THE SUSTAINABILITY OF *Eucalyptus* COMMERCIAL PLANTATIONS : THE CONGOLESE APPROACH

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SUMMARY

It is essential that congolese research should be carried out on the fundamental problem of the sustainability of the commercial Eucalyptus plantations in the Kouilou area. This article first presents a scope of work and then examines the scientific questions arising from it. It goes on to develop a methodological approach and a projected schedule relating to a study on the biogeochemical cycles and the establishment of water and mineral balances.
Key words: commercial plantations, sustainability, biogeochimical cycle, water balance, mineral balance, *Eucalyptus*, Congo.

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* (*E.PF1* and *E.12 ABL*saligna*). 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 20,000 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 by UR2PI as a priority for research. UR2PI is an association created with The Congo, CIRAD and ECO SA which has a mandate to carry out and coordinate research on the plantations.

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 (BARTHOD, 1994).

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 define and understand 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 variabilities 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) but work has already started on a project developed by ORSTOM (NIZINSKI, 1995).

2) A study on the biogeochemical 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).

IV. STUDY ON THE BIOGEOCHEMICAL CYCLE AND ESTABLISHMENT OF WATER AND MINERAL BALANCES

The nutrient cycle can be simplified through a model of compartments and fluxes (RANGER and BONNEAU, 1984) (Figure 1). The study of this cycle can lead to an assessment of, for example, the inputs and outputs of exchangeable elements and for the different time stages (vegetation season, year, rotation,...).

Previous Studies

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

- On the nitrogen cycle (BERNHARD -REVERSAT, 1993, 1996 ; BERNHARD -REVERSAT et al., 1993). The soil under the *Eucalyptus* has a much higher potential for nitrogen mineralization than the soil under the savannah or Acacia. This mineralization is essentialy ammoniacal, the nitrification being negligible.
- On the biomass and nutrient content of the plantations (LOUBELO, 1988 ; LOUMETO,

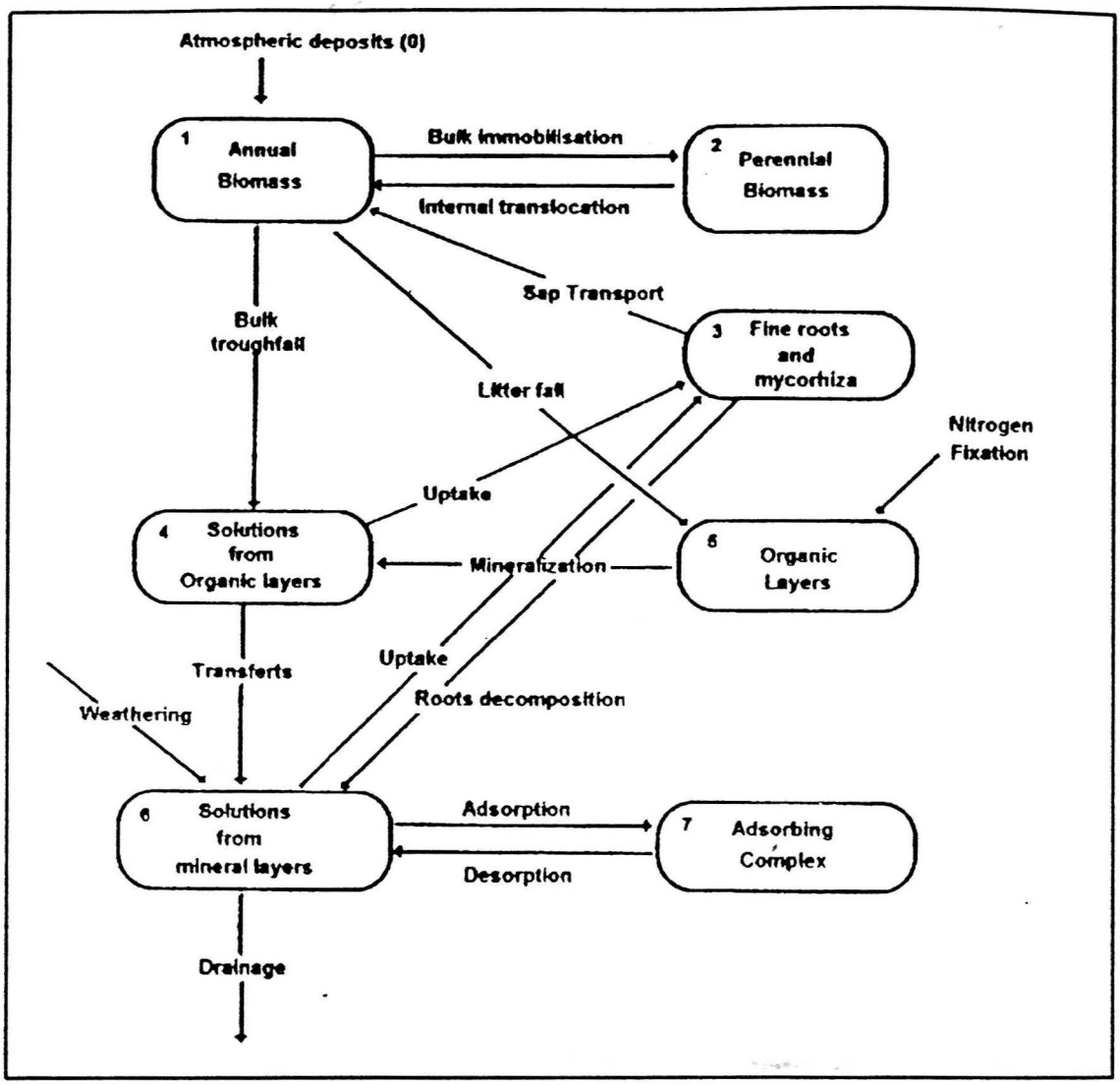

FIGURE 1. Representation of the functions of the forest ecosystems by a compartment and flux model (from RANGER), 1995)

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.

Anticipated Studies

Between 1997 and the end of 2000 a study will take 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 (≈ 20m³/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 water balance is to be carried out by a team from ORSTOM/Pointe Noire (NIZINSKI, 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 will be carried out on the savannah and the planted crop.

• There will also be in 1997, an estimation by sampling of the biomass and the nutrient content of the above ground parts (the trunk, branches and leaves) of an 8 year-old stand.

• The root system will be described and thus on the whole soil volume prospected. It is projected that this operation will be spread over a number of years between 1997 and the year 2000 and 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

• Between 1997 and 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.

• 1997-1998 will see the characterization of the mineral and organic stage: 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) <u>A study on the fluxes in the ecosystem</u>

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. It will necessite the set-up of a lasting field design (rain gauges, lysimeters,...).

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.

• During 1997 and 1998 a study will be 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) <u>The establishment of the water and mineral balances. The consequences for the management of the plantations.</u>

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

• A 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: (1)

Stock variation = atmospheric inputs + weathering + fertilization - drainage - immobilization in the wood - variation in the leaf and rootlet mineral mass - the variation of elements in the organic layers (RANGER, 1995).

The estimation can be used directly using the following equation: (2)

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 (1) and (2) will provide:

- a validation of the global approach,
- 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 system of culture being used is compatible with a sustainable maintenance of mineral fertility. The equation to establish is : budget = atmospheric inputs + weathering + fertilization - nutrient exported through harvesting - drainage (RANGER, 1995).

V. CONCLUSION

The study on the sustainability of forest plantations is obviously becoming an increasingly important theme in research. This problem is particularly acute for tropical countries or those plantations using fast growing species, such as the *Eucalyptus*, which are often planted in very poor soils. This huge area of research calls for the collaboration of different disciplines (silviculture, agronomy, pedology, ecophysiology,...) and the collaboration of countries (north and south). Thus, there is a particular interest for networks (CIFOR,...).

As far as The Congo is concerned the first steps will focus on the biogeochemical study. This will lead to the establishment of the water and mineral balances on the planted crop of a clone which is used the most on the plantations. 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.

The work from this study will 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 coming years.

V. MEANING OF THE ACRONYMS

CIFOR: Center for International Forestry Research.

CIRAD: Centre de Coopération Internationale en Recherche Agronomique pour le Développement.

ECO SA: Eucalyptus du Congo Société Anonyme.

ORSTOM: Institut Français de Recherche Scientifique pour le Développement en Coopération.

UR2PI: Unité de Recherche sur la Productivité des Plantations Industrielles

VI. REFERENCES

BARTHOD C, 1994. Idées de nature et politique de l'Environnement: La forêt. La conférence d'Helsinki. Association des Ingénieurs de l'ENGREF, Bulletin N° 35, p.15-19.

BERNHARD-REVERSAT F, 1993. Dynamic of litter and organic matter at the soil-litter interface in fast-growing tree plantation on sandy ferralitic soils (Congo). Acta Oecol., 14: p.179-195.

BERNHARD-REVERSAT F, 1996. Nitrogen cycling in tree plantations grown on a poor sandy savanna soil in Congo. Applied Soil Ecology, 4: p.161-172.

BERNHARD-REVERSAT F, DIANGANA D, TSATSA M, 1993. Biomasse, minéralomasse et productivité en plantation d'Acacia mangium et Acacia auriculiformis au congo. Bois et Forêts des Tropiques, 238: p. 35-44.

BONNEAU M, 1995. Fertilisation des forêts dans les pays tempérés. ENGREF Nancy. Nancy, 367p.

BOUILLET JP, OGNOUABI N, BAR-HEN A, 1997. Influence du mode de préparation du sol et des entretiens sur le développement racinaire d'eucalyptus hybride au Congo. Paper submitted to IUFRO meeting, "Silviculture and genetic improvement of *Eucalyptus*" Salvador, Bahia, Brazil, August 1997.

LOUBELO E, 1990. Etude comparative de quelques éléments du fonctionnement de deux peuplements d'*Eucalyptus* au Congo. Thèse de Doctorat en Sciences Biologiques, Université de Rennes, 150p.

LOUMETO JJ, 1986. Contribution à l'étude de la distribution minérale dans les *Eucalyptus* du Congo. Thèse de Doctorat de troisième cycle en Sciences de la Vie et de l'Environnement, Université de Rennes, 133 p.

MANICHON H, 1996. Les approches de la fertilité du sol: quelques éléments de discussion. Atelier: les indicateurs de diagnostic et de suivi des problèmes de fertilité. Atelier sur la fertilité des sols en zone tropicale humide, CIRAD (AGER), 13-17 novembtre 1995, Montpellier, France, 8p.

NIZINSKI G, 1995. Impact du reboisement sur les caractéristiques bioclimatiques de l'écosystème du littoral congolais: analyse des échanges d'énergie et de masse (H2O, CO2) entre savane, plantation et atmosphère. Projet de Recherche ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération), 14p.

NZILA JD, 1996. Principales caractéristiques des sols des reboisements dans la région de Pointe-Noire - revue bibliographique. Pointe-Noire, UR2PI, Note interne, 15p.

RANGER J, 1995. Le cycle biogéochimique des éléments nutritifs dans les écosystèmes forestiers. INRA, note interne, 108p.

RANGER J, BONNEAU M, 1984. Effets prévisibles de l'intensification de la production et des récoltes sur la fertilité des sols de forêts. Le cycle biologique en forêt. Revue Forestière Française, vol XXXVIII, 2, p. 93-111.