the establishment of the water and mineral balances.
Most of the work in the next few years will concentrate on this problem. Further details follow in the fourth part of this article.

3) The dynamics and functioning of the root system.
In order to establish the water and mineral balances the root system has to be taken into account. Moreover, it is important to characterize it, in relation to the development of the above ground parts of the trees:

- The dynamics of implantation of the root system.
- The influence of age and silviculture (soil preparation,...) on the development of the root system and its functions source and sink for water and nutrients.

Initial work is already performed (Bouillet *et al.*, 1997) which will eventually lead to a report of the development of SR, on the whole soil volume prospected by roots (at least to a depth of 5 metres), at both the tree and plantation level.

4) The evolution of the biological components during the production cycle in relation to time and space.
It is important to report on the eventual changes that could be induced by the production system in the areas of the soil micro-fauna (termites, bacteria,...) and in phytopathology and climatology.

5) The management of the area heterogeneousness.
The management of the plantations has to take into account the heterogeneousness of both inter areas (clone and age) and intra areas (slash/unloading inter-rows,...). A need therefore exists for a diagnostic method and/or a mutli-criteria observation system showing early possible dysfunctioning of the plantations. For instance, foliar diagnostic could be very useful (Bonneau, 1995) and has been already developed for *Eucalyptus* plantations (Judd *et al.*, 1996; Herbert, 1996).

## IV STUDY ON THE NUTRIENT CYCLE AND ESTABLISHMENT OF WATER AND MINERAL BALANCES

The nutrient cycle can be simplified through a model of compartments and fluxes (Ranger, 1995) (Figures 1 and 2).

The study of this cycle can lead to an assessment of, for example, the inputs and outputs of exchangeable elements and for the different timetages (vegetation season, year, rotation,...).

*Previous Studies*

Some studies dealing with the nutrient cycle have been undertaken on the plantations.

- On the nitrogen cycle (Bernhard-Reversat, 1993, 1996). The soil under the *Eucalyptus* has a much higher potential for nitrogen mineralization than the soil under the savannah. This mineralization is essentialy ammoniacal.

- On the biomass and nutrient content of the plantations (Loumeto, 1986). These studies were mainly carried out on the allocation of nutrients following the compartments of a tree. The number of individual trees was very small (3). Moreover the clone studied is used very little on the plantations. No conclusions can be drawn from these studies on the nutrients exported during harvesting.

The existing studies are, therefore, fragmentary and only supply a few of the elements needed for the establishment of a mineral balance of the plantations.

*Current Studies*

From 1997 a study takes place on the nutrient cycle and the establishment of water and mineral balances on a planted crop *E.PFI*, clone 1-41. This clone has been planted the most (7,000 ha), is hardy and generally growths well. The initial vegetation was savannah. The station is moderately productive (» 20m$^3$/ha/year at the end of a rotation: 7 years)

The nutrient cycle study is inspired mainly by the steps followed by the research team of INRA/Champenoux (Ranger, 1995).

The work will consist of three parts.

1) **A description of the state of the ecosystem at both the beginning and the end of the planted crop rotation.**

A VEGETATION STUDY

- In 1997 a botanical inventory was carried out on the savannah and the planted crop.
- There was also in 1997, an estimation by sampling of the biomass and the nutrient content of the above ground parts of an 7 year-old stand (Laclau, 1997).
- The root system will be described and thus on the whole soil volume prospected. This operation has began in 1997 and will be carried out up to the year 2000. It will lead to:
  - An evaluation of the root biomass and nutrient content.
  - An identification of the preferred absorption zones of the roots and an estimation of the length of the absorbing roots.
  - An estimation of the biomass and nutrient content of the dead rootlets.

A SOIL STUDY

- Up to 1998 a characterization of the principal parameters of the physics of the soil will be carried out which will permit a determination on the available water and hydrodynamics characteristics of the soils (bulk density, actual density, field capacity, wilting point, soil water potential, ...) for the whole section prospected.
- The characterization of the mineral and organic stage will be performed up to 1998: total chemical composition and the nutrients availability (total analyses, free and exchangeable elements) on the whole section prospected and on the first metre of soil of the stand. Mineralogical analyses will be carried out on some soil samples.
- Analyses reporting on the micro flora and fauna will also be carried out.

2) **A study on the fluxes in the ecosystem.**

This study will lead to a better understanding of the dynamics, over a period of time, of the mineral and water functioning of the ecosystems being studied. A lasting field design (rain gauges, stemflow collars, lysimeters, ceramic cups, ...) was set-up in 1997.

A STUDY OF WATER FLUXES

- Between 1998 and 1999 the readily available water for the savannah and the planted crop will be estimated for saturated and stress conditions for each of the different layers prospected.
- Between 1998 and 1999 drainage equations outside the savannah and planted crop ecosystems will be established.

A STUDY ON THE FLUXES OF THE NUTRIENTS

- An evaluation of atmospheric deposits (rain and dust) and leaching will be made along with an evaluation on the transfer of nutrients in the soil by gravitational solutions to the limit of the ecosystem. The composition of capillary solutions following the soil layers will be studied. This work will cover the savannah and the planted crop.
- A qualitative and quantitative estimation of root absorption on the planted crop will be carried out.
- The fixation, symbiotic or otherwise, of atmospheric nitrogen will be conducted on the savannah and the planted crop.
- On the planted crop, the dynamics of the return of organic matter and nutrients by the litter will be examined through mineralization tests *in vitro* and *in situ*.

These four operations will be carried out between 1998 and end of the year 2000.

- In 1997 a study was made on the dynamics of biomass and nutrient content incorporation in plantations of various ages covering the whole rotation of the planted crop.
- A model of weathering flux will be in place by the end of the year 2000 for both the savannah and the planted crop.

3) **The establishment of the water and mineral balances. The consequences for the management of the plantations.**

These assessments will follow on from the preceding studies.

ESTABLISHMENT OF THE WATER BALANCE

This balance will allow to reach a conclusion on the use of water resources by the planted crop compared to that of the savannah.

ESTABLISHMENT OF MINERAL BALANCES

- Nutrient uptake
  The current uptake of nutrients can be evaluated according to the following equation: (1) Uptake = Immobilization + restitutions (litter fall + canopy leaching) (Ranger, 1995). We will be therefore able to estimate the nutrient needs of the planted crop during the rotation.

- Balance of the stock of nutrients.
  This balance is designed to provide information on whether or not the stock of nutrients is maintained between any two given dates (between the initial state of the savannah and the harvesting of the first rotation or during the rotation). It will also be possible to estimate the risk of uptake restrictions.

The estimation can be used globally, indirectly, by using the following equation: (2)
Stock variation = Atmospheric inputs + weathering + fertilization - drainage - biomass immobilization - variation in the leaf and rootlet mineral mass - the variation of elements in the organic layers (Ranger, 1995).

The estimation can be used directly according to the following equation: (3)
Stock variation for one layer = Inputs through gravitational solution from the upper layer - losses of

gravitational solution through drainage to the lower layer + the nutrient content of dead rootlets - root uptake of capillary solutions.
The total stock variation will be estimated by the sum of the variations calculated for each layer.

A comparison between the balances using equations (2) and (3) will provide a validation of the global approach, and a more detailed characterization on the sustained character of a system (an uptake limitation could become apparent at the level of one particular layer when there is no variation in global stock).

- The establishment of mineral inputs-outputs budget.
  This will allow to judge if the plantation management used is compatible with a sustainable maintenance of mineral fertility. The equation (4) to establish is :
  Budget = Atmospheric inputs + weathering + fertilization - nutrient exported through harvesting - drainage (Ranger, 1995).

By the year 2000 the commercial plantations managers will have objective elements with which to judge which interventions it is necessary to use (lime, tillage, cover crops,...) on part of the plantations.

## V THE CIFOR EXPERIMENT

The work must extend to the second rotation (coppice and plantation), to the stations of different fertility, to other clones, to other hybrids and in particular, to the *E. urophylla*grandis* which will have increasing importance in the next future.

Differents experiments will be therefore conducted in the coming years, in particular the CIFOR project which will focus on the impact of soil and site management practices on the long term productivity.

The links which exist between these differents experiments are shown in figure 3.

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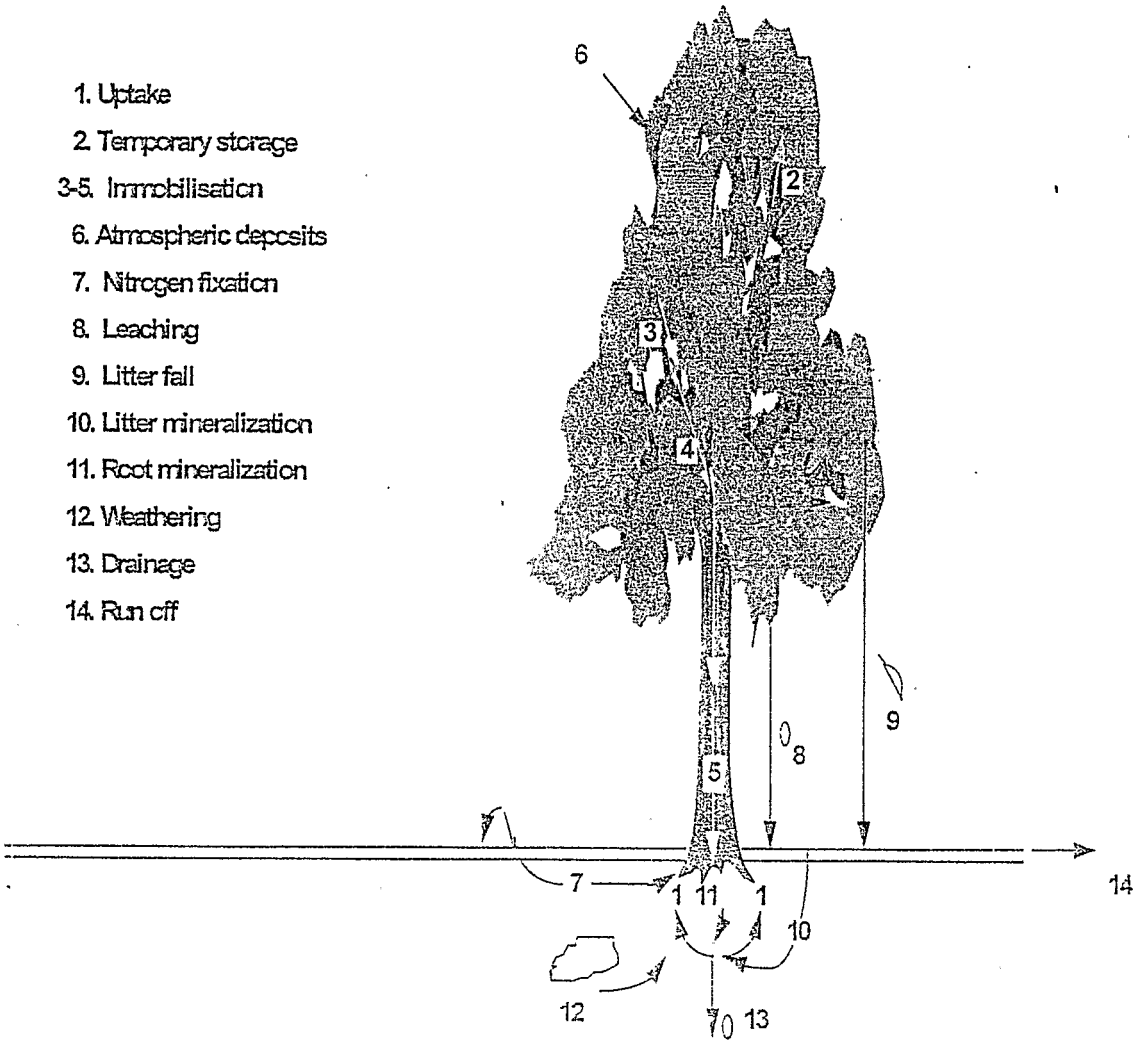



Figure 1: Representation of the different fluxes in the ecosystem

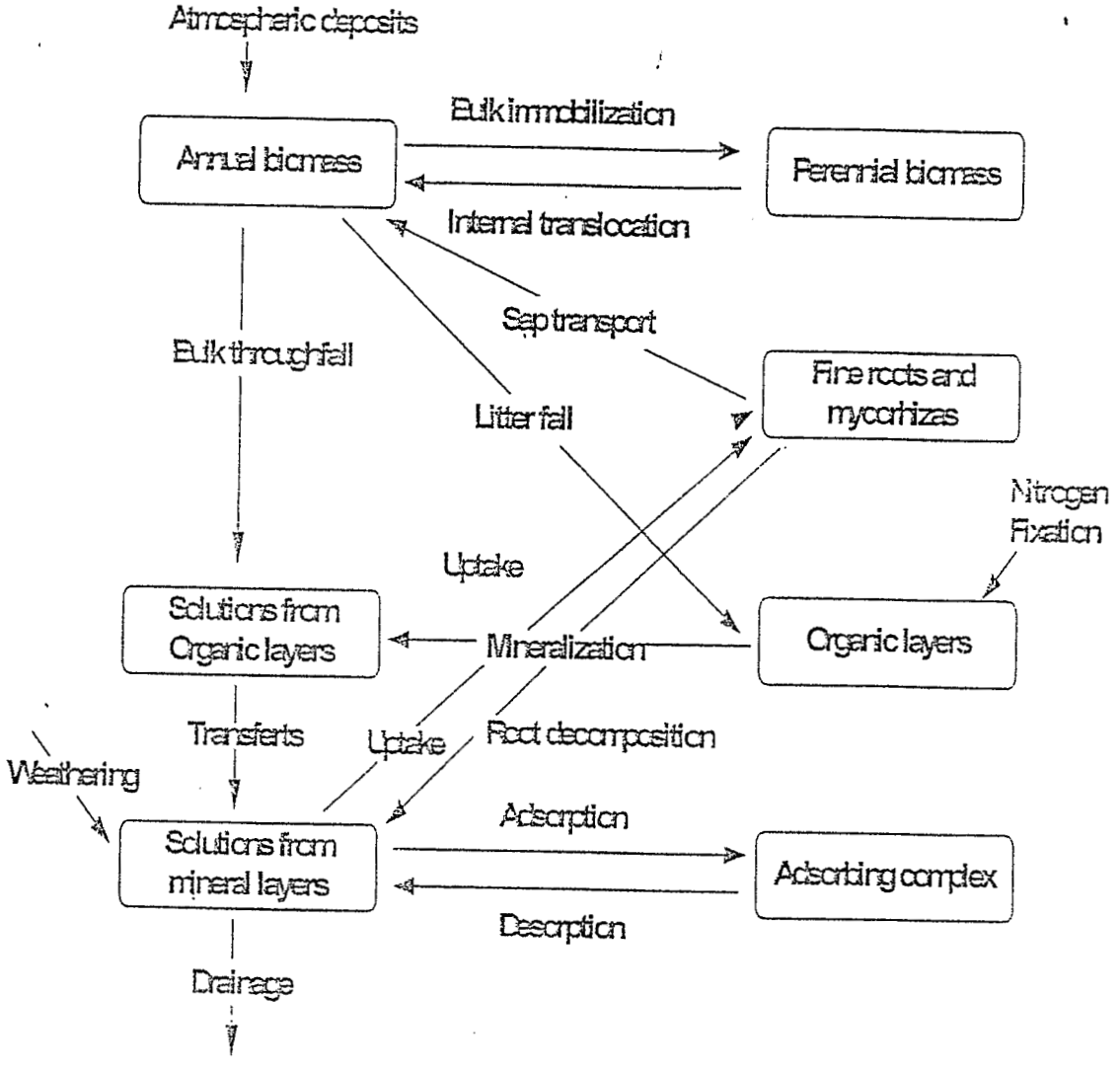
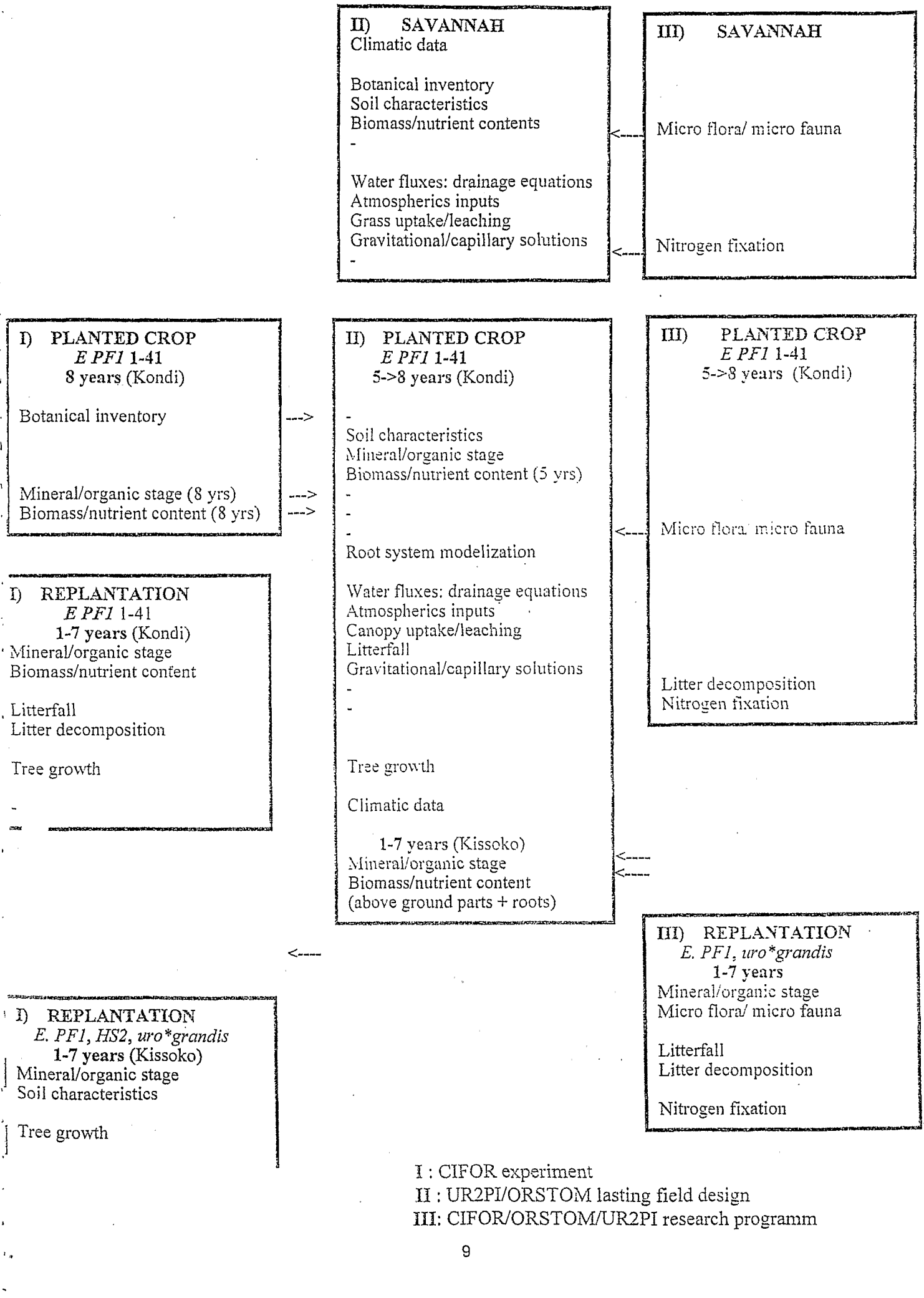



Figure 2: Representation of the functions of the forest ecosystems by a compartment and flux model (from Ranger, 1995).

Figure 3 : Links between the experiments on the sustainability of the plantations.




I : CIFOR experiment
II : UR2PI/ORSTOM lasting field design
III: CIFOR/ORSTOM/UR2PI research programm

# FICHE DE MISSION

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Pays visités:.....Afrique du Sud

Durée et date:.....8 jours (mission prise en charge par l'organisateur)

.....du 16 au 24 février 1998

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Missionnaire:

Nom, Prénom, Grade:.....NIZINSKI Georges, Chargé de Recherche 1

Département, G.P.:.....Ressources et Environnement
.....Forêts (GP42)

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**Objet de la mission:**

1) participation à l'atelier CIFOR « *Site management and productivity in tropical plantations: Impact on soils and options for management over successive rotations* »; Pietermaritzburg, Institute for Commercial Forestry Research; j'y ai présenté mon travail du Congo

2) collaboration scientifique avec Peter DYE de Division of Water, Environment and Forest Technology, University of Natal, Scottsville, Afrique du Sud.

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Ma mission en Afrique du Sud avait deux objectifs: 1[er]) participer à l'atelier de Center for International Forestry Research (CIFOR)[1] et 2[ème]) établir une collaboration scientifique avec Peter DYE dans le cadre du programme que je mene actuellement au Congo.

# A) Atelier de Center for International Forestry Research

## 1. Introduction

J'ai participé à l'atelier « *Site management and productivity in tropical plantations: Impact on soils and options for management over successive rotations* » organisé par Institute for Commercial Forestry Research[2]. Le congrés a eu lieu du 16 au 20 février 1998 à Pietermaritzburg en Afrique du Sud (Annexe n°1) sous le patronnage du Center for International Forestry Research (CIFOR)[3].

Cet atelier a permis à la communauté scientifique travaillant sur des plantations d'arbres à croissance rapide (Eucalyptus, Pin, Acacias) en zone tropicale d'entrer en contact avec les représentants de programmes d'actions menées au niveau national, et de définir des méthodes et des cadres appropriés pour un travail en commun. Dans l'Annexe n°4 les problématiques scientifiques sont développées.

De nombreuses spécialités étaient représentées: hydrologie, écophysiologie, bioclimatologie, foresterie, nutrition minérale, génétique; 26 scientifiques[4] de 11 pays tropicaux y participaient (Annexe n°2); 18 contributions ont été exposées (Annexe n°3).

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[2] lieu du congrés: Institute for Commercial Forestry Research, University of Natal, Scottsville 3209, Box 100281, Afrique du Sud, téléphone: 27-331-62-314; fax: 27-331-68-905

[3] comitée d'organisation du congrés: Christian COSSALTER (CIFOR, Indonésie), Peter J.T. ROBERTS (ICFR, Afrique du Sud) et Sadanandan E.K. NAMBIAR (CSIRO, Australie).

[4] la liste et les adresses des participants se trouve dans l'Annexe n°2

J'y ai présenté mon travail du Congo: deux communications, l'une intitulée « Effects of afforestation on soil water balance: Eucalyptus plantation in the Kouilou Basin » et l'autre « Study of the sustainability of Eucalyptus commercial plantations in the Congo » (Annexe n°5); ces communications ont été présentées avec les chercheurs de CIRAD-Forêt/U.R.2P.I. de Pointe Noire (Jean-Pierre BOUILLET et Jean de Dieu NZILA) et de l'INRA de Nancy (Jacques RANGER).

## 2.Déroulement de l'atelier

L'Atelier s'est déroulé selon le programme qui est présenté dans l'Annexe n°1; il y avait six sessions pléniaires consacrées aux résultats des recherches des sites d'études CIFOR et aux propositions d'élargissement du programme CIFOR à de nouveaux partenaires . On a abordé des aspects pratiques de fonctionnement du CIFOR: échanges d'informations, propriété des résultats des recherches, politique des publications, organisation du réseau CIFOR, nouveaux sites et perspectives de développement du réseau CIFOR. Le dernier jour a été destiné à la visite sur le terrain (Natal Midlands ) d'une station d'essais de fertilisation en pépinière d'Eucalyptus et d'une station d'étude de la compaction des sols sous plantation d'Eucalyptus.

## 3. Résultats du congrés

* Les résultats du congrés (18 contributions) sont présentés sous forme de comptes rendus édités par Christian COSSALTER, Sadanandan E.K. NAMBIAR et John TURNBULL. Je joins au rapport la table de matières de ces comptes rendus (Annexe n°3) - je les tiens à la disposition de tous les chercheurs interessés.

* Ce congrés m'a permis de suivre les mises au point sur des travaux récents en forestrie (hydrologie forestière, écophysiologie des arbres à croissance rapide, nutrition minérale) en zone tropicale (Afrique du Sud, Australie, Brésil, Chine, Congo, Etats-Unis, France, Inde, Indonésie, Madagascar, Royaume Uni).

* contribution de l'ORSTOM: j'y ai présenté mon travail du Congo - deux communications; ces communications ont été présentées avec les chercheurs de