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|---|---|
| **Acronyme** | **Intens&Fix** |
| **Titre du projet en français** | **Intensification écologique des écosystèmes de plantations forestières. Modélisation biophysique et évaluation socio-économique de l'association d'espèces fixatrices d'azote.** |
| **Titre du projet en anglais** | *Ecological intensification of plantation forest ecosystems. Biophysical modeling and socio-economical assessment of associated nitrogen fixing species.* |
| **Axe(s) thématique(s)** | **X** 1 X 2 ☐ 3 ☐ 4 |
| **Type de recherche** | ☐ Recherche Fondamentale<br>☐ Recherche Industrielle<br>**X** Développement Expérimental |

| | | | |
|---|---|---|---|
| **Aide totale demandée** | 996612 € | **Durée du projet** | 48 mois |

# 1. CONTEXTE ET POSITIONNEMENT DU PROJET

A global **increase** in the **demand for wood products** has been observed worldwide during the last decades. This trend is expected to continue in the future as a consequence of population growth. Additionally, the need for wood is augmented by the increasing substitution of fossil energy by wood biomass-based energy to mitigate greenhouse gas emissions. This demand will not be satisfied by natural and naturally regenerated forests: they are threatened by high deforestation rates and forest degradation mainly in the tropics and the costs of wood mobilization in the temperate zones is a concern. **Forest plantations (FP)** are therefore expected to provide a large part of the global wood supply. Their ability to meet wood demand is limited by competing land uses. **Higher stand yields** must be obtained on soils that may not necessarily support such intensification, especially as **nitrogen** (N) and **phosphorus** (P) exportations by biomass removal are generally not offset by fertilization. Therefore, FP sustainability is currently a major concern, particularly with regard to serious long-term N and P deficits. Innovative FP management schemes, and **attractive** to the **stakeholders** must be then deployed.

The Intens&Fix project will deal with the **ecological** intensification of FP through the association of $N_2$-fixing species (NFS) with the goal to increase stand production as, in particular, a result of better N and P availability in the soil. While numerous results have been produced on the associations of species in annual cropping systems, comprehensive assessments of ecological interactions in **mixed species FP** are lacking. The project will propose innovative **alternatives** to **FP monocultures** (mixtures of non-fixing trees with fixing trees or fixing herbaceous species). These techniques should provide a **high** and **sustainable level** of **wood** production with reduced chemical fertilizer applications.They should combine **positive environmental impacts** while ensuring **social-economical improvement** of **livelihood** for **smallholders** or **performances** for commercial companies. The project will develop an experimental approach on 3 FP schemes on 4 sites selected in France and in the tropics (Brazil, Congo) to cover an appropriate **range** of **ecological conditions**, **NFS types** and silvicultural **practices**, as well as **technical** and **socio-economic issues** that may arise in FP combined with NFS. An integrated **biophysical model** will be developed for the simulation of mixed species in FP. Outputs of virtual experiments performed with the biophysical model will feed a **plantation-level model** allowing to assess the **economical feasibility** and to test decision rules for the management of FP with NFS. Crossing models outputs and a survey of stakeholders' **innovation process** concerning the use of NFS will entitle us to assess the potential development of these systems. The approach will be multidisciplinary and involve scientists working in ecophysiology, biogeochemistry, soil science, microbiology, silviculture, socio-economics, and modelling.

## 1.1. CONTEXTE ET ENJEUX ECONOMIQUES ET SOCIETAUX

For several decades a **continuous increase in the demand of ligneous products** has been observed worldwide. From 1980 to 2005 the world production of industrial roundwood and fuelwood increased from 1450 to 1710 million $m^3$ $yr^{-1}$ and from 1530 to 1840 million $m^3$ $yr^{-1}$, respectively. Wood pulp production increased from 125 million tons in 1980 to 175 millions tons in 2005 (http://www.fao.org). A sharp increase in eucalypt pulp occurred from 2 million tons in 1980 to 11 millions tons in 2005, and the demand should reach 18 million tons in 2010 (http://www.bracelpa.org.br). In France the trend is the same (Figure 1), with **significant quantities imported** for some commodities (up to 50% for wood pulp).

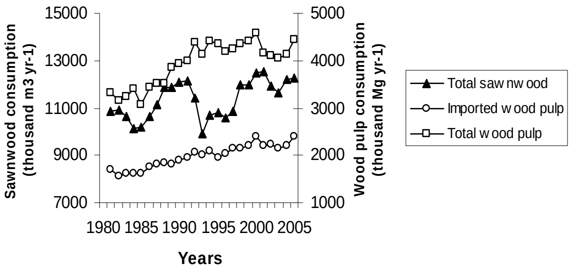


***Figure 1.*** *Changes from 1980 to 2005 in sawnwood and wood pulp consumption in France (statistics from http://faostat.fao.org)*

Wood material comes from: i) **Natural forests** (Russia, Canada, Brazil, South-East Asia…) with the risks of irreversible degradation (the current rate of world deforestation is estimated to be around 13 million hectares per year (http://www.fao.org/forestry)), ii) **Forests regenerated naturally** after harvesting, and iii) **Forest plantations** and multi-services agroforestry systems (AFS).

The overall **area** of **FP increased** dramatically during the last decades to reach 205 million ha in 2005 (Figure 2) with an increasing rate of about 2.8 million hectares planted per year during the 2000-2005 period (FAO, 2005). Even if the area covered by FP is still limited, **these ecosystems** play a **crucial role** in **providing wood material**. The Millenium Ecosystem Assessment (2005) stressed that "*…in 2000 plantation forests were 5% of global forest cover but they provided **some 33% of harvested roundwood**, an amount anticipated to increase to 44% by 2020*".

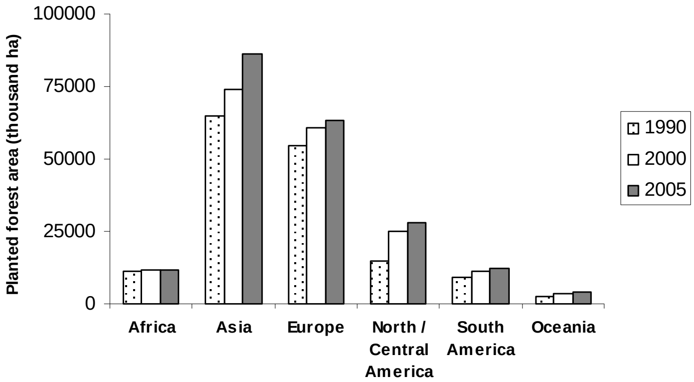


**Figure 2.** *Changes in plantation area in the world from 1990 to 2005 (statistics from FAO, 2005)*

The FP characteristics vary according to species, rotation length, markets and ownership (FAO, 2005) (Table 1).

**Table 1** Average characteristics of some European and sub-tropical and tropical FP

| Location | Species | Rotation length | Main market | Main owner type |
|---|---|---|---|---|
| Europe | *Populus sp.* | 20-25 years | Peeling | Small/medium scale owners |
| Europe | *Juglans sp., Prunus sp., Fraxinus sp…* | 30-50 years | High value timber | Farmers<br>Small/medium scale owners |
| Europe[1] | *Populus sp., Salix sp.…*<br>(Very Short Rotation Coppice) | 4-8 years | Energy | Farmers |
| Europe[2] | *Eucalyptus sp.* | 9-12 years | Pulp | Big companies<br>Medium scale owners |
| Sub-Tropics<br>Tropics[3] | *Eucalyptus sp.* | 6-8 years | Pulp, Board<br>Energy | Big companies<br>Small/medium scale owners |

[1] Scandinavia, Great Britain, Italy.… [2] Portugal, Spain…[3] South-America (**Brazil**, Argentina,...), Equatorial Africa (**Congo**, Angola), South Africa, Madagascar, India, Indonesia, China, Australia..

- In **Europe**, **broadleaf FP** produce wood for peeling (*Poplar sp.*), pulp (*Eucalyptus sp.*) but also high value timber used for veneer and top-of-the-range furniture (*Juglans sp.*, *Prunus sp, Alnus sp.…*). Only a small part of the **French** broadleaf FP is nowadays devoted to **fuelwood production** but Very Short Rotations Coppices - VSRC - (*Populus sp.*, *Salix sp.*, *Eucalyptus sp.*,..) are likely to rapidly expand to face the increasing demand in bioenergy (Ginesty et al., 2007; Wartelle and Dreyfus, 2010). In **France** FP belong mainly to private small- (< 5ha) to medium-scale owners (< 100 ha), and farmers provide also forest products through FP established on farm land and AFS (www.agroforesterie.fr)**.**

**- Sub-tropical** and **tropical FP** are dominated by *Eucalyptus* (FAO, 2005) that provide mainly raw material for pulp and particle boards, but also firewood: half of the domestic energy of Antananarivo (Madagascar) or Pointe-Noire (Congo) comes from the eucalypt plantations established around these towns (Bertrand 1999; Nkoua, 2008). The tropical *Eucalyptus* FP are partly managed by large scale commercial companies (Brazil, China, Indonesia, Congo, South Africa), and by small- and -medium-scale owners who account for 50% of the FP areas in Brazil (http://www.ambientebrasil.com.br).

Owing to the increase in the human population and the need for arable lands, FP are ever more **located on fragile** and/or **poor soils**, and their expansion under tropics is limited by conflicts with local populations (Cossalter and Pye Smith, 2003) as observed in South Africa (http://www.polity.org.za), in Indonesia (Sunderlin and Resosurdarmo, 1996), or in Brazil (http://www.natbrasil.org.br/monocultura). In France and more generally in Europe the **increasing demand** for **crop products** (for human and livestock nutrition, energy…) may also **limit the expansion** of **FP**: it can be observed that about 30% of the global FP area for productive purposes in 2005 was in Europe (63 millions ha) but, as illustrated in Figure 2, the rate of increase slowed down in the most recent period (+1.1% per year between 1990 and 2000, and 0.7% per year between 2000 and 2005). **In France,** this rate was **much lower** than the rest of Europe (+ 0.25 % per year between 1990 and 2005).

A **sustainable increase** in **production** per unit area of managed tree stands **is** then **needed** to **face** the **market** demand in the medium and long terms. A special attention must be paid to FP nutrient requirements, especially for **N** and **P** that are both **major limiting factors** of **forest tree growth** in Europe and in the tropics (Bonneau, 1995; Bridges et al., 1997; Cobo et al., 2010). **Additional N** and **P inputs** are then **required** to ensure sustainable production for many FP. But the use in FP of N and P fertilisers will be limited because they are **expensive** (≈ 400-800 € $Mg^{-1}$ in 2009) with raising costs: a four and sixfold increase has been noticed during the last decade for urea and triple super phosphate, respectively (http://siteresources.worldbank. org).

Moreover the world reserves of **high grade phosphate** ores are expected to be **exhausted** within about 90 years at the current rate of consumption of P fertilisers (Stewart et al. 2005) and large amounts of **fossil-based energy** are used and **$CO_2$ emitted**, during manufacturing fertilisers and transportation to the field (Gellings and Parmenter, 2004). From a general view point the increase in FP production must be reached while preserving natural resources. Various international conferences [Rio de Janeiro (1992), Kyoto (1996)…] refined the principles supporting sustainable development and the **role of FP** has been recognized as particularly **important**. The statement of principles for the sustainable management of forests adopted in Rio de Janeiro underlined that « *the role of planted forests… as sustainable and environmentally sound sources of renewable energy and industrial raw material should be **recognized, enhanced** and **promoted…*** ». Moreover FP and AFS can play a significant role in atmospheric $CO_2$ sequestration as well as in climate change mitigation. These roles have been considered in the Kyoto protocol as FP are eligible to the Clean Development Mechanism due to their production of renewable energies (UNFCCC, 2002). The special attention to be paid to the **environmental** functions and services of the forest ecosystems is largely shared by the civil society as in France where the **Grenelle Round Table** defined the key points of government policy on ecological and sustainable development issues for the 2007-2012 period, and **in Europe** with various EU directives (relatives to water, nitrate contamination …) and politics (Greenhouse Gas Reduction…), but also in **tropical countries** as in Brasil where the impact of FP, and especially of eucalyptus plantations, is still controversial (Vital, 2007).

An **ecological intensification** of FP is thus strongly **needed** and implies **dramatic changes** in silvicultural practices. A promising way is to **add NFS** to the **monoculture**, as these mixed-species plantations may both increase stand production and lead to positive environmental impacts, such as enhancement of soil fertility or C sequestration (Dupraz and Liagre, 2008; Forrester et al., 2006). Such mixed-species associations may be observed in France with *Juglans* or *Prunus* tree species intercropped with perennial *Medicago sativa* or *Onobrychis* fodder crops (Balandier and Dupraz, 1998). In Europe mixed tree plantations rarely include Nitrogen Fixing Trees (NFT) as these species are very uncommon (Becquey, 2008). The only native NFT used in European tree plantations are *Alnus* species. Some mixtures with the Northern American species *Robinia pseudacacia* have also been tested. Other examples include *Lupinus sp.* or *Lotus sp.* broadcasted in *Pinus radiata* plantations in New Zealand and Australia (West et al, 1991), or in some tropical countries, like Australia or Brazil where mixtures of *Acacia sp.* and *Eucalyptus sp.* have been tested (Bouillet et al., 2008; Forrester et al., 2006), Madagascar with spreading of A. *dealbata* in *E. robusta* coppices (Sutter, 1990) or India where *E. teriticornis* has been associated with *Pueraria sp.* and *Stilosanthes guianensis* (Sankaran et al., 2008).

But despite their potential interests the **mixed-species FP** with NFS are **scarce** (Forrester et al., 2006; Nichols et al., 2006). Analyses must be then performed in comparison with monospecific FP to account for the technical constraints of such associations (stand management, harvesting…), their profitability (costs, market…), and more generally for the factors that can lead to limit or promote the stakeholder innovating process to use NFS.

## 1.2. POSITIONNEMENT DU PROJET

The Intens&Fix project will be deeply **complementary** of topical initiatives and projects aiming at the **ecological intensification** of agro-ecosystems, both in **France** and at the **international** level.

**OBJECTIF TERRE 2020** is the latest **French** governmental scheme (released February 2009) for transforming the French agriculture and forestry sector. It includes 60 practical targets. Many of them will be addressed by the Intens&Fix project, such as: **promote** low input agro-ecosystems by the **use** of **N-fixing species** (Action 5); promote forest plantation in the form of agroforestry systems (Action 15); increase the energy production by forests (Action 25); increase the certification of forest (Action 39). **Intens&Fix** will be the **first project** to **address** the **value** of **NFS** in **forests plantation** ecosystems, but will draw on several former research projects on mixed species forests ecosystems:

- ✓ A project on mixed-species forests has been funded by the **ECCO-ECOGER program** (2005-2008). The ecosystems studied were associations of beech trees with pine, fir, or maple trees. The project focused on water consumption, light assimilation and carbon partitioning in young trees, and simulation of tree and stand growth on the whole rotation, accounting for silvicultural practices. However **mixed-species forests** with **NFS** ecophysiological processes, and nutrient cycles were **not studied** in this project,
- ✓ The current **French national programme** on **AFS** (2007-2010) focuses on **mixed-species FP** with intercrops, but do not explore the use of NFS in FP. This programme is led by **APCA** (Assemblée Permanente des Chambres d'Agriculture) and is scientifically managed by UMR-System, partner of our project. This programme may be replaced by a **RMT** (Réseau Mixte Technologique, which is a French partnership between research, training and development) on AFS. If successful, this RMT will be a **key partner for disseminating** the achievements of the Intens&Fix project.
- ✓ **Intens&Fix** will be related with the funded **ANR-Systerra PerfCom** (2009-2012) project which aims at gaining insights into multitrophic interactions and intergenotypic facilitation in annual plant communities, managed in low input agriculture. These exchanges will be favoured by the PerfCom coordinator (Ph Hinsinger) who is involved in the Intens&Fix project, and several scientists of UMR Eco&Sols who are both involved in the two projects.
- ✓ The **Intens&Fix** project is in line with the national INRA **CARBIO** programme ("renewable carbon and bio-industry", 2006-2009) which is split into two axes dealing with "biomass transformation" and "biomass production". Within the latter axis, the topic related to the woody biomass produced through short rotation coppice (VSRC) plantations is managed by UMR EEF (partner 3 of the Intens&Fix project). A scientist, involved in the Intens&Fix project, has been recently recruited by this partner to study the ecophysiology and the management of VSRC, especially for mixtures of *Populus sp*. and *Robinia pseudoacacia*.

Moreover Intens&Fix will take advantage of:

- ✓ The **CIFOR** (Center for International Forestry Research) **network** *"Site Management and Productivity of Tropical Plantation Forests"* - implicating 8 tropical and sub-tropical countries - which highlighted the crucial role of a conservative management of organic matter to get a sustainable production of tropical FP and to balance nutrient budgets. This finding led to the setting up a network of mixed-species plantations of NFS and *Eucalyptus* experiments in Brazil and in Congo. Results of the Intens&Fix project will be spread by this network that has been coordinated for 2009 by Cirad, and more specifically by JP Bouillet, coordinator of this proposal and JP Laclau, Cirad scientist involved in WP2 and WP3.
- ✓ The **EU** project **Makala** (2008-2012) aims at securing fuelwood for Kinshasa and Kinsangani in the Democratic Republic of Congo, in particular through the development of small-scale *Eucalyptus* and *Acacia* plantations. It is coordinated by JN Marien who is involved in the Intens&Fix project (WP4) and was the previous director of CRDPI, partner of both projects. These links will reinforce common dissemination of the findings of these projects, both in in the Democratic Republic of Congo and in the Republic of Congo.

This project addresses three general objectives of this call:

**§ 1.2.1 Go beyond a sector-based management of resources.**
This project is based on an ecosystemic approach to assess the conditions of a sustainable high level of wood biomass production, while maintaining or enhancing soil fertility, and reducing negative environmental impacts.

**§ 1.2.2 To account for the stakeholder diversity**
The results will allow **various** types of **stakeholders** to manage their FP in an ecologically intensive way: small and medium-scale forest owners and farmers in eucalypt, poplar and walnut plantations, and commercial companies for eucalypt FP. Forest plantation **stakeholders** are directly **integrated** in the **project** through **partner 6** (AFAF, Association Française d'Agroforesterie) and will participate to the **socio-economical assessement** of the introduction of NFS in FP. Results will be transferred to the scientific communities via papers in referred journals, as well as to professional organizations through **targeted conferences, informative leaflets** and **tools**: CRPF, CNPPF, APCA, forest experts, partners involved in the "*Site Management and Productivity of Tropical Plantation Forests*" Cifor network, IPEF (funded by Brazilian forest companies to share and spread scientific information), Ministère des Eaux et Forêts and NGOs (APEPF, APRCFP…) in Congo.

**§ 1.2.3 Diversifying and integrating action scales**
The project will be carried out in **controlled** (mesocosms) and ***in situ* conditions**. It will integrate **various scales** of observations, from the rhizosphere to the tree and stand levels. It will account for the variability of the processes, integrating spatial (soil depths, distance between trees and NFS, stratification of the canopy…) and temporal (within stand and among stand rotations) aspects. It will deal with the up scaling of the FP with NFS systems.

The project deals mainly with **Axis 1** "**Ecological intensification of the production systems"** of the present call through the themes 1.1 *« To know about and adjust the biogeochemical and physical functioning within the agrosystems » and 1.2 « Conception of the management of the soil ecological functions»*. It will also covers the thematic Axis 2 "**Ecological engineering from landscapes to territories"** through the themes 2.1 *"Which interactions arising between the different functionalities of a given ecosystem, or linked ecosystems"* and 2.2 *How to conceive and manage complex systems*.

# 2. DESCRIPTION SCIENTIFIQUE ET TECHNIQUE

## 2.1. ÉTAT DE L'ART

During the green revolution, the emphasis was placed only on external inputs (fertilizers, pesticides…) to increase crop productivity. But FP must be **highly productive** and **environmentally sound**. This double requirement is the core of the **doubly green revolution** (Griffon and Weber 1996) or of the **eco-agriculture** approaches (Conway et al, 1994; Griffon, 1995). Both combine natural resources preservation combined with high and sustainable productivity. To cope with the reduction of external inputs eco-agriculture considers that the approach based on biological-biophysical functions of the ecosystem used for centuries by farmers and foresters need to be renewed. An innovative **research must be developed,** focusing on the **plant-soil-climate relationships,** through the characterisation and the use of **ecosystem functions** and the **interactions** between them to get productive and environmentally sound ecosystems (Barbault, 2000; Binkley et al., 2004; Jackson et al., 2008)

N input-ouput budgets can be unbalanced even in regions with high N atmospheric deposits (≈ 20 kg $ha^{-1}$ $yr^{-1}$) owing to biomass removal at harvesting (Ranger et al., 2002). The risk of **N deficit** increases when **rapid-growth forest species** are used, especially when the stands are managed **in short rotations** as planned for bio-fuel production with repeated risks of N losses by drainage after stand harvesting, and exportations of wood with higher nutrient concentrations (Ranger et al., 2002). In the tropics, empirical observations, biogeochemical cycle studies and modelling approaches show a general upward trend in N fertilizer requirements over successive rotations in forest plantations managed in short rotations, as observed in **Congo** and Australia in eucalypt commercial stands (Corbeels et al., 2005; Laclau et al., 2005). In the soil, free concentrations of **inorganic orthophosphate** (Pi), which is the only form of P directly accessible to plants, are **very low**, ranging from 1 to 10 µM (Vance et al., 2003). Orthophosphate forms highly coordinated bonds with the macro metals in soil; these associations occur through inner sphere surface complex formation on Al and Fe oxide-hydroxydes and by precipitation of Al, Fe and Ca compound depending of soil pH (Lair, 2009; Yerokun, 2008). **Pi** is then highly **immobile** in soil and is supplied to plant roots by diffusion rather than by mass flow (Barber, 1995; Hinsinger, 2001). These conditions often lead to **P deficiencies**, as in FP with no or low P input (Trichet et al., 2009).

**Introducing NFS** in FP may lead to an **improvement** of **soil nutrient status.** Firstly soil **N** status through the recycling of the atmospheric $N_2$ fixed by NFS (Fisher and Binkley, 2000; Rothe and Binkley, 2001). Secondly, NFS enhance **P availability** due to a better soil exploration and high capacities to mobilize insoluble mineral P (Forrester, 2005; Gunes et al., 2007). The recycling of P accumulated in roots and leaves of NFS improve **soil P status** as reported by Forrester et al. (2006) and especially if heterotrophic microflora and/or symbiotic fungi associated to plant roots are able to mineralize organic P compounds accumulated in NFS tissues. This obligate step is carried out by **phosphatases** enzymes (Criquet et al, 2004; Kohler et al., 2007). Soil microbes (bacteria and fungi) are considered to produce much greater phosphatase activities than the roots (Chen, 2008; Feng et al., 2003). These phosphatases can have a broad spectrum of substrates (acid or alkaline) (Omidi, 2008) or a narrow specificity, such as bacterial phytases that can hydrolyse only phytin (Weys et al. 1999). However, as far as we know, there is no study available on qualitative and quantitative changes due to the introduction of a NFS species in FP on phosphatase and phytase activities from the micro-organisms.

Multi-species ecosystems with **annual** or **perennial NFS** may generate **greater productivity** than **monocultures** (Binkley et al., 2003; Dupraz and Liagre, 2005; Forrester et al., 2006; Laclau et al., 2008) through a **more complete** and/or **more efficient use** of **natural resources** (Kelty, 2006), resulting for example from a **niche exploration** of soil layers (Mulia and Dupraz, 2006). However, some studies have shown **no impact,** or a **depressive effect** of mixtures on the growth of non-N fixing trees or on the global stand production (Bouillet et al., 2007; Firn et al., 2007). The major difficulty in interpreting and predicting the effects of NFS in mixed-species ecosystems is to understand and quantify the **effects** of **inter-** and **intra-specific interactions**, *i.e* **competition, competitive reduction** and **facilitation** (Kelty and Cameron, 1995). By contrast to competition, facilitation in plant communities has been little accounted for in ecology (Bruno et al., 2003; Callaway and Walker, 1997), but such process may be determinant for increasing tree growth in oligotrophic FP ecosystems (Bristow et al., 2006).

Various interactions - that may evolve along stand rotation or among rotations - must be tackled in mixed species FP. Some examples are given thereafter:

**- Light and light-nutrient interactions**. Light capture depends primarily on the canopy structure (*i.e* leaf area, leaf angle…), and on the leaf optical properties. In mixed-species stands, canopy structure is generally highly dynamic: co-dominance is often observed during the early stand development (the two species occupying equivalent strata in the canopy), whereas later in the course of the rotation, the non-NFS generally dominates, leading to a stratification of the canopy (Hunt et al., 2006; Laclau et al., 2008). Increase in light-capture in mixed-species compared to pure species stands has been reported in various studies (Forrester et al., 2006), and may result from increased light-extinction coefficients (Hunt et al., 2006), or increased leaf area index, as a result, for example, of increased N or P availability (Leuning et al., 1991). Increased nutrient availability may also lead to a more efficient use of light, since photosynthetic capacities are generally strongly correlated with N and P concentration in the leaves (Kirschbaum and Tompkins, 1990; Loustau et al., 1999) but opposite result were also found (Mulligan, 1989).

**- Belowground interactions**. In addition to light capture, plants also interact for a broad range of soil resources including water and nutrients (Casper and Jackson, 1997). As for the aboveground compartment, root exploration of soil is highly dynamic (da Silva et al., 2009). During the first stages, species in mixture may be in high concurrence for resources; later on, they may be spatially complementary by exploiting different soil layers with their root systems and nutritionally by choosing different chemical forms and nutrient quantities. Three aspects have to be taken into account (Malézieux et al., 2008): (i) resource distribution within the soil and their availability, (ii) morphological and physiological plasticity of the root system (root distribution in depth, root length density, surface and biomass), and (iii) water distribution and its partitioning between plant-species evaporative demand and soil evaporation (Ozier-Lafontaine, 1998).

**- N-P Interaction**. NFS must take up P for $N_2$ fixation as energy provided by ATP is needed to reduce

$N_2$ to $NH_3$, and also presumably, because of phosphomembrane and nucleic acids over-abundance in nodules (Schultze and Drevon, 2005). Positive correlations are observed between P availability and NFS growth and/or $N_2$ fixation (Augusto et al., 2005; Tang et al., 2001). In reverse, P deficiency may decrease nodule initiation (Hoch-Jensen et al., 2002), and the efficiency of the $N_2$ fixation process (Ribet and Drevon, 1996). An enhanced competition for P between species might also be expected because the NFS is a strong P sink and might account for different behaviour of the mixture in P deficient soils as observed in Brazil (Goncalvez et al., 2008) or N deficient soil as found in Congo (Laclau et al., 2005).

- **Interactions within N Cycle**. Sufficient combined N in the soil can result in low $N_2$ fixation by the NFS (Aranibar et al., 2003). Conversely, $N_2$ fixation can be strongly enhanced by competition with non-$N_2$ fixing species as shown by Cramer (2007) for some African *Acacia*. The mechanisms of transfer of N fixed by legumes trees to associated non-$N_2$-fixing species have received little attention in mixed cropping systems. Sierra et al (2007) estimated the contribution of root exudates to N transfer to 10-15% of grass N content in a grass-*Gliricidia sepium* system. With root turnover included, the transfer accounted for 65% of grass N content. Dupraz *et al* (unpublished data) recently measured that 40% of the N content of 12 years old walnut trees originated from $N_2$ fixation by an associated alfalfa stand.

These interactions must be driven with silvicultural practices aiming at an **ecological intensification** of stand production. Some key driving practices need to be explored namely: **P** fertilisation (to what extent this fertilisation is needed to improve $N_2$ fixing by NFS, what is the optimum?) (Augusto et al., 2005), shortened or increased **stand rotations** (reduce the period when competition occurs and enhance the period where facilitation applies) (Piotto, 2008), **NFS arrangement** / **spacing** (ensure the development of all species in interaction (Boyden et al., 2009)). These practices must also be related to **environmental impacts** and **services** (carbon sequestration, water consumption, nutrient budgets, soil acidification…).

A **socio-economical** assessment of the mixed-FP studied is also needed. Even proved efficient from a biophysical point, FP with NFS may be not manageable at large scales: the introduced NFS may increase management costs (planting, harvesting...); profitability may decrease if profitable markets for the NFS wood are not in place; wood demand may be “species specific” and require too high and competitive productivity levels; skilled labour may be scarce; higher management complexity and cultural rules may limit the stakeholder innovation process; actors’ organization modalities may diverge in land use (Angeon, 2008), ect…

Single global strategy tor up-scale forestry and agroforestry systems cannot work: the **strategic approaches** must be tailored to countries, regions, systems, actors or even local sites, reflecting specific technical, economic and social conditions. Forest tree growers should be empowered to recognize in which way the principles can be applied (Fixmer and Brassac, 2004; Hillier et al., 2004) and which technical approaches are appropriate to their own situations. They should be supported to exchange their experiences and ideas to others. We must also account for the other concerns of forest tree growers, the most important being **higher incomes** through better sales of their products. If forest tree growerss are not provided with better income perspectives, in most cases other targets will be missed. For **up-scaling**, it should be ensured a close partnership from the start among diverse stakeholders in adapting, promoting and supporting uptake (Akirch, 2006; Dulcire, 2010): forest tree growers and their organizations, research, extension services, service/input/credit providers, government agencies, NGOs, and firms. The introduction of principles should be done pragmatically (Crozier and Friedberg, 1981) based on understanding of realities on the ground. Therefore, changes should be started by using **locally-available inputs** and based on local knowledge and beliefs whenever (Marie et al., 2009) and to the extent possible (Corbera et al., 2007). The start-up phase of adaptation needs special attention (Callon et al., 2009): if not skillfully organized and guided, failures are likely to occur, damaging the future willingness to change technical production approaches. For local adaptations a close interaction between stakeholders and researchers is needed (Hocdé et al., 2008, 2009). As a support to introduction and up-scaling, it will have to be demonstrated why low-input forestry systems as the association with N-fixing species, perform better and are more sustainable than conventional systems, which includes the generation of rigorous information on the benefits to farmers livelihoods, commercial companies performances and the broader society.

**Models** can help the dialog between actors and contribute to the innovation process. That can be illustrated by the use of the Farm-sAFe model that was designed by Graves et al. (2007) to predict plot- and farm-scale profitability of AFS, taking into account that the Land Equivalent Ratios of AFS (Dupraz, 1998) were greater than one (i.e. growing trees and crops as mixtures in silvoarable systems was more productive than growing them separately). The model showed that Agro-Forestery schemes may be unprofitable with low timber values and/or the opportunity cost of losing arable land, e.g. for slurry manure application in some regions (Graves et al., 2010), but that they may be profitable in many other situations.

## 2.2. OBJECTIFS ET CARACTERE AMBITIEUX/NOVATEUR DU PROJET

The general **scientific objective** of the project is twofold: address the **inter**- and **intra-specific biophysical interactions** within FP mixed with NFS, and account for the **technical** and **socio-economical context** in order to propose innovative management schemes of FP ecosystems. The aim is to achieve more productive, sustainable and profitable systems. We will test **NFS management** and silvicultural **practices** in order to **increase $N_2$ fixation**, **soil biological functioning**, **nutrient cycling** and the **overall productivity** of FP. We focus on some sivicultural practices: P fertilisation, legume tree species arrangement, tree spacing, and rotation length.

We will refine a **conceptual model** that will **include** i) **competition**, **competitive reduction** and **facilitation** applied during the whole tree rotation leading to different periods of interaction depending on the main **resources** involved, ii) **plant traits** of species in interaction, as well as **climatic** and **nutrient constraints**, iii) processes such as plant **plasticity** and plant **efficiency** to light, water and nutrient resources uses, litter and soil organic matter **decomposition** and **bioavailability** of **N** and **P** in the soil, iv**) technico** and.**socio-economical** factors that may influence the stakeholder innovation process.

The Intens&Fix partners did not include all their experimental resources of FP with NFS in the project. According to the **context analysis** (cf §1), only few of them were retained aiming at building a network of sites that will allow to enlarge the validity domain of the integrated modelling approach in order i) to offer a representative and contrasted range of **ecological conditions**, **rotation length,** risks of **nutrient unbalance, mixture composition** and **management practices**, and ii) to illustrate the **main technical** and **socio-economics issues** (advantages and constraints) that may arise in FP combined with NFS. As a result of this selection process, **three types** of **FP** ecosystems (and 4 sites) were retained to be the pillars of this project (Table 2).

**Table 2.** Criteria of complementarity and modalities of comparison hold for the site selection in Intens&Fix

| **Factor (environment/plant trait)** | **Sites** | |
|---|---|---|
| Latitude | Tropical: *Eucalyptus* | Temperate : *Juglans-Populus* |
| Water stress occurrence | Low: *Eucalyptus* (Brazil) – *Populus* | High: *Juglans-Eucalyptus* (Congo) |
| Tree Foliage type | Deciduous: *Juglans-Populus* | Evergreen : *Eucalyptus* |
| Canopy competitiveness for light | Very low: Juglans with *Medicago* | Strong: *Eucalyptus-Populus-Juglans with Alnus* |
| Tree stand density | Low: *Juglans* | High*: Eucalyptus-Populus* |
| Rotation length | Long: *Juglans* | Short: *Eucalyptus-Populus* |
| Fixation type of NFS | *Rhizobium*: *Robinia-Acacia-Medicago* | *Frankia*: *Alnus* |
| P limitation of $N_2$ fixation | Low:*Juglans - Populus - Eucalyptus (Congo)* | High: *Eucalyptus (Brasil)* |
| Risk of nutrient unbalance | Low*: Juglans* | High: *Populus-Eucalyptus* |

**1) Hybrid *Juglans* + various NFS species.** Plantations are managed in **medium rotation** (30-50 years depending on local fertility conditions) for **high value timber**. The experimental plots are established on soils with N deficiencies under Mediterranean climate with high summer water constraints (Restinclières farm, Hérault). NFS species include trees (*Alnus cordata),* perennial fodder crops *(Medicago sativa, Onobrychis sativa)* and annual pulses *(chikpea).* These plantations are typical of new **silvoarable schemes** with low density high quality timber trees currently developed in France (Graves et al., 2008). About 2,000 ha of such plantations are established annually in France since 2006 and a target of 500,000 ha of such silvoarable plantations in France is on the agenda for the next 30 years (Dupraz and Liagre, 208). The experimental plots were planted in 1995 and include control plots with trees without the NFS species. They are instrumented for climate data, soil humidity, water-table levels, tree growth and NFS species productivity since their inception. We will test the hypothesis that herbaceous NFS may provide more Nitrogen than NFS trees; conversely, NFS trees also provide wood biomass and shelter for the timber trees. The integrated model will help to compare the efficiency of the different systems.

**2) *Populus sp + Robinia pseudoacacia*. Fast growing** plantations managed in 2 to 6 year Very Short Rotation Coppices (VSRC) for **fuelwood** production, and established on ancient pastures with potential risks of rapid nutrient unbalance, but low water constraints. Robinia is used as NFS and for fuelwood production. By contrast to Scandinavia or Italy for instance, the value- and technical-chains concerning SRC has to be entirely developed in France. VSRC must be attractive for farmers without competing with agriculture, and would be mainly installed on the poorest soils with therefore a marked interest in adding NFS.

**3) *Eucalyptus grandis* / E. *urophylla x E. grandis* + *Acacia mangium*. Fast growing** plantations managed in short rotations (6-7 years) for **pulpwood** and **charcoal**, but also providing **fuelwood** - 45% of the needs of Pointe-Noire (Nkoua, 2008) - and established on N-deficient sandy soils (Congo) and P-deficient sandy-clay soils (Brazil). High temperatures and air moisture allow conducting *A. mangium* as pulpwood/ firewood tree in Congo. This species is managed on the Brazilian site as understorey, as it is suppressed rapidly by *Eucalyptus*, except in a treatment with a mixture in a proportion of 1:1 between *E. grandis* and *A. mangium* (Laclau et al., 2008). These **tropical sites** present marked added values to the **French sites**:

- ✓ The higher growth rates leads to rapid responses to any ecosystem manipulation.
- ✓ The same design was duplicated in Brazil and in Congo giving the opportunity to gain insights into the interaction processes, accounting for the variations of key ecological parameters. After harvesting (end 2009 in Brazil; mid-2010 in Congo) the trials are replanted with the same design to study cumulative processes over successive rotations.
- ✓ The sites are highly instrumented (lysimeters design, eddy flux tower…) and allowed numerous findings on eucalypt monocultures functioning (Epron et al., 2004, 2006, 2009; Laclau et al., 2005, 2010; Marsden et al. 2008; Merbold et al;, 2009; Nouvellon et al., 2008; Thongo et al., 2008).

For this association, it must be emphasized that the socio-economical survey will be focused in regions (Sao-Paulo and Minas Gerais states in Brazil; Kouilou and area around Brazzaville in Congo) where mixed-species eucalyptus plantations with NFS can be **alternatives** to eucalyptus monocultures that are widely planted and/or present potentialities of further development but whose social and environmental impacts are pretty questioned..

Except for the VSRC site, numerous results have been already obtained on the FP chosen (references in table 3) ensuring a sound scientific background of the Intens&Fix research teams on mixed-species ecosystems, as well as maximising the chances of success of this project.

**Expected scientific progresses**

**Integrative model**. A major issue of the project is to develop a dedicated and integrative model of FP with introduced NFS. To turn the above mentioned conceptual model into equations, the modelling process will benefit from both bottom-up (results and specific models from the different WPs) and top-down approaches (concepts arising from literature and past experiments). The main challenges will be to identify the appropriate decision rules for the management of FP with NFS and the appropriate models for each biophysical process. A package will be developed to integrate the outputs of the biophysical model in an economical model. This will not be fully integrated as such a task would be far too ambitious for this project. We propose to work with lockout tables produced by the biophysical model that will be used as forcing data for a plantation level model designed to be able to translate the benefits of mixtures in economic terms (Graves et al., 2010). These tables will be based on the predicted Land Equivalent Ratios of the mixtures for various technical schemes. A virtual experimental plan will be defined to test some key decision rules with the biophysical model, and the results valued with the plantation level model, integrating both production and environmental services (Palma et al. (2007).

**Plant Plasticity and Resource Use Efficiency.** Analyses of morphological and physiological plasticity of studied species will improve our understanding of how interactions between the planted species and the NFS in mixed FP will affect growth of individual trees and net primary productivity of the stand through modifications of the efficiency of the use of aboveground (i.e. light) and belowground (N, P and water) resources, and through modification of growth allocation. We will identify the occurrence of trade-off or synergetic responses. The partitioning of resources between the species in mixed stand will be characterised for a pertinent range of associations, and for one association, in various pedoclimatic contexts.

**Soil Ecology and Nutrient bioavailability.** Analyses of litter decomposition rates in pure and mixed FP will provide information on the effects of associated NFS on C dynamics and N and P recycling in relation with litter quality and environmental parameters. In particular, we will address the **Home Field Advantage** theory, *i.e.* a plant species litter decomposes faster in the presence of biota derived from the soil of that plant species, than in the presence of biota from soils of other species (Ayres et al., 2009; Vivanco and Austin, 2008). Experimental data will be used to adapt and validate C-N models in a context of mixed plantations. We will also assess changes in soil organism functional groups in response to associated NFS and how these modifications affect soil C dynamics and N and P bioavailability. One important challenge will be to identify and quantify rhizosphere mechanisms such as N transfer from NFS to non-NFS and multitrophic interactions that will contribute explaining processes of functional complementarity and competition/facilitation within mixed FP with associated NFS.

**Innovation process.** If research projects have started to study the biophysical advantages of forest systems ecological intensification, fewer have deeply analyzed possible social and economic factors and consequences. Through a participative approach to assess the staholders' innovation process, the project will contribute to this challenge, answering if introduction of NFS in FP can lead to a socially sound ecological intensification of these ecosystems.

**<u>Obstacles to get over</u>**

- The **transfer** of fixed **N** to non-fixing trees will be studied comparing different **$^{15}$N isotopic methods**. $^{15}$N natural abundance is often used to calculate how much of the tree N is derived from symbiotic N fixation (Boddey et al., 2000), but this technique was reported not to be accurate enough to give reliable estimates of N transfer on a short-term basis, and may substantially underestimate net N transfer (Hogh-Jensen, 2006). Using innovative $^{15}$N labelling methods (stem injection, leaf feeding, $^{15}N_2$ pulses) is our way to increase both spatial and temporal resolution in monitoring N fluxes among different tree species.

- The main difficulty for the **modelling** process will be to identify the appropriate **spatial dimension** (1D/2D/3D) and time step (hour/day/decade/month/year) of the integrative model which will adopt simplified assumptions on most biophysical aspects of FP. The equations for each process will either be created from scratch, or re-use previous ones when available. To ensure that concepts are correctly embedded, each module will be elaborated by comparison with more detailed models made available by each team.

**-** The main difficulty for the **economic appraisal** will be to choose the same approach for the three systems of FP with NFS, share issues and results, and finally establish a fruitful connexion between biophysical modellers and economists. The different time scales of the systems may be an obstacle. The fact that the biophysical model and the plantation-scale model will not be dynamically linked will prevent us from designing optimum rules automatically.

**<u>Final expected outcomes and innovative issues</u>** This project will contribute to the production of innovative results *i.e.* **refined methodologica**l techniques for estimation of N transfer, documentation of **mechanisms** of competition/ facilitation for **N** and **P bioavailability**, **model coupling** water, N and C functioning adapted to mixed-species forests, silvicultural **practices** (species, density…) to manage NFS in FP**,** and **socio-economical assessmen**t of these new management schemes. The results of this project should contribute to increase wood production, the sustainability of FP and enhance their beneficial environmental impacts, in accordance with technical and socio-economical factors.

**<u>Link between the scientific fields</u>**

- The project integrates the functioning of above and belowground components of the FP including the interactions with soil organisms. The complete understanding of the system is based on the **interactions** among the **scientific fields** of the project. For instance, the quantification of the input of N into the ecosystem by NFS and of N bioavailability requires the collaboration of specialists in ecophysiology (leaf gas exchange and leaf morphological traits, litterfall and root turn-over, soil water content), sylviculture (fertilisation, spacing,…), soil biology and microbiology (symbiotic microflora for $N_2$ fixation, heterotrophic microflora and macrofauna for organic matter decomposition), biogeochemistry and soil science (nutrient interactions and cycles, organic matter decomposition), and modelling (above and belowground NPP, organic matter decomposition models).

**- Strength** of this project is to link both **biophysical** and **socio-economical fields** as well as **researchers** and **stakeholders** (professionnal organisations, associations, private forest owners, farmers, forest commercial companies, experts…) in order to contribute to an ecological intensification of FP through innovative silviculural practices to be largely disseminated.

# 3. PROGRAMME SCIENTIFIQUE ET TECHNIQUE, ORGANISATION DU PROJET

## 3.1. PROGRAMME SCIENTIFIQUE ET STRUCTURATION DU PROJET

The project aims at developing an integrated tool model for mixture of tree species in FP. It will be derived from a conceptual model that deals with **mixed-species FP functioning** through the study of key biophysical and biogeochemical **interactions**, and with the **decision rules** of stakeholders accounting for **technical and socio-economical factors** to use NFS in FP. The project is structured in five Work Packages (figure 3), conducted in France, Brazil and Congo on 3 types of mixed-species FP (table 3).

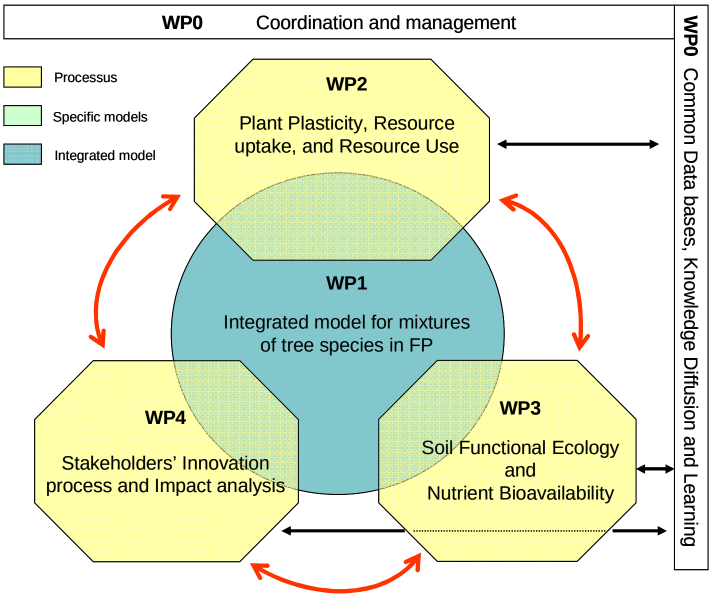


**Figure 3.** *Graphic representation of the interdependence of the work packages*

Each key point identified in the conceptual model will be characterised by at least one core treatment, several past studies that will feed the present project (table 3), and specific models explicitly designed to study some key processes. Specific studies will be conducted in a limited number of sites to focus on particular issues.

**WP0** covers all the coordination activities and related project management: organisation, planning and control of the workplan, contractual issues, project meeting and reporting, project outputs and dissemination and learning activities, as well as management of common databases.

**WP1** focuses on the elaboration of the integrative model. It constitutes the backbone of the project, ensuring that all concepts/hypotheses/models established and verified in WP2 and WP3 participate to the formalisation into equations of the conceptual model. A strong link also exists with WP4 that provides a feed-back from end-users to guide the modelling tasks, and assesses the management rules with the outputs of the simulation runs.

**WP2** deals with morphological traits, physiological processes and carbon allocation schemes that will explain changes in resource use efficiency by each species and resource partitioning among species.

**WP3** aims at assessing how the introduction of NFS in FP affects soil biological functioning, Organic Matter decomposition, soil nutrient dynamics (especially N and P) and plant nutrition.

**WP4** aims at (i) understanding the socioeconomic determinants of the former and actual forestry practices and the stakeholders' strategies to improve the forestry system implementing ecological intensification, (ii) assessing the economical and social impacts of the innovations for each wood goods and products chain stakeholder.

**Table 3.** Experimental sites and existing data base characteristics, and associated publications

| Sites | Ecosystems / experimental designs | Ecological conditions | Existing data base / Associated publications |
|---|---|---|---|
| **Montpellier = S1** | ***Juglans nigra x regia + Alnus cordata***<br><br>The plantation was set up in 1995 and includes a factorial experiment with/without N application. The walnut trees are 9 m tall in 2008 and the *Alnus* trees about 7m tall. Additional treatments include walnut trees alone or with a wheat intercrop. Tree density is 400 trees.ha$^{-1}$ (half *Juglans*; half *Alnus*) | Mean rainfall: 950 mm yr$^{-1}$<br>Mean air moisture: 59 %<br>Mean air Tre: 14.5°C<br>Dry season: 4 months<br>Deep alluvial silty fluvisol | Meteorological databases; Soil moisture monitoring since 1998; water table level monitoring since 2002; Growth (*Juglans* and *Alnus*); N content; Root vertical distribution monitored twice a year since 2004.<br><br>**Dufour et al ; 2009 ; Dupraz et al., 1999, 2005 ; Mulia and Dupraz, 2006** |
| | ***Juglans nigra x regia + herbaceous NFS (Medicago sativa, Onobrichys sativa, Cicer arietinum)***<br><br>*Three plots are available and were established in 1988 and 1995. Perenial legume intercrops were managed for the first 10 years for hay and then replaced by spontaneous vegetation. The impact of ten years of interaction with the perenial legumes will be assessed first. Then a new legume stand will be sowed. The experimental design will compare a legume and a grass intercrop. Annual legumes intercrops were introduced in 2009 and will be tested over the next years. Tree density is close to 100 trees.ha$^{-1}$ in all plots* | *Mean rainfall:1040mm yr$^{-1}$*<br>*Mean air moisture: 51 %*<br>*Mean air Tre: 14.2°C*<br>*Dry season: 4 months*<br>*Deep alluvial sandy fluvisol* | *Meteorological databases; NDFA measured on the walnut trees in 2000 in one site. Growth (Juglans and legumes); Plant nutrient content (N)*<br><br>***Balandier and Dupraz, 1998; Dupraz et al, 1998)*** |
| **Nancy = S2** | ***Populus sp. + Robinia pseudoacacia***<br><br>Split-plot design set up in 2010. Main treatment: 12,000 trees ha$^{-1}$, double rows, managed in 2-year-rotations ; 7,000 trees ha$^{-1}$, single rows, 4-year rotations; 1,400 trees ha$^{-1}$, single rows, 6-year-rotations; sub-treatment: Populus, R. pseudoacacia, Populus + R. pseudoacacia. 520, 280 or 120 trees per plot, respectively, in 5 blocks | Mean rainfall: 975 mm yr$^{-1}$<br>Mean air moisture: 80%<br>Mean air Tre: 10°C<br>Dry season: 0 month<br>Clay-silt soils | None |
| **Brazil = S3** | ***Eucalyptus grandis + A. mangium***.<br><br>Complete randomized block design set up in 2003 (100 trees per plot in 4 blocks). Complete fertilisation (P, K, Ca, Mg, B) applied in all the treatments to prevent nutrient deficiencies. Pure eucalypt (with or without N fertilization) and acacia stands compared, as well as *A. mangium* planted in a mixture at a density of 25%, 50% and 100% of the *E. grandis* density, and a mixture in a proportion of 1:1 between *E. grandis* and *A. mangium*.<br><br>Same treatments reinstalled for the 2$^{nd}$ rotation (November 2009) | Mean rainfall:1400mm yr$^{-1}$<br>Mean air moisture: 60%<br>Mean air Tre: 20°C<br>Dry season: 0 month<br>Sandy-clay soils<br>High P soil deficiency,<br>Low N soil deficiency<br>Pure *Eucalyptus* MAI: 40-50 m$^3$ ha$^{-1}$ yr$^{-1}$ | **1$^{st}$ rotation (6 years)**<br><br>Growth (annual measurement:1-6 yrs); Biomass/nutrient content (1, 3, 4, 6 yrs) ; Litter fall (0 → 6 yrs) ; $N_2$ fixation estimation: $^{15}$N natural abundance (18 and 30 months), and $^{15}$N soil labelling (18 → 30 months. Distribution of fine roots / nodule (6, 12, 18, 30 months, 5 yrs).Soil respiration (4→6 yrs); ACI curves (5 yrs); Soil water content and soil solutions monitoring (3-5 yrs)<br><br>**Bouillet et al., 2007, 2008, 2010; da Silva et al., 2009; Jourdan et al., 2008 Laclau et al., 2008** |
| **Congo = S4** | ***E. urophylla*grandis + A. mangium***.<br><br><u>Same design as in Brazil</u>, except date of planting (2004), 5 blocks, no fertilisation applied except a low N starter fertilization, and no mixture at a density of 100% of the *E. grandis* density.<br><br>Same treatments reinstalled for the 2$^{nd}$ rotation (2011) | Mean rainfall:1200mm yr$^{-1}$<br>Mean air moisture: 85%<br>Mean air Tre: 25°C<br>Dry season: 5 months<br>Sandy soils<br>No P soil deficiency,<br>High N soil deficiency<br>Pure *Eucalyptus* MAI: 15-25 m$^3$ ha$^{-1}$ yr$^{-1}$ | **1$^{st}$ rotation (6 years)**<br><br>Growth (annual measurement: 1-5 yrs) Biomass/nutrient content (1, 3 years); Litterfall (1→ 3 yrs);$N_2$ fixation estimation ($^{15}$N natural abundance : 18 and 30 months)<br><br>**Bouillet et al., 2007, 2010; Levillain et al., 2009** |

## 3.2. MANAGEMENT DU PROJET

The Intens&Fix project is organised in five Work Packages, each divided into two to three Tasks making up 12 tasks altogether. The project is primarily coordinated by JP Bouillet (Partner 1- UPR 80). Each WP is coordinated by one person. Within each WP each task is coordinated by two persons with a primary coordinator (underlined below)

**WP0. Project coordination and networking, common databases, knowledge diffusion and learning**
**Coordinator WP0**: **JP Bouillet (Partner 1- UPR 80)**
*Task 1. Coordination and networking*: JP Bouillet (Partner 1- UPR 80), C Dupraz (Partner 2 - System)
*Task 2. Common databases, knowledge diffusion and learning*: JP Bouillet (Partner 1- UPR 80), L Dufour (Partner 2 - System)

**WP1. Integrative model for mixture of tree species in Forest Plantations**
**Coordinator WP1: C Dupraz (Partner 2 - System)**
*Task 3. A conceptual model of FP with NFS*: MA Ngo Bieng (Partner 2 - System), F Liagre (Partner 6 – AFAF)
*Task 4. Turning the conceptual model into equations and coding*: L Saint-André (Partner 1- UPR 80), S Roux (Partner 2 - System)
*Task 5. Utilizing the model to explore decision rules and economical feasibility for the 4 sites of the project*: C Dupraz (Partner 2 - System), G le Maire (Partner 1- UPR 80)

**WP2. Plant Plasticity, Resource uptake and Resource Use**
**Coordinator WP2: D Epron (Partner 3 - EEF)**
*Task 6. Resource acquisition and resource use efficiencies*: A Thongo (Partner 8 - CRDPI); N Marron (Partner 3 - EEF),
*Task 7. Growth and carbon allocation*: D Epron (Partner 3 - EEF), Y Nouvellon (Partner 1 - UPR 80)
*Task 8. Plant and soil nitrogen budget*: JLM Gonçalves (Partner 7 - USP), D Gérant (Partner 3 - EEF)

**WP3. Soil Functional Ecology and Nutrient Bioavailability**
**Coordinator WP3: C Plassard (Partner 4 – Eco&Sols)**
*Task 9. Organic matter dynamics and nutrient cycling*: JM Harmand (Partner 1- UPR 80), B Zeller (Partner 3 - EEF)
*Task 10. Soil Ecology of microbial and microfaunal communities and identification of mechanisms of competition/facilitation for N and P use efficiency*: C Plassard and C Villenave (Partner 4 – Eco&Sols)

**WP4 Stakeholders' innovation process and impact analysis**
**Coordinator WP4: JM Kalms (Partner 5 – Innovation)**
*Task 11. Socioeconomic diagnosis of the determinants of the former and current forestry practices*: M Dulcire (Partner 5 – Innovation), F. Liagre (Partner 6 - AFAF),
*Task 12. Socioeconomic follow-up: analyses, stakeholders validation*: JM Kalms and MG Piketti (Partner 5 – Innovation)

For practical reasons, the WP coordinators are based in France, except JP Bouillet who is hosted by Partner 8- USP in Brazil. But the efficient involvement of both Partners 7 - USP and Partner 8 - CRDPI will be ensured owing to i) their participation as coordinators of the task 5 (CRDPI) and task 7 (USP), ii) the long-term cooperation between Partner 1- UPR 80, Partner 3 - EEF, and Partner 4 - UMR Eco&Sols with these two tropical partners, iii) the permanent position of UPR 80 scientists both in USP and CRDPI, and iv) the participation of USP and CRDPI to the annual review meetings, with one meeting held in Brazil, iv) the participation of their leader in the management team (cf infra).

The project management will be under the responsibility of a **Management Team** formed by the Project Coordinator, the Coordinators of the WPs, and the partner leaders. The Management Team will follow up:

- The monitoring of project progress.
- The control of the quality and quantity of the project outputs.
- The adjustment and adaptation, if necessary, of the annual planning, in relation with the ANR “Structure Support”.
- The solutions to be proposed to a partner, after agreement by ANR, if technical problems occur within the implementation of a given task by the partner.
- The preparation of contractual progress reports in relation with partner’s leaders; each **WP coordinator** will be responsible for the scientific management (agreement supervision on common protocols, supervision of instrumentation setting up, WP common database implementation…) and output of an individual Work Package, including the compilation and analysis of data; according to the ANR rules, each **partner leader** will be responsible of the financial report of his team but the summary of expenditures will also be submitted to the Project Coordinator.
- The Project coordinator will consolidate and validate each scientific and technical contribution, as well as the financial reports in order to submit integrated documents to ANR.
- The organisation of the project strategy for scientific publications and the targeted international journals; without prejudice to contract signed with ANR, agreeing procedures and policies in accordance with the Consortium Agreement signed at the beginning of the project for the management of the knowledge and access rights of each partners
- The organisation of the project disseminations and learning activities (project, web site, networks of stakeholders and finale end-users) press release for raising public participation and awareness).

**Review meetings** will be held **annually** including **all partners**, with a 1-2 days special event dedicated to the professional organizations and **stakeholders**, as private owners, forest experts, CRPF, and APCA (France), IPEF (Brazil), EFC (Congo)**.** They will comprise systematically i) a field day component, and ii) an indoor meeting to exchange results (via oral presentations) and make decisions for the following year. Four meetings will be held in the 2 French locations (6 months, years 1, 2 and 4), and one in Brazil (year 3).

## 3.3. DESCRIPTION DES TRAVAUX PAR TACHE

| WP0 | Project coordination and networking - Common data bases, Knowledge Diffusion and Learning |
|---|---|

**WP coordinator: JP Bouillet (Partner 1 - UPR 80)**
**Other partners:** All partners

### TASK 1. COORDINATION AND NETWORKING

Objectives
- Establishment of consortium agreement
- Exchange of information among partners of the project and other actors implied
- Organising workshops to take decisions at various key steps of the project i) confrontation and critical assessment of results, and ii) analyses and drawing final conclusions
- Ensuring deliverables and reports produced in due time
- Organising annual and final, concluding reports
- Coordinating the writing of annual and final reports

Detailed Work plan and methods
- Signature of a Consortium Agreement in order to define the respective rights and obligations of the partners, including provisions on intellectual property rights, and to supplement the provisions of the contract signed with the ANR on the internal project management.
- A one week **kick-off meeting** aiming at defining the operational management of the project to provide the deliverables of the project. A very special focus will concern the way to collect and share the information relating to the decision rules of stakeholders accounting for technical and socio-economical factors to use NFS in FP. In this respect it will be largely discussed the organization, in the different countries and systems studied, of the inception meetings of WP1 gathering stakeholders (private owners, farmers, NGOs, forestry and agroforestry projects leaders, moderators helping to conduct and synthetise the discussions, …)
- Yearly meeting of the **management team** to (i) evaluate the evolution of the project (ii) ensure an effective share of information between partners and WPs, (iii) discuss and approve solutions proposed by the partners if problems occur, (iv) revise, if necessary, the strategy, and propose adaptations or adjustments of the activities and (v) validate the contractual progress reports vi) define the strategy of scientific publication of project results and agree on the targeted international journals. Besides theses yearly meetings, regular (at least monthly) computer-to-computer / visio - **conferences** will be held.
- **Review meetings** (2 in year 1 and then 1/year) including all partners, and dedicated stakeholders to report on the progress, and to redefine (if necessary) the Project Programme. The first review meeting will mainly aim to present and share the results concerning the inception meetings of WP1, held in the differents countries during the first 6 months in relation with WP4.
- Dedicated ftp server (hosted by Partner 1 - UPR 80) for data and report exchanges between partners and web site for world wide diffusion of some information dealing with the project (contacts, description of partners and field trials, publications…).
- Progress and financial reports sent at 6, 18, 30, 48 months on the basis of the reports sent by WP Leaders
- PhD students (at that stage: 5 students) and their respective supervisors will be gathered at mid-term of the project to further exchange ideas and favour innovation in their respective theses (mind-mapping approaches).

Deliverables

| Task 1 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Coordination and Networking** | JP Bouillet (Partner1-UPR 80) C Dupraz (Partner 2- System) | All partners End users | D1.1: Consortium agreement | Partner1-UPR 80 | Month 0 |
| | | | D1.2: Kick off meting | „ | Month 1 |
| | | | D1.3: Dedicated ftp server for data and report exchanges | „ | Month 1 |
| | | | D1.4: Intens&Fix website | „ | Month 6 |
| | | | D1.5: 1st review meeting | „ | Month 7 |
| | | | D1.6: 2nd review meeting | „ | Month 12 |
| | | | D1.7: 3rd review meeting | „ | Month 24 |
| | | | D1.8: Report on mid-term PhD student meeting | Partner2- System | Month 24 |
| | | | D1.9: 4th review meeting | Partner1-UPR 80 | Month 36 |
| | | | D1.10 Closure meeting | „ | Month 46 |
| | | | D1.11: Progress and financial reports | „ | Months 6, 18, 30, 48 |

Partner involvements
This task will be managed by Partner 1 - UPR 80 and the management team constituted by WP coordinators and partner leaders

Risks and Backup Solutions
- A challenge is to ensure the participation of all the partners to the review meetings, both from France, Brazil, and Congo. Problems could appear due to i) financial reasons; project funds will be devoted for this purpose, ii) a possible reticence of certain stakeholders to mixed-species plantations (higher management complexity…). A rapid and efficient interaction with the stakeholders (inception meetings of WP1, discussions, result presentations…) will be of a major importance,
- Financial difficulties for the participation of the Congolese or Brazilian PhD students to the mid-term project meeting. Additional support funding (Cirad Desi…) will be secured to allow the participation of a good panel of foreign PhD students.

### TASK 2. COMMON DATABASES, KNOWLEDGE DIFFUSION AND LEARNING

Objectives
- Establishment of a data base easy to use and opened to all the partners including past and ongoing measurements
- Systematising the main finding of the research project and communicate them to the stake holders
- Implying Master students and engineers both in France (Nancy University, Montpellier Sup-Agro, Agro-ParisTech…), in Congo (Marien N'Gouabi University), and Brazil (USP, Visoça University…), in knowledge acquisition. The project will give examples of ecological intensification in FP. It will allow them to understand mixed-plantations functioning through the quantification of interaction processes, as well as the technical management of this ecosystem way (spacing, duration of rotation,…) and the way to integrate technical-economical factors
- Implying scientist and especially young ones in the acquisition and diffusion of knowledge on ecological intensification

Detailed Work plan and Methods
- Database management. Data will be gathered regularly to implement a data base on past and ongoing

measurements on the experimental sites. These data will be used especially in the WP1 frame work.
- Field days will be organised annually as part of review meetings. Professional and scientists will thereby exchange their experience and points of views on the mixed-species forest plantations.
- Two Summer Schools will be organised as part of the Socrates Intensive Programme Network of European Universities in which Montpellier SupAgro is implied – this shall gather 20-30 PhD students from various countries, including **Brazil** and **Congo**, and the PhD students implied in the project. It will be organised at SupAgro for 2 weeks and comprise lectures, practical work, field trip and students' talks. The two focuses will be on:

(i) The fuctioning of mixed-species FP with NFS
(ii) The social methods and concepts applied to forestry and agroforestry innovations

- Schedule of press release in French and English for raising public participation and awareness
- Meeting with the Board of the French National programme for the extension of Agro-forestry (www.agroforesterie.fr) led by the Assemblée Permanente des Chambres d'Agriculture to foster dissemination of projects results toward final end-users
- The results on mixed-species plantation *Acacia* and *Eucalyptus* will be disseminated in the "Site management and productivity of tropical forest plantations" network, nowadays coordinated by Partner 1 - UPR 80, as well as within the network on mixed-species plantations established in Brazil with a strong implication of forest companies (PTSM meeting), and the project Makala on small-scale FP in Democratic Republic of Congo.

Deliverables

| Task 2 | Task Managers | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Common databases, knowledge diffusion and learning** | J.P Bouillet (Partner 1 – UPR 80) L. Dufour (Partner 2 – System) | All partners End users | D2.1: Data base implementation<br>D2.2: Summer school on methods and concepts applied to forest and agroforest innovations<br>D2.3 Report meeting with the board of French AFS National.Program<br>D2.4: Summer school on mixed species FP<br>D2.5: Schedule of press<br>D2.6 Manuscript on the ecological intensification of wood production through association of nitrogen fixing species in forest plantations | Partner 2- System<br>Partner5-Innovation<br>Partner 2 - System<br>Partner4- Eco&Sols<br>Partner 1- UPR 80<br>Partner 1 – UPR 80 with all partners | Month 12<br>Month 12<br>Month 24, 48<br>Month 36<br>Month 48<br>Month 48 |

Partner involvements
This task that will be coordinated by partner 1 - UPR 80 will concern all the partners of the project.

Risks and Back up Solutions
Summer Schools will take place providing it is accepted by other participant Universities of Socrates Intensive Programme and providing enough students register to attend. Will be cancelled if not.

| WP1 | Integrated model for mixtures of Nitrogen Fixing Species in Forest Plantations |
|---|---|
| **WP coordinator: C Dupraz (Partner 2 - System)**<br>**Other partners:** All partners | |

**WP1** will design integrative model of FP with introduced NFS to produce an evaluation of various management schemes of FP with and without NFS. A conceptual model based on two sub-systems (biophysical and economical) is proposed to guide this process (Le Gal et al., 2010). This integrative modelling process raises four **scientific questions**: **i)** Which processes of each sub-system should be included in the model? **ii)** Which formalisms should be adopted for each key process? **iii)** How should these formalisms be translated into mathematical equations considering the multi-scale temporal and spatial context? **iv)** How should the integrative model be evaluated and validated?

WP1 will benefit from both bottom-up (results from the different WPs) and top-down approaches (concepts arising from literature and past experiments) and will be structured into three tasks.

### TASK 3. A CONCEPTUAL MODEL OF FP WITH NFS

Objectives

This conceptual model should identify both the biophysical processes to be included, and the appropriate driving rules that should be explored with the model.

Detailed Workplan and Methods

To address inter- and intra-specific interactions within mixed-species FP, the biophysical component will deal with competition, competitive reduction and facilitation processes (Kelty, 2006; Vandermeer, 1989). The model should fit the following criterion: integrate these mechanisms over the whole tree rotation; include the fact that the resources concerned by each mechanism may change with time; be generic enough so as to take into consideration the plant traits of the species in interaction, as well as the climatic and nutrient constraints; include the processes such as plant plasticity, plant efficiency to light, water and nutrient resources under the control of WP2; include litter and soil organic matter decomposition, bioavailability of N and P in the soil under the control of WP3.

This task will take advantages of the diversity and complementarities of the experimental sites and species included in the project to select the key processes to be included. A bottom-up approach will be set up with the researchers involved into WP2 and WP3 to identify a list of candidate key processes and to propose solutions for their formalisms. This list will be confronted to a top-down approach where results from past experiments of the consortium as well as literature reviews and previous models for mixtures (e.g. Forrester et al., 2005) will contribute to refine the proposed list.

The technical and socio-economical components will be defined, concomitantly with WP4, in inception working meetings with FP stakeholders, including key professional partners such as Partner 6 - AFAF in relation with the Chambre d'Agriculture des Vosges. Many professional partners will be invited, including APCA in France, and the forestry organizations with wich works Partner 7-USP and partner 8 - CRDPI (as IPEF and many forest companies in Brazil, and EFC and the Service National de Reboisement in Congo). These meetings will be held in the first 3 months. In parallel it will be delivered a synthetic document showing not only the potential gains brought by NFS in FP but also the specific technical aspects (plantation design, amount of fertilizers etc..) which will be both of major interest to the forest managers. Together with the FP stakeholders and Intens&Fix partners, national and international specialists on tree mixtures from outside the project will also be invited at these meetings. This dialog between modellers and end-users will help in defining the appropriate specifications of the integrated system: for example, decision making processes need values of some state variables of the system, and it is essential to ensure that the integrated model will include the appropriate variables; we can also expect that the process will help in deciding about the spatial dimension (1D/2D/3D) and the time step (hour/day/decade/month/year) of the model in order to reach a good representation of the system and a good technical applicability. A key point to be addressed will be the balance between the potential gains of mixed-species FP and the technical costs of the changes in the management, this balance depending strongly on the economical constraints faced by the stake-holders.

At the end of task 3, essential biophysical, and technical and economical specifications of the integrated model will be adopted. These specifications will be shared by all partners and will act as lighthouses for the project.

Deliverables

| Task 3<br><br>**A conceptual model for FP with NFS** | Task Managers | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| | M.A. Ngo Bieng (Partner 2- System)<br>F. Liagre (Partner 6- AFAF) | Partner1-UPR 80<br>Partner2- System<br>Partner5 - Innovation<br>Partner 6- AFAF<br>Partner 7- USP<br>Partner8- CRDPI<br>Stakeholders<br>All site leaders | D3.1: Inception meeting with stake-holders in France on mixed-species poplar plantations in short rotations | Partner 6 - AFAF | Month 2 |
| | | | D3.2: Inception meeting with stake-holders in France on mixed-species Juglans AFS | Partner6 – AFAF | Month 3 |
| | | | D3.3: Inception meeting with stake-holders in Brazil on mixed-species eucalyptus plantations | Partner 7 - USP | Month 3 |
| | | | D3.4: Inception meeting with stake-holders in Congo on mixed-species eucalyptus plantations | Partner8- CRDPI | Month 3 |
| | | | D3.5: synthetic document on FP with introduced NFS | Partner2 -System | Month 6 |
| | | | D3.6: List of fully documented driving rules | Partner 6 -AFAF | Month 9 |
| | | | D3.7: List of included and excluded processes | Partner2 -System | Month 12 |
| | | | D3.8: Modelix specifications | Partner2 -System | Month 12 |

Partner involvements

This task will be managed by Partner 2 - System which has a long experience in the dialog between stakeholders and modellers in tree based forest ecosystems, and particularly in agroforestry systems. Partners 6 - AFAF, Partner 7 - USP and Partner 8 - CRDPI will organize and contribute to the working meetings with the various forest wood chain stakeholders in France (nurseries, forest owners, forest and agricultural cooperatives, fire fighting, harvesting companies, industry...) in order to combine the different visions of the socio-technical factors linked with FP with NFS. This will lead to fully documented driving rules, regarding constraints, gains and drawbacks of the different alternatives for a successfull inclusion in the territorial development projects.

The literature review as well as the model specification will be performed by all partners and the results will be shared through a WEB tool. Phone conferences will be also planned to facilitate multi-polar exchanges between researchers and stakeholders. A review paper on NFS in FP will be published in a referred journal.

Risks and Backup Solutions

Two main risks arise from this task: (i) stakeholders may not be aware of the potential interest of mixed-species FP. An efficient dialog between Intens&Fix partners and end-users, and the envolvment of the main representative stakeholders during the inception working meetings will be of major importance (ii) specifications of the integrated model may evidence some antagonisms between the biophysical part and the economical one. As a solution, we will propose a multi-stage road-map based on a cost-precision approach to reach the appropriate mid-point between the representation of the system and the economical feasibility.

### TASK 4 TURNING THE CONCEPTUAL MODEL INTO EQUATIONS AND CODING

Objectives

The integrated model will reasonably adopt simplified assumptions on most biophysical aspects of mixed-species FP. This task aims at assembling the appropriate models for each process. They will be either created from scratch, or re-use previous modules when available.

Detailed Workplan and Methods

Each module will be elaborated by comparison with more detailed models made available by each team for each key process: for example, Maestra (Bauerle et al., 2006; Medlyn et al., 2005) for tree photosynthesis and respiration; E-Dendro (Saint-André et al. 2002) for production and between tree competition; Stretch (Vincent and Harja, 2008) for canopy plasticity; Hi-sAFe (Mulia and Dupraz, 2006) for tree root plasticity; Continuous Evolution Model (CEM: Agren and Bosatta, 1996; D'Annunzio et al., 2008), and MOMOS (Pansu et al., 2004) for litter decomposition and soil Nitrogen dynamics for fate of fixed N, including N and P interactions.

In a first step, each detailed model will be confronted (and calibrated if necessary) to the data gathered in WP2 and WP3. More than the true restitution of each studied process (which will constitute of course a baseline), we will focus on the interaction between models to favour the emergence of the appropriate simplifications to be included in the integrated model. For example, a particular attention will be paid to the articulation between Growth and Yield models (such as E-Dendro) and process-based ones (such as Maestra): in the first case, the competition process is simplified and efficient (concept to be kept) but works only in even-aged and pure stands because it gathers water, nutrient and light competition into one single equation with two parameters; in reverse, process-based models are able to both retrieve the relationship used in growth and yield models and dissociate the different competition factors. By articulating the two approaches, we will then be able to produce a set of simplified equations to address inter- and intra-specific interactions within the integrated model. Similar confrontation and/or model association will be done, for example, to address coherent plant plasticity rules (Stretch/Hi-Safe), and organic matter dynamics (CEM coupled with MOMOS).

In a second step, all candidate modules will be assembled and the resulting system of equations will be confronted to the previous attempts of modelling such mixtures as reviewed into task 3. The experimental sites of the project will also be used for a complete validation of the biophysical model. The cost of simplification will be assessed by comparing the simulations performed with the integrated model to the simulations made process by process by each dedicated model.

A two-year post-doc position will be opened for coordinating the coding of the model, with the support of modellers of the different partners. A modelling platform well adapted to the purpose will be selected. The CAPSIS platform (Coligny et al., 2003) which is designed for the long term modelling of forests and which offers a large set of generic tools (stand and tree representation, thinning operations, etc..) to the modeller community, may be adopted if agreed by all participants.

Deliverables

| Task 4 | Task Managers | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Coding "Modelix" the Intens&Fix numerical model** | L. Saint-André (Partner 1- UPR 80)<br>S. Roux (Partner 2 - System) | Partner 1 - UPR80<br>Partner 2 - System<br>Partner 3 - EEF<br>Partner4- Eco&Sols<br>Partner 6 - AFAF | D4.1: Modelix structure approved | Partner 1 - UPR 80 | Month 24 |
| | | | D4.2 : Modelix beta version released with documentation | Partner 2 -System | Month 26 |
| | | | D4.3 : Final report of validation of Modelix modules | Each responsible. of a model used to validate a module of Modelix | Month 28 |

Partner involvements

This part will imply all modellers of the different teams. As for Task 2, the key point will be to share concepts and constraints between modellers. This will be achieved by regular meetings, telephonic/visio conferences, specific workshops dedicated to each processes to be organized in collaboration with researchers involved in WP2 and WP3. The two-year post-doc position opened for this task will considerably facilitate the integration process.

Risks and Backup Solutions

Build an integrated system is definitely a risky option, but it is worth the challenge. The current Hi-sAFe model was designed for tree mixtures or tree-crop mixtures and could be used as a spare model if necessary, but would need to be upgraded for several processes.

### TASK 5. UTILIZING THE MODEL TO EXPLORE DRIVING RULES AND ECONOMICAL FEASIBILITY FOR THE 4 SITES OF THE PROJECT

Objectives

Using the integrated model will stimulate the comparisons across sites and result in a multidisciplinary asesessment of NFS in FP. Several technical management options will be explored with the model. The biophysical outputs of the model will be used to feed an economical analysis that will be conducted in close cooperation with the stakeholders.

Detailed Workplan and Methods

To ensure an efficient diffusion of the model outside of the modellers group, a member of each team will be trained to use the model. This also implies that a standardized documentation (model approach, range of application, parameterisation and calibration specifications, input data, program control) will be provided according to the recommendations given in the Project QLK5-CT2000-01349 funded by EC (Pretzsch et al. 2002). The main idea is to check what is necessary to (i) use the model, and (ii) adapt it to new situations – This work will be done in close collaboration with WP2, WP3, and WP4.

In parallel, a set of baseline simulations will be produced for each experimental site. Specific mathematical and statistical tools (uncertainty analysis, sensibility analysis) will be used to assess the stability of the system of equations and its ability to simulate a wide range of mixed-species FP with NFS. Exploring driving rules will be either direct by introducing the integrated biophysical model into Farm-sAFe (a decision software for technical and economical simulations provided by partner 6 - AFAF), or indirect via look-up tables computed with the integrated biophysical model. In both cases we intend to explore the sensibility of appropriate state variables to key management rules or environmental constraints (as extension of the uncertainty analysis), and to test appropriate management schemes and the associated costs. The risk analysis is included in the functionalities of the economic output. The balance between the potential gains of mixed-species FP and the technical costs of the changes in the management will be calculated to guide the decision making. Some management practices that are not available on the experimental sites will be explored with the validated model, such as various proportions of NFS in the mixture, or several schemes of cutting back the NFS. The results will be discussed with the stakeholders in order to define the best decision rules, compared with the traditional practices

Deliverables

| Task 5 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Exploring decision rules with "Modelix"** | C. Dupraz (Partner 2- System)<br>G. le Maire (Partner 1-UPR 80) | Partner 1-UPR80<br>Partner 2 -System<br>Partner 3- EEF<br>Partner 5 - Innovation<br>Partner 6 - AFAF<br>Partner 8 - CRDPI<br>End-users<br>All site leaders | D5.1: Training partners to utilize Modelix<br>D5.2: Set of simulations for the 4 main sites of the project (global validation of Modelix on few experimental sites)<br>D5.3: Analysis of sensibility<br>D5.4: Assessment of decision rules | Partner 2 - System<br>Each site leader for his site<br>Partner 1- UPR 80<br>Partner 2 - System | Month 32<br>Month 38<br>Month 42<br>Month 48 |

Partner involvements

All partners will be involved in this task. As in task 4, the place of stakeholders will be essential to (i) validate the different scenarios proposed by the integrated model, (ii) define the conditions of an extended diffusion of the model to the interested stakeholders.

Risks and Backup Solutions

If the model is validated, this task should run smoothly. Therefore the risks are mainly in task 4. The main risk is a late delivery of the validated model by task 4. The overall coordinator of WP1 will be very stringent in the calendar of deliverables by tasks 3 and 4 to avoid such a mishap.

| WP2 | Plant Plasticity, Resource uptake and Resource Use |
|---|---|

**WP coordinator: D Epron (Partner 3 - EEF)**
**Other Partners:** Partner 1- UPR 80, Partner 2 - System, Partner 4 - Eco&Sols, Partner 7 - USP, Partner 8 – CRDPI

The main objectives of **WP2** are (1) to estimate whether the introduction of NFS in FP may lead to an improvement of the N status of non N-fixing tree and of the soil, (2) to determine the effect of this potential change on the growth of non N-fixing trees and on the total stand biomass production. Emphases will be placed on efficiency of resources acquisition and use and on carbon allocation, by analysing morphological and physiological plasticity, and how they are related together. Comparing results of different species association will answer the following **scientific questions**: **i**) What are the pertinent adaptative plant traits that characterize the response of trees in mixed stands?, **ii**) Are they shared between the four non N-fixing species at the different sites?, **iii**) Is there evidence for niche differentiation in mixed stands likely to improve the amounts of natural resources available for stand development? **iv)** high N inputs to the soil through $N_2$ fixation are they likely to lead to soil acidification through large amounts of nitrate leaching?

Comparison of the same species association (Eucalyptus-Acacia) in two contrasted sites (S3 / S4) will permit to disentangle environmental effects on the observed plasticity. The main fluxes of carbon, water and nutrients in monospecific *Eucalyptus* plantations have been compared with the native ecosystem of savannah in Congo (Laclau et al., 2005; Bombelli et al., 2009; Nouvellon et al., 2009), and soil organic matter stocks were compared under 60 years of monospecific *Eucalyptus* cultivation with the native savannah and pastures in Brazil (Maquère et al., 2008). Resource uptake and resource use estimated in WP2 for *Eucalyptus-Acacia* plantations will be **compared** with our current knowledge for **native ecosystems** in the same regions. The use of different planting density (Populus-Robinia, S2) will permit to study the effect of intraspecific competition on the benefice of species mixture at both species and stand levels.

### TASK 6. RESOURCE ACQUISITION AND RESOURCE USE EFFICIENCIES

Objectives

In this task we will assess the effects of introducing NFS in FP on canopy structure and root system distribution to better understand how morphological plasticity will affect the acquisition of aboveground (light) and belowground (nutrient and water) resources in a competitive environment and how these resources are partitioned between the two species in mixed plantations. We will investigate how the increase in N availability affects the light-, nitrogen- and water-use efficiencies of both species. Efficient uses of belowground resources are key factors for sustainable improvement of productivity on low fertility soils and in region where there is competition among users for water resources.

Detailed Workplan and Methods

- Photosynthetically active radiation (PAR) absorption (APAR) by each species will be computed using the multispecies version of the individual tree-based, 3D canopy model MAESTRA (Medlyn et al., 2005; see also http://www.bio.mq.edu.au/maestra/ for a complete description of this model, and associated references). The main parameters for this model are the coordinate position of each tree, the tree height, crown length and crown diameter, and tree leaf area (of each tree), leaf area distribution within tree crowns, and leaf angle distribution. Tree leaf area and crown dimensions will be estimated from species specific allometric relationships with tree diameter and height. Leaf angle distribution functions (LADF) will be parameterized from leaf angle measurements. The model will be validated using direction gap fraction measurements obtained with an LAI2000 or by hemispherical photography. The model will then be applied at a semi-hourly time step using continuous measurements of incoming shortwave radiation (meteorological station above the canopy), in order to estimate the PAR absorbed by each species, and to investigate intra- and inter-species competitions for light.
- Light-use efficiency of both species will be assessed by combining estimation of net primary productivity and absorbed light, and will be analysed in regard to the main leaf traits (chlorophyll and N contents, leaf area

to mass ratio and leaf photosynthetic characteristics) for different positions in the canopy.
- Leaf gas exchange measurements and leaf water potential measurements will be carried out periodically on each species during the growing season (sites S2, S3, S4) in order to parameterize a leaf stomatal conductance and a leaf photosynthesis model (Ball and Berry model for stomatal conductance, and Farquhar model (Farquhar et al., 1980) for photosynthesis). These two models are coupled and embedded in the MAESTRA model.
- Intrinsic Water-use efficiency (WUE) estimated at the leaf level (WUE = carbon assimilation / stomatal conductance) will be compared to its well-known surrogate, the carbon isotope composition ($\delta^{13}C$) in leaves measured by mass spectrometry (all sites). The fully-parameterized MAESTRA model will be applied using meteorological data (incomping PAR and global radiation, air temperature and relative humidity, wind speed) in order to estimate GPP, and transpiration of each tree of the pure and mixed stands. Model simulations will be validated by comparing simulated transpiration with sap flow measured on several trees (sites S2 and S3). WUE at the whole plant level will be computed as the ratio between simulated GPP and transpiration ($WUE_{GPP}$), and the ratio between measured biomass production and water consumption ($WUE_{ANPP}$). These WUE will be compared with the $\delta^{13}C$ in cellulose in the most recent annual ring.
- Nutrient-use efficiencies (NUE) will be determined as NUE = net primary productivity / net uptake of N or P, from chemical analysis of samples representative of the different tree organs collected at each site (successive destructive tree sampling throughout the rotations). At the leaf level, nutrient-use efficiency depends on photosynthesis per unit nutrient, mean residence time of nutrient (which depends on leaf life span) in the foliage and resorption.
- Trench profiles (root density maps on front profile) and auger core samplings will be done one and three years after site plantation to describe the vertical and horizontal distribution of the root system of both species in pure and mixed stands (S2, S3, S4).

Deliverables

| Task 6 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Resource acquisition and resource use efficiencies** | A Thongo (Partner 8- CRDPI) N. Marron (Partner 3 - EEF) | Partner 1- UPR80<br>Partner 2- System<br>Partner 3 - EEF<br>Partner 7 - USP<br>Partner 8 - CRDPI | D6.1: Preliminary report on the effect of NFS on PAR absorption in different types of FP | Partner1- UPR80 | Month 18 |
| | | | D6.2: Preliminary report on the effect of NFS on root distribution in different types of FP | Partner1- UPR80 | Month 18 |
| | | | D6.3: Preliminary report on the effect of NFS on the efficiency to use water and nutrients in different types of FP | Partner 3 -EEF | Month 18 |
| | | | D6.4: 3D model of light distribution | Partner1- UPR80 | Month 36 |
| | | | D6.5: Preliminary report on the effect of NFS on PAR absorption in different types of FP | Partner1- UPR80 | Month 36 |
| | | | D6.6: Report on the effect of NFS on root distribution and architecture in different types of FP | Partner1- UPR80 | Month 48 |
| | | | D6.7: Report on the effect of NFS on the efficiency to use water and nutrients in different types of FP | Partner 3 -EEF | Month 48 |

Partner involvements
Experiments will be conducted on all sites except i) leaf gas exchange done only on sites S2, S3 and S4, ii) sap flow measured only on S2 and S3. Partner 1- UPR80 will be in charge of the coordination of the description of the light microclimate and the estimation of light transmission, LAI and gap fractions on all the sites. This partner will also characterize root distribution and implement MAESTRA. Partner 3-EEF will be in charge of C and N analyses and of coordination of leaf level measurements (morphology, life span, gas exchanges and isotope composition).

Risks and Backup Solutions

There is little risk of failure since most the measurements in Task 6 rely on experienced methodologies for the involved teams.

### TASK 7 GROWTH AND CARBON ALLOCATION

Objectives

In this task we will consider the modulation of carbon allocation among plant organs of both species by the availability of plant resources, and how change in N availability will change the allocation of photosynthetate to roots and to the associated microflora. The hypothesis tested is that the increase in N availability in mixed-species plantations will shift allocation from belowground to above ground organs of the non-N fixing tree (Forrester et al., 2006), but that the magnitude of this shift will depend on the species and, for a given species, on the limitation by other resources (P, light, water) and by intraspecific competition through planting density. In addition, we will compare spatial variability of soil respiration between pure and mixed stand and we will relate this variability to heterogeneity in rooting, litter fall and microbial activities (in cooperation with WP3).

Detailed Workplan and Methods

- Annual wood volume and biomass increments will be calculated from tree inventories, biomass sampling and allometric equations, and further converted into biomass C increments knowing C concentration of plant organs. Total NPP will be determined through repeated measurements of the dry mass of vegetation components and through estimation of litterfall and root production.
- Total below ground carbon allocation (TBCA: Giardina and Ryan, 2002) will be derived from measurements of soil respiration (dynamic closed chambers connected to IRGA), aboveground litterfall, and from the change in belowground C biomass. Collars for soil respiration and litter traps will be installed to cover spatial heterogeneity induced by the planting scheme, especially in the mixed stands. Root biomass increment and litter layer increment will be calculated from sequential measurement of root biomass and litter mass. Changes in soil carbon with time will be evaluated. No leaching of carbon will be checked in the experiment set up in Brazil (Eucalyptus-Acacia) and assumed in the other experiments. A particular emphasis will be put on the changes in fine root lifespan and turnover rate which would allow the partitioning of TBCA between root (and rhizosphere) production and respiration.
- This approach provides estimations of TBCA at the stand level, and therefore a comparison of the TBCA of pure and mixed-species stands will be possible. However, it does not allow a quantification of the TBCA of each species in the mixture. A second approach will be used on some specific sites. TBCA for each species will be derived from gross primary productivity (GPP) of each species estimated from an individual tree-based model (MAESTRA) and aboveground net primary productivity (task 6) assuming a constant carbon use efficiency (CUE). It will be checked that the TBCA estimated from the second approach is consistent with the TBCA estimated from the first approach. At site S3, the hypothesis of a constant CUE will be checked from measurements of leaf, branch and bole respiration.

Deliverables

| Task 7 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Growth and Carbon Allocation** | D. Epron (Partner 3 - EEF) Y. Nouvellon (Partner 1- UPR80) | Partner1- UPR80 Partner2- System Partner 3- EEF Partner 7 - USP Partner 8-CRDPI | D7.1: Preliminary report on fine root dynamics and life span | Partner 3 - EEF | Month 18 |
| | | | D7.2: Final report on fine root dynamics and life span | Partner 3- EEF | Month 36 |
| | | | D7.3: Report on growth and primary productivity from an individual tree-based model | Partner1- UPR80 | Month 36 |
| | | | D7.4: Report on the effect of NFS on the spatial variability of soil respiration in different types of FP | Partner 3 - EEF | Month 36 |
| | | | D7.5: Report on the effect of NFS on the TBCA in different types of FP | Partner1- UPR80 | Month 48 |

Partner involvements

Experiments will be conducted on all sites. Partner 1- UPR 80 will be in charge of tree growth measurements (inventories and biomass) and of modelling growth primary productivity from an individual tree-based model for estimating TBCA at species level. Partner 3 - EEF will be in charge of soil carbon budget (soil respiration, litter fall, root turnover) and will calculate TBCA at stand level.

Risks and Backup Solutions

There is little risk of failure since most the measurements in Task 7 rely on experienced methodologies for the involved teams. Accurate estimates of fine root life span are still challenging but failure will not jeopardize other aspects of the task.

### TASK 8. PLANT AND SOIL NITROGEN BUDGET

Objectives

The objective of this task will be to elucidate how site characteristics or legume tree management influence the spatio-temporal variations in $N_2$ fixation of the NFS the N budget of the plant and that of the soil. For perennial plants, a predominant function is the storage of carbon and nitrogen compounds to sustain regrowth during the following growing season or after harvest. Due to N limitation in the soil and within the tree, N is mainly invested during the growing season in aboveground organs to maximize C gain. So N storage in perennial organs mainly occurs when growth slows down (winter or dry season according to the species). $N_2$ fixation is directly related to the biomass production of the NFS, and its fixing efficiency. Biomass production of NFS is generally positively correlated with resource (light, water, nutrients) availability. However efficiency of $N_2$ fixation can be limited by sufficient soil N, but is expected to be positively correlated with P availability and also competition with other species for N. Increased N input in the soil through $N_2$ fixation by NFS may lead to adverse consequences as N-$NO3^-$ leaching and soil acidification (Tang et al., 1999).

Detailed Workplan and Methods

- $N_2$ fixation of the legume species and the N budget of the plant system will be quantified using $^{15}N$ labelling (dilution method) in pure stands and in mixed stands on all sites, and in different tree arrangement densities of mixed stands on all sites. N concentration and $\delta^{15}N$ values of above and belowground components of N-fixing and non N-fixing, trees will be determined 1 and 3 years after planting in all sites.
- For all the FP studied, the NFS associated with native *Rhizobium* will be grown in controlled conditions with different levels of P in the solution. Growth measurement and total N accumulation in plants will enable us to calculate P efficiency of $N_2$ fixation for each nodulated NFS.
- The different components of the internal cycle of N (resorption, storage, remobilisation) and their contributions the whole plant N budget (recycling *vs* absorption and/or fixation) will be studied by destructive samplings operated on a selection of non-N-fixing trees in pure and mixed stands at each site, at two determinant periods of the year (dormant/dry and growth/wet periods) and during the 3 years. Roots, leaves, buds, branches, stems and stumps will be harvested, weighted and analyzed. Seasonal variations of nitrate, amino acids, soluble proteins (VSP, electrophoresis), starch and soluble sugars will be studied. Total amount of N and/or C incorporated in starch, soluble sugars, soluble proteins and amino acids and nitrate for each organ and tree will be calculated by taking into account the biomass of each tree compartment. In addition, the fate of $^{15}N$ absorbed by the plants after labelling in the storage compartments will be monitored from their accumulation to their remobilization.
- The nitrogen soil budget will be assessed at site S3. This site has been chosen because the soils have high hydraulic conductivities (sandy texture), are highly weathered with relatively low buffering capacity and thus sucessive rotations of fast-growing trees are likely to lead to nutrient unbalance, nitrate losses by leaching, and soil acidification. Moreover biogeochemical studies have been conducted for 7 years on pure eucalyptus stands located nearby the experiment (Laclau et al., 2010) and extra funds have already made it possible to set up a lysimetry device. Nitrogen soil budget will be calculated from differences between input and output fluxes. The main inputs to the soil will be: i) $N_2$ fixation, ii) Nitrogen fertilisation, and iii) Wet and dry atmospheric depositions (Laclau et al., 2010). Output fluxes from the soil will be: i) N content within tree biomass that will be quantified annually, ii) $N_2O$ emissions that will be neglected in this sandy soil

(Hergoualc'h et al., 2008), and iii) N losses by deep drainage. Concerning this last flux, the time course of N-$NO3^-$ and N-$NH4^+$ leaching will be quantified from soil solution collected every 7 days and bulked every four weeks. Lysimeters have been installed in 3 blocks for 3 treatments: the pure *Eucalyptus grandis* and *Acacia mangium* stands, as well a mixture in a proportion of 1:1 between *E. grandis* and *A. mangium*. In each treatment plot 3-5 replicates of mini-lysimeters have been installed under the litter and ceramic cups at the depths of 30, 50, 100 and 300cm. Ceramic cups are connected to a vacuum pump maintained at a suction of about -60 kPa checked automatically every 6 hours. Three to five replicates of Campbell CS616 probes have also been installed representatively near and between the trees at the depths of 15, 50, 100, 200, 300, 400, 500 cm to monitor soil water content every 30 minutes in the 3 treatments (in one block). N losses will be expressed on an area basis by multiplying water fluxes at the depths where the lysimeters were installed by N concentrations in gravitational solutions for each period. Water fluxes at each depth will be estimated calibrating the Hydrus 1D model from the monitoring of soil water content at each depth. Besides nitrogen, all the major cations and anions will be analysed in the samples of soil solutions in order to compute proton budgets and to assess the risks of soil acidification for each treatment.

Deliverables

| Task 8 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Nitrogen Budget** | JLM Gonçalves (Partner 7- USP) D. Gérant (Partner 3 - EEF) | Partner 1- UPR80<br>Partner 2 - System<br>Partner 3 - EEF<br>Partner4- Eco&Sols<br>Partner 7 - USP<br>Partner 8 - CRDPI | D8.1 Preliminary report on the factors influencing $N_2$ fixation of the different NFS | Partner 1-UPR80 | Month 18 |
| | | | D8.2 Preliminary report on the soil N budget and soil acidification | Partner 7 - USP | Month 24 |
| | | | D8.3 Report on the intra and inter annual variations of the amounts of N and C storage compounds at the whole tree level. | Partner 3 - EEF | Month 36 |
| | | | D8.4: Report on P efficiency of NFS for $N_2$ fixation | Partner4-Eco&Sols | Month 36 |
| | | | D8.5 Report on the factors influencing $N_2$ fixation of the different NFS | Partner 1 - UPR80 | Month 48 |
| | | | D8.6: Report on N budget of plant system | Partner 3 - EEF | Month 48 |
| | | | D8.7: Report on N soil budget and soil acidification | Partner 7 - USP | Month 48 |

Partner involvements

Experiments will be conducted on all sites, except for soil nitrogen soil budget (site S3). Partner 3-EEF will be in charge of nitrogen storage and internal cycling. Partner 1-UPR 80 will be in charge of estimating nitrogen fixation by the NFS. Partner 4-Ecosol will manage experiments in controlled conditions. Partner 8-USP will be in charge of nitrogen soil budget

Risks and Backup Solutions

The $^{15}$N labelling method is reliable in all cases, if used properly, in contrast to natural abundance methodology. Consequently, the former approach will be used in all sites. The method which uses the natural abundance of $^{15}$N will still be used for specific studies of secondary importance in some sites.

| WP3 | Nutrient bioavailability and soil Functional Ecology |
|---|---|

**WP coordinator: C Plassard (Partner 4 - Eco&Sols)**
**Other Partners:** Partner 1 - UPR80, Partner 2 - System, Partner 3 - EEF, Partner 4 - Eco&ols, Partner 7 - USP, Partner 8 – CRDPI

**WP3** aims at assessing how the introduction of NFS in FP affects soil biological functioning, Organic Matter (OM) decomposition, soil nutrient dynamics (especially N and P) and plant nutrition. The belowground processes of competition / facilitation / complementarities for N and P bioavailability will be elucidated. Soil communities involved in OM decomposition and N and P cycling will be studied and a major objective of our approach is the establishment of indicators of functional diversity. The different functional groups of nematodes according to their food regime and life-history traits will be quantified (the abundancy and diversity of bacterial-feeding nematode community play a key role in controlling bacterial communities included those involved in N and P cycles). Concurrent to the study of micro-organisms functional traits and root mechanisms, such as the exudation of protons and organic compounds, WP3 will also focus on multi-trophic interactions occurring in the rhizosphere, which drive dynamics of soil N and P and thus mineral nutrition of trees. N transfer from NFS to non-NFS is an important positive flux due to $N_2$ fixation that will be quantified and the possible pathways for N transfer identified (root exudates, turn-over of NFS OM, direct transfer through AM fungi). Comparing results of different species association in sites under contrasting pedo-climatical conditions will contribute to answer to the following scientific questions: (i) Is plant species diversity increasing litter decomposition of both species and thus enhancing soil C, N and P cycling? (ii) What are the changes in functional groups of soil organisms induced by associated NFS that modify C dynamics and improve N and P bioavailability? (iii) What are the main processes of competition-facilitation modifying belowground N and P fluxes?

### TASK 9. ORGANIC MATTER DYNAMICS AND NUTRIENT CYCLING

Objectives

In Task 9 we will assess the changes in soil organic matter dynamics and N and P cycling resulting from the introduction of NFS. Decomposition rates of mixed litter as well as N and P release will be evaluated in relation with litter quality and environmental factors. We will assess the effects of new organic inputs on the changes in soil C, N, and P fluxes and associated microbial activities. We will adapt and validate C-N models with new experimental data; those models will be included in WP1.

Detailed Workplan and Methods

- Chemical and biochemical characteristics of litter of the different tree species will be carried out combining different methods (Van Soest, RMN and NIRS) and the minimum data set will include macronutrients (especially N, P), total C, lignin, soluble C, soluble polyphenolics, a-cellulose, and ash.
- Decomposition of single and mixed litter from both the NFS and the non-NFS will be measured in situ using litterbags. To evaluate the fate of litter N in the different soil components, litter of one tree species will be $^{15}N$ labelled. Single species litter from both species and mixed litter from both species (50% NFS + 50% non-NFS) will be deposed in monoculture and mixed stands. At regular intervals (to be defined, site by site, according to the respective length of dry and wet seasons), 9 samples per treatment will be collected and the NIRS technique will be used to analyse the chemical and biochemical composition of each sample.
- Organic matter decomposition experiments will be carried out also in situ on one selected system using litterbags containing labelled organic material ($^{15}N$ and $^{13}C$) and soil. The fate of litter C and N and soil C and N (priming effect) will be assessed. The distribution and the activities of microbial communities will be evaluated. This experiment will be essential to calibrate the MOMOS model (Pansu et al., 2004).
- The dynamic of soil organic matter after afforestation on previous C4 culture (S2) or pasture (S3) will also be studied in pure and mixed plantation by measuring the change with time of the isotope composition of soil respired $CO_2$ and of soil organic matter (Epron et al. 2009).

- Soil N mineralization and nitrification will be measured in standard conditions in laboratory in order to compare the different sites and treatments. In order to take into account specific local climatic conditions and variations throughout the year, mineralisation and nitrification of soil N will be studied by field incubation in monocultures and mixed-species plantations (Raison et al., 1987).
- Then the results obtained in the different sites on litter and soil C and N dynamics will be used into the CEM flow developed by Agren and Bosatta (1996) for forest humus and used in Eucalypt and beech plantations (D'Annunzio et al., 2008) and into the MOMOS Model developed by Pansu et al. (2004) for SOM dynamic (see WP1).
- Easily available mineral P (Pi) and organic P (Po) will be quantified after bicarbonate extraction (Olsen). Composition of Po will be identified using $^{31}$PNMR. Potential mineralization of Po will be assessed using phosphatases or phytases from a fungal (either ectomycorrhizal or saprophyte species) or bacterial origin. Also, phytate degradation by soil enzymes will be quantified following soil incubation with known amounts of phytate.

Deliverables

| Task 9 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Organic matter dynamics and nutrient cycling** | JM Harmand (Partner 1- UPR80) B. Zeller (Partner 3 – EEF) | Partner 1 - UPR80<br>Partner 2 - System<br>Partner 3 - EEF<br>Partner4-Eco&Sols<br>Partner 7 - USP<br>Partner 8 - CRDPI | D9.1: Preliminary report on the effect of NFS on litter decomposition and N and P release | Partner 3 -EEF | Month 18 |
| | | | D9.2: Preliminary report on the effect of NFS on N and P availability in different types of FP | Partner4- Eco&Sols | Month 18 |
| | | | D9.3: Report on organic input on SOM turnover | Partner4- Eco&Sols | Month 36 |
| | | | D9.4 Adaptation and validation of C-N models | Partner 1 – UPR 80 | Month 36 |
| | | | D9.5: Report on the effect of NFS on N and P availability in different types of FP | Partner 1- UPR 80 | Month 40 |
| | | | D9.6: Report on the effect of NFS on litter decomposition and N and P release | Partner 3 - EEF | Month 42 |
| | | | D9.7: Report on the effect of NFS on in situ SOM turnover | Partner 3 - EEF | Month 42 |
| | | | D9.8 Report on C-N models | Partner 1- UPR 80 | Month 42 |

Partner involvements

Experiments will be conducted on all sites except the effect of new organic input on soil organic matter turnover that will be conducted by Partner 4- Eco&Sols in only one selected site. Partner 3 - EEF will be in charge of the coordination of litter decomposition experiments. Partner 1-UPR 80 will be in charge of the coordination of the studies on soil N mineralisation. Partner 4-Eco&Sols will be in charge of soil P availability studies. Partner 3 -EEF will be in charge of *in situ* SOM turnover studies. Partner 1-UPR 80 and Partner 4 - Eco&Sols will be in charge of adaptation and validation of soil C and N models.

Risks and Backup Solutions

The main risk is to be unable to produce rapidly a sufficient amount of $^{15}$N labelled litter from a given or two given species. Our backup solution is to start as soon as possible with the $^{15}$N labelled litter production, and to label more trees that normally needed to increase the amount of litter. According to the tree species the best labelling methods will be selected.

**TASK 10. SOIL ECOLOGY OF MICROBIAL AND MICROFAUNAL COMMUNITIES AND IDENTIFICATION OF MECHANISMS OF COMPETITION / FACILITATION FOR N AND P BIOAVAILABILITY**

Objectives

For this task we will identify differences in soil microfaunal and microbial community structure as affected by the presence of NFS. We will also assess the variation of microbial/microfaunal functions possibly involved in N and P cycling (nitrifying, P solubilising, phosphatase and phytase producers). Mechanisms of N transfer between NFS and non NFS will be elucidated and quantified, and the role of trophic interactions in the rhizosphere for improvement of N and P nutrition of non fixing species will be assessed.

Detailed Workplan and Methods

- Assessment of nematofauna (density and diversity of functional groups) will be carried out at least once in each plot during the project. Sampling, extraction and identification of soil-inhabiting nematodes will be completed according to the ISO 23611 norm, Elutriation, and identification in mass slides of nematodes. Relationships between soil parameters, silvicultural treatments and nematode communities will be studied in order to establish whether or not significant traits of nematode communities can reflect the presence of NFS and the improvement of N and P cycling.

- Functional bacterial communities involved in cycling of N and P will be characterized using 3 descriptive parameters: (i) the activity (estimated in Task 9), (ii) the density of genes involved in the cycles by real-time PCR (Henry et al., 2006) and (iii) the genetic structure by molecular fingerprinting (PCR-DGGE, Muyzer et al., 1993). Soils displaying significant effect of NFS introduction regarding nitrification rates (N cycle) and phytase and/or phosphatase activities (P cycle) will be used to analyse gene density and diversity of total nucleic acids (RNA and DNA) extracted from soil (Martin Laurent et al., 2001). Nitrifying bacterial communities will be studied using molecular probes (already available) to target AMOA and NOR genes. Whole bacterial communities potentially involved in phytate and organic P degradation will be identified using specific tools (produced during the project) to probe phytase and acid phosphatase genes. In parallel, bacteria able to use phytate as sole source of P will be isolated *in vitro*. This collection will also be screened for acid secretion activities (solubilisation of inorganic P) by cultivation on Phosphate Solubilising Bacteria medium (Kim et al., 1997) and used further to determine the specificity of the tools (phytase primers) designed during this project. In addition to soil bacterial communities' analysis, we will also focus on the capacity of rhizobial strains to produce phytase and acid phosphatase in nodule or at its surface using *in situ* RT-PCR with specific primers recently designated for *Phaseolus* nodules (Amenc, 2008).

- The fungal communities colonising soil organic matter and tree roots will be identified by molecular methods that will be carried out on DNA extracted from these materials. A special attention will be paid to the AM species that could be associated simulataneously with fixing and non-fixing species.

- The *in situ* pathways of the N transfer from NFS species to non-NFS in field conditions will be studied using the stem labelling technique which consists of injection of labelled $^{15}$N ($NO_3$,) into the stem of $N_2$ fixing trees during a few hours at days when transpiration is significant. Labelled $^{15}$N is metabolized in the leaves and reallocated to growing leaves and roots according to their sink strength. $^{15}$N is released by the roots (root exudates) (fine root turnover) or directly transferred by AM fungi to surrounding non fixing trees which become subsequently enriched in $^{15}$N. A necessary precaution to confirm those pathways is to exclude during 2-3 weeks other possible tree - to - tree N transfers like throughfall and litterfall. A dynamic sampling of fine roots and leaves of non NFS will allow to access both the short term (2-3 weeks) and the mid term (a few months) dynamics of the N transfer. The mid term transfer will include the other N recycling pathways, i.e. litter turnover and throughfall.

- To elucidate further the mechanisms and controls of the N transfer, a detailed study of the role of trophic interactions in the rhizosphere for improvement of N and P nutrition of non NFS will be carried out in controlled conditions. The legume species, inoculated with rhizobium isolated from field-sampled nodules, will be grown in simplified conditions, as well as the non-fixing tree species. NFS species, whether nodulated or not, and tree will then be transplanted in mesocosms composed of different combinations of native soil, either intact or heat-disinfected and re-inoculated with soil bacterial populations, bacteria-feeding nematodes and earthworms if they are present. N fixation transfer rates will be assessed using $^{15}N$ labelling methods ($N_2$ supply or leaf feeding with urea); impact of NFS species and trophic interactions on N and P nutrition of non NFS will be assessed measuring plant N and P accumulation dynamics. Mineralization capacities of rhizosphere communities, including rhizobium populations, involved in these changes of N and P availability will be assessed using methods described previously. In addition, mycorrhizal associations, whether ectomycorrhizal or endomycorrhizal, will be established by molecular analysis of DNA extracted from roots of both type of plants.

Deliverables

| Task 10 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| **Soil ecology and Mechanisms of competition / facilitation** | C. Plassard (Partner4-Eco&Sols)<br>C. Villenave (Partner4-Eco&Sols) | Partner 1-UPR80<br>Partner 2 - System<br>Partner 3- EEF<br>Partner 4-Eco&Sols<br>Partner 7- USP<br>Partner 8-UR2PI | D10.1: Production of Phytase and Pase gene probe to target bacterial communities | Partner4-Eco&Sols | Month 18 |
| | | | D10.2: Report on Nematofauna communities | Partner4-Eco&Sols | Month 36 |
| | | | D10.3: Report on functional bacterial communities in N and P Cycles | Partner4-Eco&Sols | Month 36 |
| | | | D10.4: Report on N transfer pathway *in situ* | Partner 3 - EEF | Month 36 |
| | | | D10.5: Report on Trophic relationships in mesocosms | Partner4-Eco&Sols | Month 36 |
| | | | D10.6: Report on the effect of NFS nematofauna distribution in different types of FP | Partner4-Eco&Sols | Month 40 |
| | | | D10.7: Report on the effect of NFS on mechanisms of N transfer and modulation by trophic relation-ship in different types of FP | Partner 1- UPR80 | Month 48 |

Partner involvements
Partner 4-Eco&Sols will be in charge to assess nematofauna and microbial communities and the quantification trophic interaction in the rhizosphere. Partner 1- UPR 80 and partner 3 - EEF will be charged to quantify N transfer in the field. Assessment of nematofauna and N transfer will be carried out in all sites. Variations of microbial populations involved in N and P cycling will be established in one site exhibiting a significant effect of NFS introduction on nitrification rates and/or P mineralization rates. The detailed study of the role of trophic interactions will be carried out in Montpellier (Partner 4 - Eco&Sols) in the *Populus sp./Robinia pseudoacacia* plots (S2) because these experiments require to use great amounts of soil that will be difficult to import and then to manipulate in controlled conditions. Similar experiments might be performed in Brazil (S3) and Congo (S4) by partner 7 - USP and partner 8 - UR2PI in collaboration with partner 1- UPR 80 if extra funding is obtained.

Risks and Backup Solutions
The main risk is to be unsuccessful in producing specific tools to target functional bacterial communities producing phytase and phosphatase if we cannot find conserved domains among the sequences in public data bank. Nevertheless, the diversity of culturable bacterial populations able to release phytase and phosphatase activities *in vitro* has never been identified and will constitute a first approach that could compensate for the lack of specific primers.

| WP4 | Stakeholders' Innovation process and impact analysis |
|---|---|

**WP coordinator: JM Kalms (Partner 5 - Innovation)**
**Other Partners:** Partner 1- UPR 80, Partner 2 - System, Partner 3 - EEF, Partner 6 - AFAF, Partner 7 - USP, Partner 8 – CRDPI

The main objectives of **WP4** are: 1. To understand the socioeconomic determinants of the former and actual forestry practices and the stakeholder's motivations to improve the forestry system efficiency by implementing an ecological intensification. 2. To assess the economical and social impacts of these innovations for each wood goods and products chain stakeholder, compared if possible with former practices ones.

WP4 will develop a close cooperation with **WP1** (task 3): the design of the biophysical model should be fit to address practical questions raised by stakeholders, as evidenced during the inception meetings. WP4 will finally use the simulation outputs of **WP1** (task 5) to feed the cost-benefit analysis of the innovative options.

Emphasis will be put on a participative approach at all steps of the activities including meetings with all groups to share the diagnosis results up to validate the conclusions and make joint recommendations with the other WP. A participative approach is even more necessary because in most studied cases the rotation is much longer than the project cycle (4 years).

Comparing the socioeconomic effects of different technical schemes involving various $N_2$ fixing species associations adapted to the local conditions, will help to answer the following **scientific questions**:

- **i)** Can these forestry associations contribute to an ecological intensification socially sound?
- **ii)** Can a participative approach used to validate these innovations lead to improve the wood goods and products chain?

### TASK 11. SOCIOECONOMIC DIAGNOSIS OF THE DETERMINANTS OF THE FORMER AND CURRENT FORESTRY PRACTICES

Objectives

The main objective is to identify for each site the determinant factors of the evolution of forestry practices leading to the current ones, and to guide the biophysical modelling process by identifying key variables and processes that should be incorporated.

Detailed Work plan and Methods

- Inception meetings in the different sites in **connexion** with **WP1** will be focused on a participative approach of this diagnosis to take into account the stakeholders' perception, point of view and expectation about this topic. All stakeholders involved in the wood goods and products chain are considered: large landholders, smallholders, technical and financial support institutions, wood products enterprises, civil society (as traditional rulers, etc.).
- The results of this preliminary diagnosis will be used to define the hypothesis for the agrarian diagnosis (i.e M. Mazoyer http://www.inapg.inra.fr/ens_rech/ses/index.htm). The survey will use semi-structured interviews and will be performed in several regions of the three countries (namely two regions for agroforestry schemes in France, two regions for VSRC in France, two regions for Eucalyptus plantations both in Brasil and in Congo). This will allow identifying the determinants of farmers and forest growers former land use changes decisions. A methodological framework with definition of common variables for the various fields to support such interviews will be elaborated during the first month of the project.
- A field work in each site will define the studied zone and the stakeholders.
- The diagnosis should analyze the context components (public policy, public support to forestry development, FSC, etc.) to define the main evolution phases of forest tree plantations growing

dynamic.

- The diagnosis should focus also on the relations between the various wood goods and products chain actors, especially for the different types of forest tree growers.
- The objectives and perceptions of the forest tree growers should be analyzed in relation with their production factors, their local knowledge of forestry and their expectations for the forestry activity function (economic or/and patrimonial role, cultural value).
- In some cases (Africa), the identification of the importance of some traditional/cultural rules for social actors.
- Restitution of the results to the stakeholders to validate or adjust the conclusions.

Deliverables

| Task 11 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| | M Dulcire<br>(Partner 5 – Innovation)<br>F Liagre<br>(Partner 6- AFAF) | Partner 1- UPR80<br>Partner 2- System<br>Partner 3 - EEF<br>Partner5- Innovation<br>Partner 6 - AFAF<br>Partner 7 - USP<br>Partner 8 - CRDPI | D11.1: For each site, preliminary report on the inception meeting and study hypothesis for all sites | Congo : CRDPI<br>France : AFAF<br>Brazil : Innovation | Month 3 |
| | | | D11.2: For each site, working documents on the survey design and field work | Congo : CRDPI<br>France : AFAF<br>Brazil : Innovation | Month 6 |
| | | | D11.3: Synthesis report on the requirements for the biophysical model in terms of processes and variables to be included | System | Month 6 |
| | | | D11.4: For each site, analysis report on: i) main phases of agrarian evolution for forest tree growers, ii) the wood goods and product chain analysis, iii) the forest tree growers perception and practices determinants and evolution until actual ones | Congo : CRDPI<br>France : AFAF<br>Brazil : Innovation | Month 12 |
| | | | D.11.5: For each site, report on restitution meeting with the stakeholders- shared conclusions | Congo : CRDPI<br>France : AFAF<br>Brazil : Innovation | Month 14 |
| | | | D11.6: Synthesis on socioeconomic determinant of local forest growers practices: comparative study for all sites | Innovation | Month 16 |

Partner involvements

Most of the activities of task 11 are under the responsibility of Partner 5 - Innovation, in close relationship with Partner 2 - System (WP1 leader) and local Partners who will be mobilized for field survey and data analysis: in France Partner 6 - AFAF, in relation with the Chambre d'Agriculture des Vosges for the VSRC association; in Brazil Partner 5 – Innovation with a local contractor (Ecomidia); in Congo Parner 8 - CRDPI.

Risks and Backup Solutions

One of the risks in this task is the current bias of the information given by some of the stakeholders: this can be avoided by a confident relationship established between stakeholders and researchers, that is fundamental.

## TASK 12. SOCIOECONOMIC FOLLOW-UP: ANALYSES AND STAKEHOLDER'S VALIDATION

Objectives

The main objective is i) to assess the socioeconomic performance of the tested or promoted associations with NFS, leading to ecological intensification of forestry and agroforestry systems and ii) to value the simulation results of innovative options provided by WP1. In each site, the other objective is to verify the various social and economic factors that may prevent or favour the development of the innovations by the stakeholders.

Detailed Work plan and Methods

- Full utilisation of simulation runs provided by WP1 (task 5) on several innovative options for each study site. In France, the results will be integrated in a decision-support modelling tool (Farm-sAFe model upgraded for NFS impact), that will help to optimise plantation schemes at the farm level. This model may be evaluated in Congo to question 1) the forestry versus Agroforestry patterns dilemma 2) the with/without $N_2$ fixing species option.
- The cost-benefit analysis of the implementation and maintenance of the mixed-species system introduced will be tested by the several growers involved, in each site experiments, and may take advantage of partial data from selected growers.
- The results will be faced to the current constraints and strategies of the main growers types identified in each region and the possible changes expected in the wood products chains dynamic.
- A special attention will be paid to the possible adjustments or supports needed so that the smallholders have the means to develop the innovation after checking they need it.
- Definition of accurate indicators of sustainability for these innovations in each site.
- All results will be shared with stakeholders in each site for validation and conclusions.
- The closure project meeting will give the opportunity to discuss the various sites results, to compare the conclusions, and make recommendations.

Deliverables

| Task 12 | Task Manager | Partners | Deliverables | Deliverable responsible | Delivery time |
|---|---|---|---|---|---|
| | JM Kalms (Partner 5- Innovation) MG Piketty (Partner 5- Innovation) | Partner 1- UPR80<br>Partner 2- System<br>Partner 3 - EEF<br>Parter5- Innovation<br>Partner 6 - AFAF<br>Partner 7 - USP<br>Partner 8 - CRDPI | D12.1: For each site, report on economic performance of the implementation and maintenance of the innovation | Congo : CRDPI<br>France : AFAF<br>Brazil: Innovation | Month 18 |
| | | | D12.2: For each site: report on the various stakeholders innovation process (link between research and their beneficiaries) | Congo : CRDPI<br>France : AFAF<br>Brazil: Innovation | Month 30 |
| | | | D12.3: Calibration/validation of Farm-sAfe model (France-Congo) | System | Month 30 |
| | | | D12.4: For each site: report on restitution meeting for validation with the stakeholders and shared conclusions | Congo : CRDPI<br>France : AFAF<br>Brazil: Innovation | Month 40 |
| | | | D12.5: Best options for N2 fixing species in FP as deduced from simulation runs provided by WP1 | System | Month 42 |
| | | | D12.6: Final meeting report | Innovation | Month 48 |

Partner involvements

The task will be under the Partner 5 coordination, in close relationship with Partner 2 - System (WP1 leader). For each deliverable one local Partner will be responsible for field survey and data analysis, and for reporting:

in France Partner 6 - AFAF; in Brazil Partner 5 – Innovation with a local contractor (Ecomidia); in Congo Parner 8 - CRDPI.

Risks and Backup Solutions

- As for the previous task, a risk is the current bias of the information given by some of the stakeholders: this should be avoided by a confident relationship established with the research local co-responsible of the task.
- The availability of the Farm-sAFe model will help to reach our objectives, as it will save much time in the design of an appropriate micro-economic model of the innovations. However, this model was designed for French farms ruled under the European Common Agriculture policy. There is a risk that the adaptation of the model to the Congo conditions may not be straightforward.

## 3.4. CALENDRIER DES TACHES, LIVRABLES ET JALONS

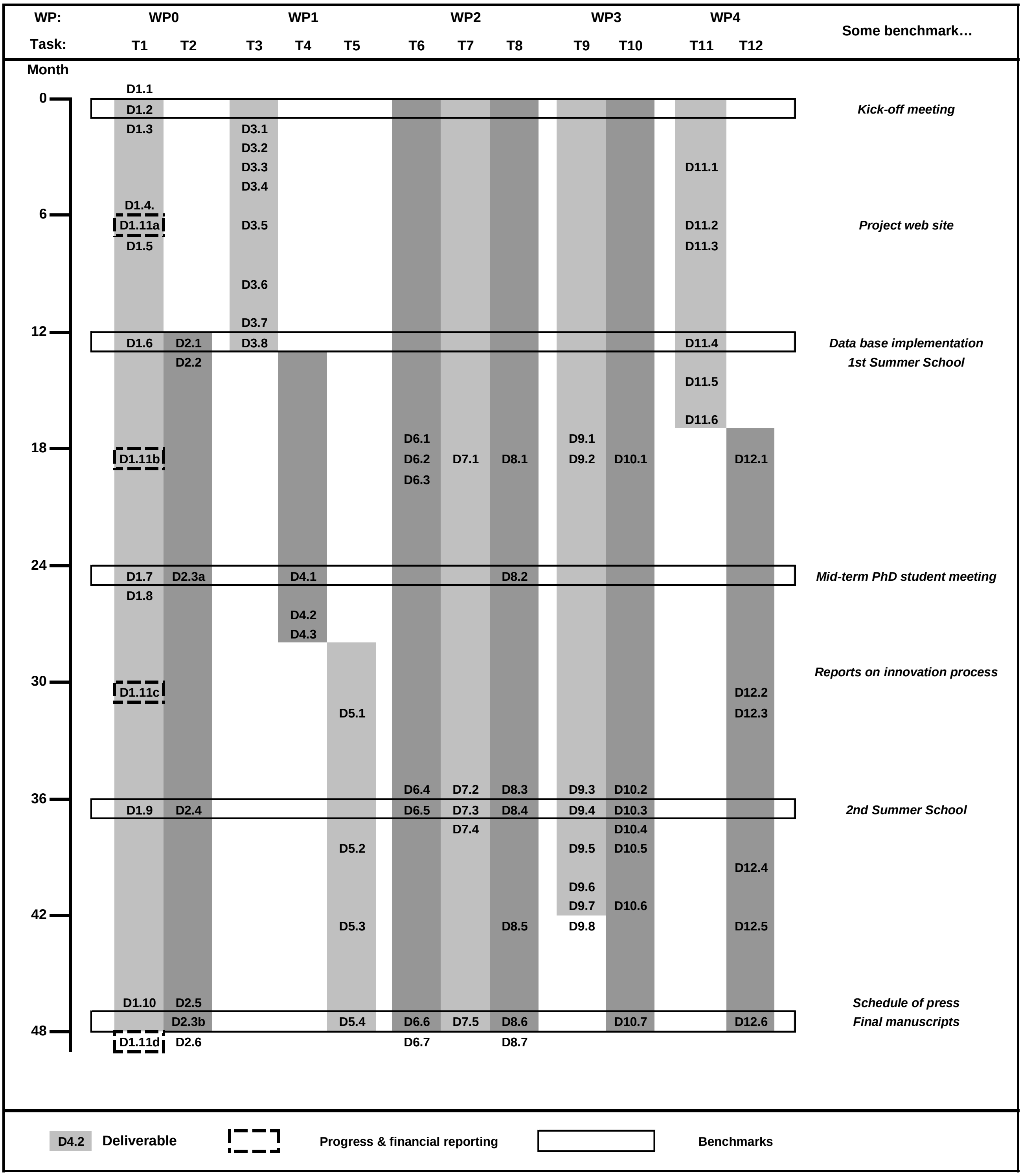


**Figure 4.** *Intens&Fix task schedule*

*TABLE OF DELIVERABLES & MILESTONES*

| WP | Title and types of deliverables / milestones | Date of delivery | Responsible |
|---|---|---|---|
| **WP0** | | | |
| **Task 1** | **D 1.1**: Consortium agreement | Month 0 | Partner 1- UPR 80 |
| | **D 1.2**: Kick off meting | Month 1 | Partner 1- UPR 80 |
| | **D 1.3**: Dedicated ftp server for data and report exchanges | Month 1 | Partner 1- UPR 80 |
| | **D 1.4**: Intens&Fix website | Month 6 | Partner 1- UPR 80 |
| | **D 1.5**: 1st review meeting | Month 7 | Partner 1- UPR 80 |
| | **D 1.6**: 2nd review meeting | Month 12 | Partner 1- UPR 80 |
| | **D 1.7**: 3rd review meeting | Month 24 | Partner 1- UPR 80 |
| | **D 1.8**: Report on mid-term PhD student meeting | Month 24 | Partner 2- System |
| | **D 1.9**: 4th review meeting | Month 36 | Partner 1- UPR 80 |
| | **D 1.10**: Closure meeting | Month 46 | Partner 1- UPR 80 |
| | **D 1.11**: Progress and financial reports | Months 6-18-30-48 | Partner 1- UPR 80 |
| **Task 2** | **D 2.1:** Data base implementation | Month 12 | Partner 2- System |
| | **D 2.2** Summer school on methods and concepts applied to forest and agroforest innovations | Month 12 | |
| | **D 2.3** Report meeting with the board of French AFS | Months 24-48 | Partner 2 - System |
| | **D 2.4**: Summer school on mixed species FP | Month 36 | Partner 4- Eco&Sols |
| | **D 2.5**: Schedule of press | Month 48 | Partner 1- UPR 80 |
| | **D 2.6** Manuscript on the ecological intensification of wood production through association of nitrogen fixing species in forest plantations | Month 48 | Partner 1 – UPR 80 with all partners |
| **WP1** | | | |
| **Task 3** | **D 3.1**: Inception meeting with stake-holders in France on mixed-species poplar plantations in short rotations | Month 2 | Partner 6 - AFAF |
| | **D 3.2** Inception meeting with stake-holders in France on mixed-species Juglans AFS | Month 3 | Partner 6 - AFAF |
| | **D 3.3** Inception meeting with stake-holders in Brazil on mixed-species eucalyptus plantations | Month 3 | Partner 7 - USP |
| | **D 3.4**Inception meeting with stake-holders in Congo on mixed-species eucalyptus plantations | Month 3 | Partner 8 - CRDPI |
| | **D 3.5**: synthetic document on FP with introduced NFS | Month 6 | Partner 2 -System |
| | **D 3.6**: List of fully documented driving rules | Month 9 | Partner 6 –AFAF |
| | **D 3.7**: List of included and excluded processes | Month 12 | Partner 2 -System |
| | **D 3.8**: Modelix specifications | Month 12 | Partner 2 -System |
| **Task 4** | **D 4.1**: Modelix structure approved | Month 24 | Partner 1 - UPR 80 |
| | **D 4.2** : Modelix beta version released with documentation | Month 26 | Partner 2 –System |
| | **D 4.3** : Final report of validation of Modelix modules | Month 28 | Each responsible of a model used to validate a module of Modelix |
| **Task 5** | **D 5.1**: Training partners to utilize with Modelix | Month 32 | Partner 2 - System |
| | **D 5.2**: Set of simulations for the 4 main sites of the project | Month 38 | Each site leader |
| | **D 5.3**: Analysis of sensibility | Month 42 | Partner 1- UPR 80 |
| | **D 5.4**: Assessment of decision rules | Month 48 | Partner 2 - System |
| **WP2** | | | |
| **Task 6** | **D 6.1:** Preliminary report on effect of NFS on light transmission and distribution in different FP types | Month 18 | Partner 1- UPR80 |
| | **D 6.2**: Preliminary report on the effect of NFS on root distribution and architecture in different FP types | Month 18 | Partner 1- UPR80 |
| | **D 6.3**: Preliminary report on the effect of NFS on the efficiency to use water and nutrients in different types of FP | Month 18 | Partner 3 -EEF |
| | **D 6.4** 3D model of light distribution | Month 36 | Partner 1- UPR80 |
| | **D 6.5**: Report on the effect of NFS on light transmission and distribution in different types of FP | Month 36 | Partner 1-UPR80 |
| | **D 6.6**: Report on the effect of NFS on root distribution and architecture in different types of FP | Month 48 | Partner 1- UPR80 |
| | **D 6.7**: Report on effect of NFS on the efficiency to use water and nutrients in different FP types | Month 48 | Partner 3 –EEF |
| **Task 7** | **D 7.1**: Preliminary report on fine root dynamics and life span | Month 18 | Partner 3 – EEF |
| | **D 7.2**: Final report on fine root dynamics and life span | Month 36 | Partner 3- EEF |

| | | | |
|---|---|---|---|
| | **D 7.3**: Report on growth and primary productivity from an individual tree-based model | Month 36 | Partner 1- UPR80 |
| | **D 7.4**: Report on effect of NFS on the spatial variability of soil respiration in different FP types | Month 36 | Partner 3 – EEF |
| | **D 7.5:** Report on the effect of NFS on the TBCA in different types of FP | Month 48 | Partner 1- UPR80 |
| **Task 8** | **D 8.1** Preliminary report on the factors influencing $N_2$ fixation of the different NFS | Month 18 | Partner 1- UPR80 |
| | **D 8.2** Preliminary report on the soil N budget and soil acidification | Month 24 | Partner 7- USP |
| | **D 8.3** Report on the intra and inter annual variations of the amounts of N and C storage compounds at the whole tree level. | Month 36 | Partner 3 - EEF |
| | **D 8.4**: Report on P efficiency of NFS for $N_2$ fixation | Month 36 | Partner 4 -Eco&Sols |
| | **D 8.5** Report on the factors influencing $N_2$ fixation of the different NFS | Month 42 | Partner 1 – UPR80 |
| | **D 8.6** Report on N budget of plant system | Month 48 | Partner 3 – EEF |
| | **D 8.7**: Report on N soil budget and soil acidification | Month 48 | Partner 7 –USP |
| **WP3** | | | |
| **Task 9** | **D 9.1**: Preliminary report on the effect of NFS on litter decomposition and N and P release | Month 18 | Partner 3 –EEF |
| | **D 9.2**: Preliminary report on the effect of NFS on N and P availability in different types of FP | Month 18 | Partner 4 - Eco&Sols |
| | **D 9.3**: Report on organic input on SOM turnover | Month 36 | Partner 4 - Eco&Sols |
| | **D 9.4** Adaptation and validation of C-N models | Month 36 | Partner 1 – UPR80 |
| | **D 9.5:** Report on the effect of NFS on N and P availability in different types of FP | Month 40 | Partner 1- UPR 80 |
| | **D 9.6**: Report on the effect of NFS on litter decomposition and N and P release | Month 42 | Partner 3 – EEF |
| | **D 9.7:** Report on the effect of NFS on in situ SOM turnover | Month 42 | Partner 3 – EEF |
| | **D 9.8** Report on C-N models | Month 42 | Partner 1- UPR 80 |
| **Task 10** | **D 10.1**: Production of Phytase and Pase gene probe to target bacterial communities | Month 18 | Partner 4- Eco&Sols |
| | **D 10.2**: Report on Nematofauna communities | Month 36 | Partner 4- Eco&Sols |
| | **D 10.3**: Report on functional bacterial communities in N and P Cycles | Month 36 | Partner 4- Eco&Sols |
| | **D 10.4**: Report on N transfer pathway *in situ* | Month 36 | Partner 3 - EEF |
| | **D 10.5**: Report on Trophic relationships in mesocosms | Month 36 | Partner 4- Eco&Sols |
| | **D 10.6**: Report on the effect of NFS nematofauna distribution in different types of FP | Month 40 | Partner 4- Eco&Sols |
| | **D 10.7**: Report on the effect of NFS on mechanisms of N transfer and modulation by trophic relationship in different types of FP | Month 48 | Partner 1- UPR80 |
| **WP4** | | | |
| **Task 11** | **D 11.1**: For each site, preliminary report on the inception meeting and study hypothesis for all sites | Month 3 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 11.2**: For each site, working documents on the survey design and field work | Month 6 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 11.3**: Synthesis report on the requirements for the biophysical model in terms of processes and variables to be included | Month 6 | Partner 2- System |
| | **D 11.4**: For each site, analysis report on: i) main phases of agrarian evolution for forest tree growers, ii) the wood goods and product chain analysis, iii) the forest tree growers perception and practices determinants and evolution until actual ones | Month 12 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 11.5**: For each site, report on restitution meeting with the stakeholders- shared conclusions | Month 14 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 11.6**: Synthesis on socioeconomic determinant of local forest growers practices: comparative study for all sites | Month 16 | Partner5-Innovation |
| **Task 12** | **D 12.1**: For each site, report on economic performance of the implementation and maintenance of the innovation | Month 18 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 12.2**: For each site: report on the various stakeholders innovation process (link between research and their beneficiaries) | Month 30 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 12.3**: Calibration/validation of Farm-sAfe model (France-Congo) | Month 30 | Partner 2 - System |
| | **D 12.4**: For each site: report on restitution meeting for validation with the stakeholders and shared conclusions | Month 40 | Partner5-Innovation<br>Partner 6 - AFAF<br>Partner 8- CRDPI |
| | **D 12.5**: Best options for N2 fixing species in FP as deduced from simulation runs provided by WP1 | Month 42 | Partner 2 – System |
| | **D 12.6**: Final meeting report | Month 48 | Partner5-Innovation |

**Critical paths, risks and backup solutions**

- **Task 1**. A challenge is to ensure the participation of all the partners to the annual review meetings, both from France, Brazil, and Congo. Problems could appear due to i) financial reasons; project funds will be devoted for this purpose, ii) a possible reticence of certain end-users to mixed-species plantations (higher management complexity…). A rapid and efficient interaction with the stakeholders (discussions, result presentations…) will be of a major importance. Financial difficulties for the participation of the Congolese or Brazilian PhD students to the mid-term project meeting. Additional support funding will be secured to allow the participation of a good panel of foreign PhD students.
- **Task 2**. Summer schools will take place providing it is accepted by other participant Universities of Socrates Intensive Programme and providing enough students register to attend. Will be cancelled if not.
- **Task 3**. Two main risks arise from this task: (i) stakeholders may not be aware of the potential interest of mixed-species FP. The synthetic document will be of major importance to get an efficient inception working meetings, (ii) specifications of the integrated model may evidence some antagonisms between the biophysical part and the technical one. As a solution, we will propose a multi-stage road-map based on a cost-precision approach to reach the appropriate mid-point between the representation of the system and the economical feasibility.
- **Task 4**. The current Hi-sAFe model was designed for tree mixtures or tree-crop mixtures and could be used as a spare model if necessary, but would need to be upgraded for several processes.
- **Task 5**. If the model is validated, this task should run smoothly. Therefore the risks are mainly in task 4. The main risk is a late delivery of the validated model by task 4. The overall coordinator of WP1 will be very stringent in the calendar of deliverables by tasks 2 and 3 to avoid such a mishap.
- **Task 6**. There is little risk of failure as most the measurements rely on experienced methodologies for the involved teams
- **Task 7**. There is little risk of failure since most the measurements rely on experienced methodologies for the involved teams. Accurate estimates of fine root life span are still challenging but failure will not jeopardize other aspects of the task.
- **Task 8**. The $^{15}N$ labelling method is reliable in all cases, if used properly, in contrast to natural abundance methodology. Consequently, the former approach will be used in all sites. The method which uses the natural abundance of $^{15}N$ will still be used for specific studies of secondary importance in some sites.
- **Task 9**. The main risk is to be not able to produce rapidly a sufficient amount of $^{15}N$ labelled litter from a one or two tree species. Our backup solution is to start as soon as possible with the $^{15}N$ labelled litter production, and to label more trees that normally needed to increase the amount of litter. According to the tree species the best labelling methods will be selected.
- **Task 10**. The main risk is to be unsuccessful in producing specific tools to target functional bacterial communities producing phytase and phosphatase if we cannot find conserved domains among the sequences in public data bank. Nevertheless, the diversity of culturable bacterial populations able to release phytase and phosphatase activities *in vitro* has never been identified and will constitute a first approach that could compensate for the lack of specific primers.
- **Task 11**. The main risk is the current bias of the information given by some of the stakeholders: this can be avoided by a confident relationship established between stakeholders and researchers, that is fundamental
- **Task 12**. As for the previous task, a risk is the current bias of the information given by some of the stakeholders: this should be avoided by a confident relationship established with the research local co-responsible of the task. The availability of the Farm-sAFe model will help to reach our objectives, as it will save much time in the design of an appropriate micro-economic model of the innovations. However, this model was designed for French farms ruled under the European Common Agriculture policy. There is a risk that the adaptation of the model to the Brazil and Congo conditions may not be straightforward, especially for larger planting companies.

# 4. STRATEGIE DE VALORISATION DES RESULTATS ET MODE DE PROTECTION ET D'EXPLOITATION DES RESULTATS

In order to supplement between themselves the provisions of the contract signed with the ANR, the partners of Intens&Fix **will sign** a **Consortium Agreement** at **Month 0** to define to define the respective rights andobligations of the partners, including provisions on intellectual property rights.

Intens&Fix is an academic project **producing generic information** and **knowledge towards** the **public domain**, therefore no major results are expected to be valorised though commercial exploitation. Nevertheless the consortium agreement will be written under the following main lines:

- ✓ Knowledge shall be the property of the partner generating it. If, in the course of carrying out work on the project, a joint invention, design or work is made (and at least two partners are contributors), and if the features of such joint invention design or work are such that it is not possible to separate them for the purpose of applying for, obtaining and/or maintaining in force the protection of the relevant intellectual property right, the contractors concerned (the “contributors”) agree that they may jointly apply to obtain and/or maintain the relevant rights and shall strive to set up amongst themselves appropriate agreements in order to do so. As long as any such rights are in force, such contributors shall be entitled to use and to license such rights on a non exclusive basis, with a financial compensation decided on case by case basis with the prior consent of the other contributors, in accordance with the contributor agreements set up.
- ✓ Each partner who is not itself able to commercialize the knowledge generated within Intens&Fix, shall give the other partners a prior right, on fair and reasonable terms and conditions, to commercialise such knowledge before it may grant such rights to third parties. Each of the partners agrees that, before any agreement concerning a commercial exploitation is reached with a third party by a partner who is not itself or whose affiliates are not incorporated or established principally to undertake manufacturing activities and, due to its size or nature, is itself unable to commercialise the knowledge, the other partners shall themselves have a prior right to agree to undertake such commercial exploitation on fair and reasonable terms and conditions.
- ✓ The strategy of scientific publication will be under the responsibility of the Management Team of the project that will determine targeted international journals.

The **valorisation** of Intens&Fix is both orientated towards ambitious **scientific publications** and strong **dissemination plans** towards **final end-users** of project outputs. The project will give particular importance to the transfer of the results to **maximise impact** amongst **stakeholders**.

- ✓ The results will be valorised through publications in **high level scientific journals,** in Agronomy, Forestry, Microbiology, Ecophysiology, Ecology, Socio-economics and Modelling **as well as** in **R/D journals** as “Agroforesteries, La revue française des arbres ruraux”, published by partner 6 - AFAF, in order to facilitate their large dissemination to development institutions and end-users. Preparation and schedule of leaflets and press release in French and English will be also prepared for raising public participation and awareness.
- ✓ Participation to **international conferences** will also give the opportunity of an efficient diffusion of the results. As an example, the next conference of the IUFRO 2.08.03 ”Improvement and culture of *Eucalyptus*” (Bahia, Brazil - 2011), coordinated by USP/UPR 80 in relationships with the Brazilian companies, will partly focus on mixed-species *Eucalyptus* plantations with NFS. The third World Agroforestry Congress is scheduled in 2013 and may be hosted in France (Montpellier) and would also be a perfect opportunity to share Intens&Fix achievements.
- ✓ Intens&Fix is targeted to produce **recommendations** for tree plantations that may be incorporated in national recommendations for tree plantations. We will suggest updating the French Regulation on agroforestry systems (Measure 222 of the French Rural Development Regaulation) with the outputs of the project, so that NFS species may be incorporated in the technical. In the north of France, dissemination of the results concerning mixed short rotation plantations will be achieved through meetings with the Chambres d’Agriculture and partner 6 - AFAF, and within the framework of the RMT Biomasse. Special training session on the management of mixed-species plantations with NFS will be jointly organized by CRDPI and the EU Makala project (such type of session was already organized by UR2PI in December 2007 within the EU project “Carboafrica” on biomass estimation in forest ecosystems).
- ✓ More generally the participative approach deployed, and the strong partnership that will be developed with producer organisations in France, Brazil and Congo will warrant a large and efficient dissemination of the Intens&Fix results.

From an **operational point of view**, the Intens&Fix project should lead to **significant improvement** in **FP management.**

- ✓ The project will give innovative information on the **ecological** ways to **intensify** stand **production** of FP through i) quantification of change in $N_2$ fixation within stand rotation and/or among rotations that will contribute to limit the amount of N chemical fertilizer to be applied (**all FP** studied), ii) adequate proportions of NFS to add to non-N fixing tree and total stand density (*Populus* + *Robinia*; *Eucalyptus* + *Acacia*; *Juglans* + *Alnus*), iii) first results on the optimum length of VSRC stand rotations (*Populus* + *Robinia*). The effect of minimum P inorganic fertilisation on $N_2$ fixation of NFS will be also investigated.
- ✓ In **Brazil**, the results will be used to better assess the change of production of the mixed-species *Eucalyptus* stands that have been established since 2005 in various forest companies. In particular the density of *Acacia* to be planted within *Eucalyptus* stand could be defined according to ecological conditions, especially air humidity and duration of the dry season. The project should also give the scientific basis to test native N-fixing tree species as *Mimosa scabrella* (Coelho et al., 2007) in eucalypt commercial plantations. These results could be **applied** on a **large scale** (several **hundred thousand hectares**), both by commercial companies, and private forest owners and farmers to provide wood mainly for energy, board and pulp production.
- ✓ If this project confirms that in **Congo** *A. mangium* grows well and is very efficient to fix atmospheric $N_2$ (Bouillet et al., 2007, 2010), mixed-species plantations of *Acacia* and *Eucalyptus* could represent an attractive option to monocultures. These mixtures could spread both in commercial plantations (EFC: 40,000 ha around Pointe-Noire) and in small-scale plantations (Brazzaville and Kinshasa regions) to provide **firewood** for local populations while **balancing N** stand **budgets**.
- ✓ In Europe, the potential for new FP in the form of AFS with high quality timber species is considered to be large, with more than **90 million hectares suitable for AFS** (Palma et al, 2007). From 2009, the activation by France of Article 44 of the European Rural Development Regulation (European Commission, 2005) is expected to boost plantations, with a target of 500,000 ha of silvoarable agroforestry in France during the next 20 years (Barnier, 2009). For **AFS** aiming at producing **high value timber,** the Intens&Fix project should provide a sound basis to introduce **new management schemes** integrating the "green N fertilization" provided by NFS. This aspect was never considered in the previous projects on AFS.

Finally, Intens&Fix results, will give a **sound base** to further explore the **feasibility** of FP mixed with both annual and perennial NFS including various systems that were not studied in the project for the sake of the rigour of the experimental and modelling approach (as *Prunus avium* and *Robinia* in France, or tropical systems with *Leucaena leucocephala* or *Gliricidia sepium*). **Technical** and **socio-economical** factors, as well as the conditions needed to implement **successful mechanisms** of **payment** for **ecosystem services** related to green N fertilization will be part of the Intens&Fix achievements that could be further disseminated for other NFS based FP systems.

# 5. ORGANISATION DU PARTENARIAT

## 5.1. DESCRIPTION, ADEQUATION ET COMPLEMENTARITE DES PARTENAIRES

- **UPR 80** (partner 1) is nowadays the coordinator of the previous "Cifor" network on "*Productivity and management of tropical plantation forests*". Within this network UPR80 has been for 2003 the scientific leader with USP and CRDPI of the group on mixed-species FP. This group includes 5 Brazilian commercial companies and one Congolese company managing 800, 000 ha and 40,000 ha of *Eucalyptus* plantations, respectively. In strong relationships with scientific southern research organizations, and involved in numerous research projects on plantation functioning (Integrated Project Ulcos, Strep CarboAfrica...) as well as scientific networks (FluxNet, OzFlux, AsiaFlux, ORE F-ORE-T,..), UPR 80 deploys recognized competences in ecophysiology, biogeochemistry, silviculture, and modelling and carries out studies in highly instrumented FP designs (lysimiters, eddy correlation devices…) as those installed in Brazil and Congo.

- **UMR System** (partner 2) coordinated the Silvoarable AgroForestry for Europe Project (2001-2005) that succeeded in quantifying the productivity of some forest plantations with intercrops (agroforestry systems, AFS) for Europe, and suggested policy changes to allow farmers to develop agroforestry. Following these results, AFS were included in the new European Rural Development Regulation, and are now supported throughout Europe. UMR SYSTEM is the scientific leader of the French national programme of agroforestry that resulted in 1400 ha of new high quality timber plantations plots to be settled up in 2007. C. Dupraz very recently published a textbook on temperate agroforestry (Dupraz and Liagre, 2008). UMR System is also managing the major AFS experiments in Europe, in three major experimental sites

- The **UMR EEF** (partner 3) and more precisely the *Tree – Ecosystem Integrated Functioning* team, has a long-term experience of forest ecophysiology and in particular of the effect of climatic changes on the water, carbon and nitrogen cycles in forest ecosystems. The Unit coordinates or is currently involved in several national and European contracts dealing with this topic in traditional forests (e.g. ANR Blanche CATS) but also in short rotation coppice (e.g. ERA-Net Bioenergy CREFF). The Unit is composed of a large scope of skills beneficial for the Intens&Fix project, including gas exchange measurements, storage compound analysis, isotope labelling and tracing, etc. The Unit is also composed of an analytical pole with elemental and isotope analysis facilities.

- **UMR Eco&Sols** (partner 4) is a multidisciplinary research group composed of soil scientists, microbiologists, plant physiologists and biologists from INRA and IRD. The Inra group has a reknown experience in several fields such as the study of rhizosphere, $N_2$ fixation in relation with P availability, physiological properties of ectomycorrhizal fungi, whether or not associated with trees, for P mobilisation improvement. Their expertise lead them to chair the COST Action 631 about Understanding and Modelling Rhizosphere interactions (until 2006), leading to the international Rhizosphere Conference gathering ca 500 participants in Munich in 2004 and in Montpellier in 2007 (with P. Hinsinger was Chair of organizing Committee). In the area of $N_2$ fixation, the group has been leading the FABAMED cooperative network in the Mediterranean basin for the last 12 years, resulting in two major EU projects (FYSAME, FP5 coordinated by JJ Drevon, and AQUARHIZ FP6). The group has also been part of the Integrated Project GRAIN LEGUME of the EU. The group has also cooperated with CGIAR (INRA-CIAT cooperation) for selecting contrasting recombinant inbred lines of common bean for efficiency in use of P for symbiotic $N_2$ fixation, that are use jointly with Mexico in agropolis platform and with Brasil and Cuba in the on-going FAO-IAEA cooperative project for N and P efficiencies. The IRD group has well recognized competences in the study of soil biological communities (bacteria, nematofauna and macrofauna with a particular interest on soil "engineers" represented by termites, worms and ants) and their effects on C and N fluxes in soil or at the soil-plant-atmosphere interface in tropical and Mediterranean ecosystems. It has coordinated several projects such as the ANR Biodiversité MICROBES project aiming at understanding and managing tropical agro-ecosystems by studying ecosystem soil services. It targeted the biota involved in these functions and characterized the assemblage of their various components. Particular emphasis was laid on the microbial component developing a multi-faceted approach covering the abundance, activity, genetic diversity and functional diversity.

- **UMR Innovation** (partner 5) associates competences in agronomy and social sciences (economy, sociology, anthropology, geography, sciences of management…) to carry out researches on processes of innovation in Agriculture, considered as technical and organizational processes, both at the individual and collective level. The whole innovation process is taken into account from the objectives of the stakeholders to innovate until the effects on the development induced by these innovations; the SPACTO team ("Systèmes de production agricole et changements techniques et organisationnels") to which belongs the scientists included in the Intens&Fix project, works more specifically on farm and production management, socio-technical and organizational processes of innovation, and processes of coordination between actors. Within this team a special attention is paid on the processes of innovation in tree-based agro-ecosystems in France, in Africa, and in Brazil. Another competence is the action-research in partnership approach, with the organization of various workshops in France and Africa.

- **AFAF** (partner 6) is the French Agroforestry Association. Its membership includes most stakeholders involved in the management of trees outside forests in France. AFAF is dealing with farm forestry, traditional and innovative agroforestry systems, hedges, short rotation coppice for biomass production, isolated trees. AFAF is coordinating the dissemination of Agroforestry schemes in France. AFAF members are farmers, foresters, private sector experts, extension officers from both governmental authorities and professional organisations. The acting president is Yves Bachevillier, expert on agroforestry at the Chambre d'agriculture de l'Hérault. AFAF is recognised as a key partner for Agroforestry issues by the French authorities, and was involved in the writing of the implementation of article 44 of the European Regulation 1698/2005 providing incentives for farmers to use tree plantations with an agroforestry philosophy. AFAF is the top resource organisation for all legal, fiscal, and technical aspects of agroforestry adoption by farmers in France, and manages a network of experimental agroforestry plots in more than 40 French departments. AFAF is currently upgrading the Farm-sAFe model which allows calculating the economics of various agroforestry schemes at the farm scale. AFAF is publishing since 2008 the journal « Agroforesteries, La revue française des arbres ruraux »

- The Piracicaba campus of the Sao Paulo University (named thereafter **USP** - partner 7) is a major scientific institution in Brazil. The partners selected have a long experience in forest management and environmental studies. The strong collaboration between the USP Forest Department (USP-Esalq) and Brazilian forest companies will make it possible to further establish experiments in different ecological situations. If the projects shows that the silvicultural practices studied lead to potential environmental and/or economical benefits, they will be apply at a large scale in Brazil. The Brazilian silviculture is well recognized and modifications resulting from this project might be potentially valuable for other tropical countries. The collaboration with scientists in USP-Cena A will make it possible to perform chemical and isotopic determinations with the best accuracy. Equipments in USP-Cena laboratories are the best available in that field and training of the technical staff is excellent. The partners in USP-Cena have been working for a long time in forest ecosystems, in particular in Amazon with American scientists, and are specialized in agronomy and ecology.

**- CRDPI** (partner 8) is a Congolese research association which works on the functioning and the sustainability of fast growing forest species plantations. In collaboration with Northern research organizations (Cirad, Inra...), CRDPI has established instrumented field designs on nutrient, water and carbon cycles in *Eucalyptus* plantations that have been continuously followed for 10 years. The results have been valorised through numerous scientific publications in reference journals (Tree Physiology, Annals of Forest Sciences, Forest Ecology and Management…). CRDPI has been involved in various international research projects (IP Ulcos, CarboAfrica,), as well as regional R&D projects (Makala). Member of the Cifor "*Site management on Productivity of Tropical plantation forests*" CRDPI has developed strong links with the main Southern forest research organizations working on FP (ICFR, CSIRO, USP…).

The **partners** of the project are recognized as top scientific teams and present numerous **complementarities**:

- **UMR System** and **UMR EEF** have worked on French and European FP for a long time: AFS for **UMR System** and broad-leaf FP for **UMR EEF**. **UMR Eco&Sols** participated to the first integrated study on ecophysiology, soil P availabilty and root functioning of *Pinus pinaster* plots in the Landes forest relative to the P fertilization applied to the trees (funded by ECCO-PNBC program, 2005-2008). Through the ANR-Biodiversity funded project (FUNDIV, 2007-2009) **UMR Eco&Sols** mastered enzyme profiling of ectomycorrhizal roots in the same *P. pinaster* ecosystem.

**- UPR 80**, **UMR EEF**, **CRDPI** and **USP** have carried out intensive works on tropical FP for a long time, with a special focus on *Eucalyptus* plantations. **UMR Eco&Sols** have also conducted researches on fucntional microbial biodiversity in eucalypt plantations in cooperation with **USP**, **CRDPI** and **UPR 80**.

- In Brazil, a network of collaboration has been established since 2002 with **USP** (the major university in South America), IPEF (organisation funded by forest companies to spread the results of forest researches over several millions of hectares in Brazil), and **UPR 80**, to study C, water and nutrient cycles in fast-growing plantations. Complementary competences of partners working together with the support of various organisations (USP-COFECUB, FAPESP, French Ambassy in Brasilia, INRA-CIRAD) will help carrying out the studies proposed in the Intens&Fix project. More specifically the BEPP project managed by **USP** has dealt for 10 years on the water and carbon functioning of *Eucalyptus* plantations in various Brazilian states. These results will be used to model the functioning of Brazilian mixed-species plantations of *Eucalyptus* with *Acacia*.

- **CRDPI** is the most important forest research group in Central Africa and is deeply involved in capacity building and training that will allow efficiently disseminating the results of this project to the African forest research community.

- **UMR Innovation** is a reference research group for the innovation processes in agriculture and forestry. In close relationship with **AFAF**, **USP** and **CRDPI**, this partner will conduct the socio-economical assessment of mixed-FP with NFS to evaluate the actual potential of the ecological intensification of these systems.

- Besides the bridge that **AFAF** will build between research and FP stakeholders (WP4), this partner will contribute to WP1 by upgrading Farm-sAFe model.

Even the Intens&Fix project will permit to **strengthen existing links** between some partners teams, it will also to generate **news relationships** : i) among French teams (**UMR System** *vs* **UPR80**, **UMR System** vs **UMR EEF** and **AFAF** vs the other French partners), and ii) among tropical and French teams (**UMR System**, **UMR Innovation** and **AFAF** *vs* **USP** and **CRDPI**). This project will then contribute to reenforce the French research capacity and its international partnership on FP, especially on mixed-species FP with NFS.

Owing to their own specific expertise, **some partners** will be **scientific** and **technical supervisors** of specific works: **- UMR System** which coordinates **WP1** has a long experience in tree growth and interaction modelling and the dialog between end-users and modellers. It will work in close relationships with **UMR Innovation** and **AFAF** which have developed a strong expertise in FP technical and socio-economical surveys.

**- UMR EEF** that leads **WP2** has a long historical involvement in tree physiology and forest ecology research, and will support NPP, WUE and NUE assessments within the Intens&Fix project. N transfer *in situ* will be supervised by one scientist of Inra-Bef (B Zeller) involved in **UMR EEF**. Additionally, the EEF unit which is fully equipped with gas exchange facilities as well as an isotope ratio mass spectrometer for $^{13}C$ and $^{15}N$ analyses of organic materials will carry out isotopic analyses for the French team and for all partners for tree reserves analyses.

**- UPR 80** will supervise for the all sites the experiments concerning TBCA experiments, root biomass assessment, and root dynamics modelling. It will work in close relationships with **USP** and **CRDPI** for the all experiments in Brazil and Congo. **UPR 80** will also bring its expertise concerning, ecophysiological, growth and yield, biomass and CEM models (d'Annuzio et al., 2008; Nouvellon et al., 2000; Saint-André et al., 2002), as well as the implementation of Soil Vegetation Atmopshere Transfert model (Maestra).

**- UMR Eco&Sols** will be in charge of the coordination of **WP3** on all the sites. It will determine the P efficiency of $N_2$ fixation of all NFS species associated with Rhizobia, carry out studies on nematofauna and assess the quality of organic P released by NFS introduction by enzyme measurements for all the partners.

- **UMR Inovation** will coordinate the socio-economical assessment of the introduction of NFS in FP.

The close **relationships** between **Intens&Fix partners**, including AFAF and **professional organizations** (Chambres d'Agriculture, commercial companies, forest owners, farmers, experts,…) is a trump card for a large and efficient **dissemination** of the **results** and their **rapid** on-field **application**.

## 5.2. Qualification du coordinateur du projet

**Jean-Pierre Bouillet, 52 years, married (2 children)**
**Cirad scientist,** Persyst Dept, UPR 80 “Functioning and Management of tree-based planted Ecosystems »

***Academic qualification***
PhD in Forest Sciences, Ecole Nationale du Génie Rural, des Eaux et des Forêts, France, 1993.
Forest engineer, Ecole Nationale du Génie Rural, des Eaux et des Forêts, France, 1984
Engineer in wood sciences, Ecole Supérieure du Bois, France, 1980

***Key qualifications***
Silviculture, productivity and sustainability of tropical forest plantations, biogeochemical cycles

***Work experience***
September 2008 - present. Visiting Professor at USP-Esalq (Piracicaba, SP, Brasil). Up to end 2009, head of the research unit “Functioning and management of tree-based planted ecosystems” (UPR 80).
2002- 2008. Senior scientist in Cirad-Forêt and Cirad-Persyst (France). Head of UPR 80
1995-2001. Director of UR2PI (Congo) - nowadays CRDPI - devoted to commercial plantation productivity. Head of the silviculture & environment research programme for the Eco sa and National Forest Service eucalypt plantations (40,000 ha)
1986-1995. Head of the silviculture research team, Drfp-Fofifa (Madagascar): silviculture of the Fanalamanga and Matsiatra pine plantations (100,000 ha); silviculture of eucalypt coppices managed by smallholders.
1985-1986. Forest scientist in CTFT (French Guyana): research on silviculture and breeding of FP species.

***List of relevant publications in the last five years***
- **Bouillet J.P.**, Laclau J.P., Gonçalves J.L.M., Moreira M.Z., Trivelin P., Jourdan C., Galiana A., 2008. Mixed-species plantations of *Acacia mangium* and *Eucalyptus grandis* in Brazil. 2. Nitrogen accumulation in the stands and $N_2$ biological fixation. *Forest Ecology and Management*, 255, 3918-3930
- Laclau J.P., **Bouillet J.P.**, Gonçalves J.L.M., Silva E.V., Jourdan C., Cunha M.C.S., Moreira M.R., Saint-André L., Maquère V., Nouvellon Y., Ranger J., 2008. Mixed-species plantations of *Acacia mangium* and *Eucalyptus grandis* in Brazil. 1. Biomass allocation and net primary production. *Forest Ecology and Management*, 255, 3905-3917
- Laclau J.P., Ranger J., Deleporte P., Nouvellon Y., Saint-André L., Marlet S., **Bouillet J.P.**, 2005. 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. *Forest Ecology and Management*, 210, 375-391.
- Roupsard O., Dauzat J., Nouvellon Y., Deveau A., Feintrenie L., Saint-André L., Mialet-Serra I., Braconnier S., Bonnefond J.M. Berbigier P., Epron D., Jourdan C., Navarro M., **Bouillet J.P**, 2008. Cross-validating Sunshade and 3D models of light absorption by a tree-crop canopy. *Agricultural and Forest Meteorology*, 148, 549-564
- Silva E.V., Gonçalves J.L.M., de Freitas Coelho S.R., Moreira e Moreira, R., de Miranda Mello S.L., **Bouillet J.P.**, Jourdan C., Laclau J.P., 2009. Dynamics of fine root distribution after establishment of monospecific and mixed-species plantations of *Eucalyptus grandis* and *Acacia mangium*. *Plant and Soil*, 325 (1), 305-318

***Number of papers in referred journals (published or under press): 26***

***Other information***
- Member of the Editorial team of the *Southern Forest Journal* (from 2007)
- Reviewer of the journals *Australian Journal of Botany*, *Forest Ecology and Managemen*t, *Ecological Modelling*, *New Forest…*
- Deputy coordinator of the 2.08.03 IUFRO group “*Culture and improvement of Eucalyptus*” (1997-2007)
- AERES evaluator, ARP Vega expert, French Science Academy reviewer (2006) on the “Cycles biogéochimiques” report.
- Member of the Board of the INRA “Commission Scientifique Spécialisée” Agriculture-Elevage-Sylviculture (from 2007)
- Coordinator of “Site management and productivity of tropical plantation forests” network (from 2009)

***Project leading experience***

Dr JP Bouillet is very used to managing projects and research programs. Between 1986 and 1995 he coordinated the research program on the silviculture of pines and eucalypts in Madagascar. Between 1995 and 2001, he was the director of UR2PI in Congo (45 staff, 10 scientists, annual budget: 1 million €). From 2002 to 2009, he was the Head of the CIRAD-UPR 80 research team (currently 15 permanent scientists, 2 VIE, 22 PhD). During the last five years, JP Bouillet has coordinated a project “Action Thématique Programmée” funded by Cirad (2003-2006; budget: 150 k€), two Inra-Cirad “Action Incitative Programmée” (45 k€ and 100 k€). He has been a WP leader in the European Commission FP6 “CarboAfrica” project “Quantification, understanding and prediction of carbon cycle and other GHG gases in Sub-Saharan Africa” (2005-2009; WP budget: 400 k€), as well as a task coordinator of the FP6 Integrate Project “Ulcos” “Ultra Low CO2 Steel Making” (2004-2010; task budget: 370 k€). .

## 5.3. QUALIFICATION, ROLE ET IMPLICATION DES PARTICIPANTS

| Partner 1 - UPR 80 | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| Leader<br>Project Coordinator<br>WP0 coordinator | BOUILLET | Jean-Pierre | Scientist<br>Silviculture, Nutrient cycles | *14*<br>+<br>10 | *Project leader, Partner 1 leader*<br>*Task 1, 2 coordinator*<br>Evaluation of root dynamics, $N_2$ fixation, fate of N fixed, and organic matter decomposition - Tasks 7, 8, 9 (Brazil) |
| Other staff members | SAINT-ANDRE | Laurent | Scientist<br>Modelling | 6 | Task 3 coordinator<br>Modelling Tasks 5, 6, 7, 9 (Congo, Brazil) |
| | HARMAND | Jean-Michel | Scientist<br>Nutrient cycles | 12 | Task 9 coordinator<br>Organic matter dynamics, fate of fixed N Tasks 9, 10 (Congo, Brazil) |
| | LACLAU | Jean-Paul | Scientist<br>Nutrient cycles | 12 | Brazilian site leader_Task 1, 2<br>“Modelix” testing Task 5<br>Evaluation of root dynamics, stand growth and organic matter decomposition<br>Tasks 7, 8, 9 (Brazil) |
| | NOUVELLON | Yann | Scientist<br>Ecophysiology | 18 | Task 7 co-coordinator<br>Modelling, Ecophysiological tree processes, Soil respiration TBCA<br>Tasks 5, 6, 7 (Brazil) |
| | JOURDAN | Christophe | Scientist<br>Root system Modelling | 8 | Root system characterization and root dynamics<br>Tasks 6, 7 (all sites) |
| | MARESCHAL | Louis | Scientist<br>Geochimist, Nutrient cycles | 12 | Evaluation of N2 fixation, fate of N fixed, and organic matter decomposition<br>Tasks 8, 9, 10 (Congo) |
| | LE MAIRE | Guerric | Scientist<br>Modelling | 4 | Modelling<br>Task 5 co-coordinator, tasks 4, 5 (all sites) |
| | X | X | Microbiology (recruited 1st semester 2010) | 6 | Identification of fungal communities<br>Task 9 (all sites) |
| | CAQUET | Blandine | Scientific Nat. Volonteer Ecophysiology | 6 | Ecophysiological tree processes, Soil respiration TBCA<br>Tasks 6, 7 (Congo: 2010-2011) |
| | X | X | Scientific Nat. Volonteer Ecophysiology | 16 | Ecophysiological tree processes, Soil respiration TBCA<br>Tasks 6, 7 (Congo: 2011-2013) |
| | X | X | PhD student ½ funded by Cirad and ½ by USP | 36 | Ecophysiological tree processes, Soil respiration TBCA<br>Tasks 6, 7 (Brazil) |

| Partner 2 - UMR SYSTEM | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| Leader WP1 Coordinator | DUPRAZ | Christian | Director of Research | 12 | Partner 2 leader<br>WP1 leader Task 5 coordinator<br>Task 1 co-coordinator, task 2 |
| Other staff members | WERY | Jacques | Head of UMR System | 4 | Linking biophysical and decision-making models<br>Task 3 |
| | NGO BIENG | Marie-Ange | Modelling Scientist | 10 | Task 3 Coordinator |
| | METAY | Aurélie | Scientist Nutrient cycles | 6 | N budget of tree mixtures<br>Task 8 |
| | DUFOUR | Lydie | Scientist Ecophysiology | 12 | Site leader (Montpellier)<br>Task 2 co-coordinator<br>Tasks 1, 7, 8, 9, 10 |
| | ROUX | Sébastien | Computer Scientist | 12 | Coding and debugging Modelix<br>Task 4 co-coordinator |
| | X | Y | PhD student (1/2 time ANR funded ; other half planned to be funded by the Languedoc Roussilon region) | 36 | N budget of tree mixtures (Montpellier sites)<br>Task 8 |
| | X | Y | Scientist Modelling | 18 | Coding “Modelix”<br>Task 4 |

| **Partner 3 - EEF** | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| WP2 Coordinator | EPRON | Daniel | Professor | 12 | WP2 coordinator<br>Task 7 Coordinator<br>Soil respiration (Nancy, Congo) Task 7<br>Fine root dynamics, TBCA (Nancy) Task 7 Involvement in the project management team (Task 1) |
| | MARRON | Nicolas | CR1<br>Scientist | 18 | Partner 3 leader<br>Nancy Site (S2) leader<br>Task 7 Co- coordinator<br>NUE / WUE (Task 7)<br>Involvement in the project management team (Task 1) |
| | GERANT | Dominique | Assistant Professor | 12 | Task 8 Co- coordinator<br>Intra and inter annual variations of N and C storage compounds (Task 8) - All sites |
| | MAILLARD | Pascale | CR1<br>Scientist | 12 | Isotopic analysis (Task 9)<br>All sites |
| | PRIAULT | Pierrick | Assistant Professor | 9 | WUE, isotopes, gas exchanges, sap flows Task 7 (Nancy) |
| | PLAIN | Caroline | IE<br>Scientist | 4 | Isotopes, gas exchanges (Nancy) |
| | GROSS | Patrick | IE<br>Scientist | 2 | Field experiment monitoring<br>(Nancy) |
| | CLERC | Bernard | Technician | 2 | Field experiment (Nancy) |
| | GIORA | Jean-Marie | Technician | 2 | Field experiment (Nancy) |
| | COURTOIS | Pascal | Technician | 2 | Field experiment (Nancy) |
| | HOSSANN | Christian | Technician | 2 | Isotopic analyses |
| | MARCHAND | Jacqueline | Assistant Ingeneer | 2 | Elementary analyses |
| | ZELLER* | Bernd | IR2<br>Scientist | 9 | Co-coordinator Task 9<br>N transfer Task 9 (all sites) |
| | X | X | Post-doctoral scientist | 9 | Root analysis – Belowground carbon allocation (Task 7) |
| | X | X | Technician | 10 | Tree C and N storage – Isotope analysis (Tasks 7, 9) |
| | X | X | Ph.D. student (not funded by ANR) | 36 | Carbon and nitrogen budgets within the mixed plantations (Tasks 7, 8) |

* Scientist from Inra-BEF Research Unit (Nancy)

| Partner 4 - Eco-Sols | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| Leader & WP3 Coordinator | PLASSARD | Claude | CR1 Scientist Microbiology, Enzymes, | 12 | Partner 4 leader<br>WP 3 coordinator<br>Task 10 coordinator<br>P availability<br>Trophic relationships<br>Involvement in the project management team (Task 1) |
| | VILLENAVE | Cécile | CR1 Scientist Soil ecologist | 6 | Task 10 Co-Coordinator<br>Nematode communities |
| | BRAUMAN | Alain | DR2 Scientist Microbiology | 4 | Nitrifying Microbial communities<br>Phytate degrading bacteria<br>Task 10 |
| | PANSU | Marc | IR Scientist OM cycles | 4 | Litter decomposition and MOMOS model<br>Task 9 |
| | HINSINGER | Philippe | DR2 Scientist Biogeochemistry | 6 | Fate of P in soil<br>Task 9 and 10 |
| | DREVON | Jean-Jacques | DR2 Scientist NFS Ecophysiology | 8 | P use efficiency of NFS, Phytase and Pase gene expression in nodule<br>Tasks 8, 10 |
| | AMENC | Laurie | Technician | 4 | Phytase and Pase gene expression with in situ RT-PCR<br>Task 10 |
| | LEGNAME | Elvira | Technician | 12 | P availability determination, molecular determination of mycorrhizal association<br>Tasks 9, 10 |
| | PERNOT | Catherine | Technician | 12 | Screening of phytate-degrading bacteria<br>Task 10 |
| | PABLO | Anne-Laure | AI (Assistant Engeneer) | 4 | DNA extraction from soil, molecular studies of bacteria communities<br>Task 10 |
| | VILLENAUVE | Manon | Technician | 4 | Soil collection, set-up of experiments in mesocosms<br>Task 9, 10 |
| | X | X | AI To be recruited | 18 | Soil collection, nematofauna isolation and identification, follow-up of mesocosms<br>Task 9, 10 |

| **Partner 5 Innovation** | **Name** | **Surname** | **Position** | **Contribution Man-month** | **Role in the project** |
|---|---|---|---|---|---|
| Leader<br>WP4 coordinator | KALMS | Jean-Marie | Socio-economist | 12 | Task 12 coordinator, Task 11<br>Involvement in the project management team (Task 1) |
| | DULCIRE | Michel | Socio-economist | 4 | Coordinator Task 11,<br>Task 12<br>Stakeholder perceptions and strategies |
| | SIBELET | Nicole | Sociologist and anthropologist Forestry /Agroforestry | 4 | Task 11, Task 12<br>Stakeholder perceptions and strategies |
| | PIKETTI[1] | Marie-Gabrielle | Economist | 4 | Co-ordinator Task 12, Task 11<br>Stakeholder perceptions and strategies<br>Technico-economical analyses |
| | MARIEN[2] | Jean-Noël | Forest socio-economist | 4 | Task 11, Task 12<br>Stakeholder perceptions and strategies (Congo, Brazil) |

[1] Scientist from UMR Moisa [2] Scientist from Cirad UPR 105 (BSEF)

| **Partner 6 - AFAF** | **Name** | **Surname** | **Position** | **Contribution Man-month** | **Role in the project** |
|---|---|---|---|---|---|
| Leader | LIAGRE | Fabien | Secretary of AFAF<br>Agroforestry expert | 5 | Partner 7 leader<br>Task 3 and 11 co-coordinator<br>Tasks 5, 12<br>Conceptual model assessment and “Modelix” testing<br>Stakeholder point of view<br>Involvement in the project management team (Task 1) |
| Other staff members | BACHEVILLIER | Yves | Extension Officer<br>Agroforestry schemes in south france | 2 | Tasks 11, 12<br>Stakeholder perceptions and strategies |
| | CANET | Alain | Expert on tree plantation | 3 | Tasks 11, 12<br>Stakeholder perceptions and strategies |
| | SANTI | Frédérique | Expert on improved trees for AF systems | 3 | Tasks 11, 12<br>Stakeholder perceptions and strategies |
| | X (to be hired) | | Farm scale economist ( ½ half time with UMR System) | 24 | Tasks 3, 5<br>Conceptual model assessment and testing<br>Use of Farm-sAFe |

| Partner 7 - USP | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| Leader | GONCALVEZ | Leonardo | Professor Silviculture | 12 | Partner 8 leader , Tasks 2, 3 Stand growth, root dynamics, nutrient budget Task 8 co-coordinator, Task 9 Interactions with partners tasks 11 and 12 Involvement in the project management team (Task 1) |
| Other staff members | TRIVELIN | Paulo Cesar | Lab Head 15N Labelled analysis | 2 | N budget:, $^{15}N$ labelled analysis, N transfer Tasks 8, 9, 10 |
| | DA SILVA | Luciana Duque | Professor Ecophysiology | 8 | Ecophysiological tree fuctioning Task 6 |
| | TADEU | Sergio | Professor Ecophysiology | 4 | Ecophysiological tree fuctioning Task 6 |
| | MOREIRA | Marcello | Lab head isotopic natural abundance analysis | 2 | N budget: $^{15}N$ natural abundance analysis Task 8 |
| | PICCOLO | Marisa | Professor N Cycling in agro-ecosystems | 8 | Nitrogen mineralisation and litter decomposition Task 9 |
| | TSAI | Sui Mui | Professor Head Lab Molecular biology | 8 | Functional bacterial communities Task 10 |
| | X | Y | PhD student (Fund agency planned: FAPESP or CNPQ) | 36 | N transfer and litter decomposition Task 9 |
| | MOREIRA | Rildo | Research station head | 6 | Fied experiment monitoring Tasks 6, 7, 8, 9, 10 |

| Partner 8 – CRDPI | Name | Surname | Position | Contribution Man-month | Role in the project |
|---|---|---|---|---|---|
| Leader | THONGO | Armel | Scientist<br>Root system modeling | 20 | Partner 9 leader<br>Congolese site leader, Task 6 coordinator, Tasks 2, 3<br>Evaluation of root dynamics, stand growth and organic matter decomposition<br>, Tasks, 7, 9<br>Involvement in the project management team (Task 1) |
| Other staff members | NKOUA | Méthode | Scientist<br>Socio-economy | 12 | Stakeholder point of view<br>Technical economical analyses<br>Tasks 3, 11, 12 |
| | DZOMAMBOU | Séraphin | Engineer<br>Database, computing | 14 | Data base management Task 3<br>"Modelix" testing Task 5<br>Fied experiment supervision<br>Tasks 6, 7, 8, 9, 10 |
| | MAZOUMBOU | Jean-Claude | Field technician nutrient cycles | 14 | N2 fixation, N budgets, N transfer<br>Tasks 8, 9, 10 |
| | KINANA | Antoine | Field technician Ecophysiology | 14 | Ecophysiological tree processes, Soil respiration TBCA<br>Tasks 6, 7 |
| | MAYINGUIDI | ULRICH | Field technician Ecophysiology | 14 | Ecophysiological tree processes, Evaluation of root dynamics and stand growth<br>Tasks 6, 7 |
| | X | Y | PhD Student (Funded by CRDPI) | 36 | Litter decomposition (Home field advantage) and N transfer<br>Tasks 9, 10 |
| | X | Y | Post doc | 10 | Growth modelling, Stand growth, biomass and nutrient contrent equations,<br>Tasks 4, 6 |
| | X | Y | Field technician | 24 | Tasks 6, 7, 8, 9, 10<br>Fied experiment setting-up and following-up |

# 6. JUSTIFICATION SCIENTIFIQUE DES MOYENS DEMANDES

The budget is well balanced among partners. The ANR grant amounts 996 612 € (figure 5) for a full cost of 5 894 927 € (Figure 6).

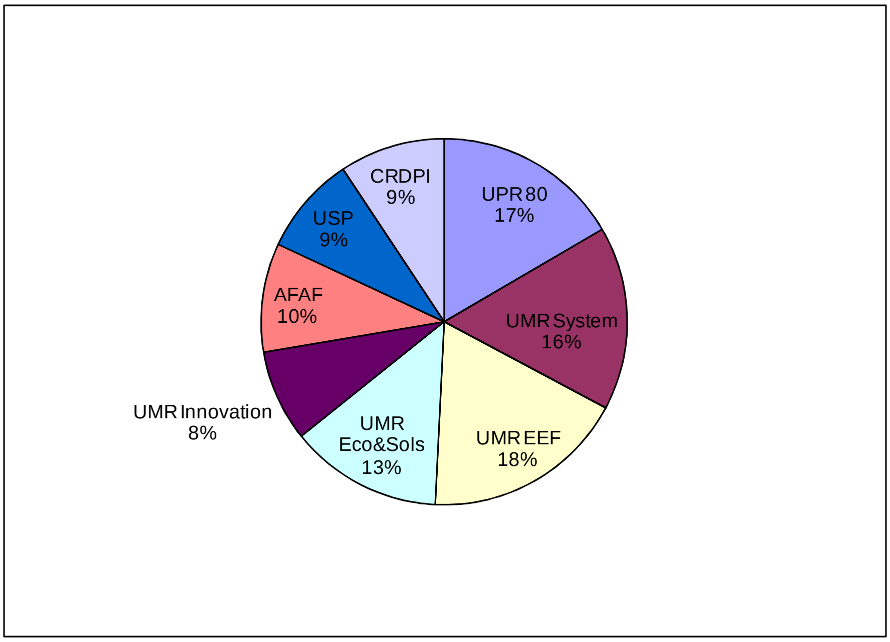


**Figure 5.** *Allocation of ANR grant among the Intens&Fix project partners (€)*

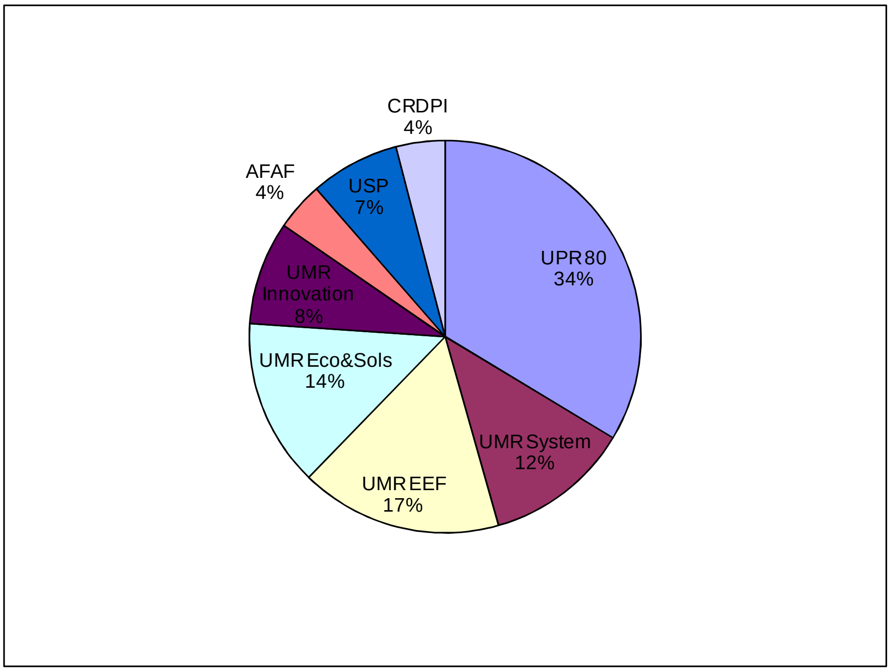


**Figure 6.** *Full cost sharing among the Intens&Fix project partners (€)*

## 6.1. PARTENAIRE 1: CIRAD – UPR 80

### *Équipement*

**Field equipment for the Brazilian site**

- Sap flow measurement probes to monitor tree transpiration in pure and mixed-species plots: 10.20 k€, and related CR1000 and data loggers : 5.23 k€
- PAR sensors allowing to measure light interception through the canopy in pure and mixed-species plots: 3.49 k€
- Data collecting device for Trase system (soil moisture monitoring): 0.79k€

Total: 19.8 k€

### *Personnel*

Beside the **102 man-months of CIRAD-UPR 80 permanent staff** involved in the project, student trainees will be recruited to contribute to the implementation of the following activities:

**France**

- One MSc student in France: 6 months * 430€ /month = 2.58 k€. These students will be involved in analysing tree and stand growth using the Growth and Yield model E-Dendro (Task 3)

Total: 2.6 k€

**Brazilian site**

- Two French MSc students: 6 months * 550€/month (salary + accommodation) * 2 = 6.6 k€. These students will be involved i) in measuring and upscaling root, stem and branch $CO_2$ effluxes measurements to the tree and stand scale mixing-species plantations of *E. grandis* and *A. mangium* (task 6), and ii) on the variability of *in situ* N mineralization according to the distance to trees in mono-specific and mixed-species plantations of *Eucalyptus grandis* and *Acacia mangium*; comparison with the dynamics of soil $CO_2$ effluxes and root biomasses of each species in the upper soil layer at the same spatial positions (task 8). Their results will be used to improve and parameterize the woody respiration submodel in MAESTRA (in interaction with the PhD student: cf infra)
- For the record one **PhD student**, will be recruited and funded half by Partner 1- UPR80 and half by Partner 8 - USP. He will work on the modelling of carbon budgets in *Acacia-Eucalyptus* association (task 7). Simulation results will be used for estimating TBCA of each species in mixed stands. D Epron (Partner 3), WP2 coordinator will belong to the thesis committee.

Total: 6.6 k€

**Congolese site**

- Two French MSc students: 6 months * 750€/month (salary + accommodation) * 2 = 9.0 k€. These students will be involved i) in measuring and upscaling chamber gas-exchange measurements to the tree and stand scale in mixed *E. urophylla * grandis* and *A. mangium* plantations (task 6), and ii) on the Home Field Advantage for leaf decomposition in mono-specific and mixed-species plantations of *E. urophylla * grandis* and *Acacia mangium* (task 8).

Total: 9.0 k€

### *Prestation de service externe*

### *Missions*

**Project coordination**

The project leader - JP Bouillet - is located in Brazil.
Four missions JP Bouillet Brazil-France for project coordination and annual meeting: 12 k€
Two missions JP Bouillet Brazil-Congo for project supervision: 8 k€
Total: 20.0 k€

**France**
- French MSc transportation: 0.5 k€
- Local missions in Nancy and Montpellier for cross discussions/data analyse /Task 3, 4, 6, 8 co-coordination: 2.5 k€

Total: 3.0 k€

**Brazil**
- Local transportation (15,000 km $yr^{-1}$, including car hiring): 16 k€
- Support missions: (basis 3 k€ / mission, including travel, per-diems for 10 day mission + 1k€ for extra salary costs for UPR 80-Cirad scientists)): 17.0 k€
    - 1 support mission B Zeller (EEF) for N transfer and labelled litter decomposition : 3 k€
    - 1 mission from D Epron (EEF) for participation of thesis committee of PhD on WP2: 3 k€
    - 1 mission from C Plassard (Eco&Sols) for year 3 annual meeting : 3 k€
    - 1 mission from C Jourdan (UPR 80) on root modelling: 4 k€
    - 1 mission G Le Maire for the inception meeting WP1: 4 k€
- Participation to international conference (2 scientists): 7.0 k€
- Flight French MSc + PhD students: 4.0 k€

Total: 44.0 k€

**Congo**
- Local transportation for field data collecting (10.000 km $yr^{-1}$): 14.0 k€
- Support missions: (basis 3 k€ / mission, including travel, per-diems for 10 day mission + 1 k€ for extra salary costs for UPR 80-Cirad scientists)): 25.0 k€
    - 2 support missions B Zeller (EEF) for N transfer and labelled litter decomposition : 6 k€
    - 1 mission from L Saint-André (UPR 80) for the inception meeting WP1: 4 k€
    - 1 mission from L Saint-André (UPR 80) on litter decomposition and biomass modelling: 4 k€
    - 1 mission from C Plassard (Eco&Sols) for microbiology and WP3 coordination : 3 k€
    - 1 mission from C Jourdan (UPR 80) on root modelling: 4 k€
    - 1 missions from JM Harmand (UPR 80) for N and P dynamics: 4 k€
- Participation to international conference (1 scientist): 3.5 k€
- French MSc student flight: 2.8 k€

Total: 45.3 k€

*Dépenses justifiées sur une procédure de facturation interne*

*Autres dépenses de fonctionnement*

- Coordination: renting of rooms for meetings, phone, phone conference, visioconference, paperwork: 3.0 k€
- Organisation costs for running the summer school (renting of lecture theatres, rooms for meetings and practical classes, paperwork…): 5.0 k€

Total: 8.2 k€

- Management costs: 6.4 k€

**Total Partner 1 CIRAD-UPR 80 = 164.8 k€**

## 6.2. PARTENAIRE 2: UMR SYSTEM

### *Équipement*

**Field equipment for the Montpellier site**

- *Lidar equipement for validation of the light capture modules of the integrated model*

This laser portable system will be used for quantifying the canopy structure of the trees in the experimental plots, and validate the light competition module. Only part (20 k€) of this investiment is applied in this call. The Lidar will be available on all sites of the project.
Total: 20 k€

### *Personnel*

UMR-SYSTEM permanent stafff will dedicate **56 man-months to** the project. A contracted modeller will be responsible for the coding and testing of the integrated Modelix model (18 months, 61 k€). A Ph.D. student will be contracted to model the N budget of the Montpellier Juglans based mixed species systems. Only half the grant (44.6 k€) is expected from the Intens&Fix project, the other half will be provided by the Languedoc-Roussillon Region or by Inra.
Total: 105.6 k€

### *Prestation de service externe*

### *Missions*

WP1 leader – C Dupraz - is located in Montpellier.
- Two missions (Brazil, Congo) for C Dupraz for WP1 coordination and annual meeting: 4.0 k€
- Two missions for S. Roux and M.A. Ngo Bieng (Brazil-Congo) for model training of partners: 7.0 k€
- Eight missions to Nancy for site monitoring and project animation for L. Dufour, C. Dupraz, A. Metay, S. Roux, M.A. Ngo Bieng : 2.0 k€
- Participation to international conference (1 scientist): 2 k€

Total: 15.0 k€

### *Dépenses justifiées sur une procédure de facturation interne*

### *Autres dépenses de fonctionnement*

- Consumables for trial setting up and following up : 6 k€
- Nitrogen 10% $^{15}N$ labelled: $N_2$ fixation, litter decomposition, and 99% $^{15}N$ labelled: N transfer: 3 k€
- Analyses ($^{15}N$ plant): 6 k€

Total 9 k€

- Management costs: 6.2 k€

**Total Partner 2 UMR-System = 161.8 k€**

## 6.3. PARTENAIRE 3: UMR EEF

### *Équipement*

**LiCor 840 soil $CO_2$ analysers**
LiCor gaz analyzers for trunk and soil respiration (WP2, tasks 6): 12.5 k€
Total: 12.5 k€

### *Personnel*

Beside the **88 man-months of UMR EEF permanent staff** involved in the project, a post-doctoral researcher and a technician will be recruited:

- The post doctoral researcher will be recruited for 9 months to develop a scanner-based device for fine root observation and an image analysis procedure to estimate root lifespan. He/she will have in charge the data collection and the organisation of a data basis including information on soil respiration, litter fall, root biomass increment and litter layer increment for all sites. He/she will use this information to estimate changes in total belowground carbon allocation (task 6): 30.3 k€
- A technician will be recruited for laboratory work during 10 months. He will be in charge of the sample preparation (grinding, micro-weighing) for the IRMS analysis and for the storage compounds analysis of all sites (Tasks 5 and 7): 22.3 k€
- For the record a PhD student will be recruited on Inra grant to work on C and N budgets (Task 5 and 6)

<u>Total: 52.6 k€</u>

### *Prestation de service externe*

### *Missions*

**France**

- Local missions in Nancy and Montpellier for cross discussions / data analyse / WP2 coordination: 6.4 k€
- Participation to international congresses and symposiums (2 scientists): 6.4 k€

<u>Total: 12.8 k€</u>

### *Dépenses justifiées sur une procédure de facturation interne*

### *Autres dépenses de fonctionnement*

- Small material for LiCor 840 chamber building (S2): 5k€
- Light sensors, micro-dendrometers and soil water probe (TDR) for the Nancy site (S3): 8.0 k€

<u>Total: 13 k€</u>

- Storage compound analyses (WP2) for all French sites and for the non $N_2$ fixing species only (pure and mixed treatments):
  - For the Nancy site (S2): 8.5 € per analysis x 1344 samples (3 years x 2 dates x 2 treatments x 2 densities x 7 organs x 8 replicates) = 11.5 k€
  - For Montpellier (S1): 8.5 € per analysis x 672 samples (3 years x 2 dates x 2 treatments x 7 organs x 8 replicates) = 5.75 k€

<u>Total: 17.25 k€</u>

- The IRMS analyses of all French sites will be realised using the facilities of Partner 3, EEF: For the Nancy site (S2): 8 € per analysis x 192 samples (3 years x 4 treatments x 2 densities x 1 organ x 8 replicates) = 1.6 k€. For Montpellier (S1): 8 € per analysis x 96 samples (3 years x 4 treatments x 1 organ x 8 replicates) = 1.55 k€ per site = 0.8 k€

<u>Total: 2.4 k€</u>

- $N_2$ fixation (WP2) for the Nancy site (S2): (10 € per analysis x 108 samples) + 0.42 k€ $^{15}N$ labelled fertilizer (1 € per kg and 2 kg per ha)

<u>Total: 1.5 k€</u>

- C/N/P analyses (WP2)

- For the Nancy site (S2): 4 € per analysis x 2688 samples (3 years x 2 dates x 4 treatments x 2 densities x 7 organs x 8 replicates) = 10.8 k€
- For Montpellier (S1): 4 € per analysis x 1344 samples (3 years x 2 dates x 4 treatments x 7 organs x 8 replicates) = 5.4 k€

Total: 16.2 k€

- Transfer labelling analyses (WP3) for the Nancy site (S2): 2 k€ $^{15}N$ + 0.5 k€ small equipment + 1.6 k€ analyses (2 dates x 80 samples)

Total: 4.1 k€

- Home Field Advantage (WP3) for the Nancy site (S2): 2 € (1 € per litter bag + 1 € perNIRS analysis) x 4 treatments x 180 samples

Total: 1.44 k€

- In situ N mineralization (WP3) for the Nancy site (S2): 300 samples x 5 € per analysis

Total: 1.5 k€

- Litter decomposition (WP3) for the Nancy site (S2): 1 k€ $^{15}N$ + 3.6 k€ analyses (10 € x 360 samples) + 0.4 k€ litter bags

Total: 5.0 k€

- SOM dynamic in situ (WP3) for the Nancy site (S2):
  - 8 € per analysis x 720 gas samples (6 dates x 4 treatments (2 species x pure or mixed) x 5 concentrations x 6 replicates) = 5.76 k€
  - 8 € per analysis x 768 organic matter samples (2 dates x 4 treatments x 4 sample types (bulk, incubation, C fumigated soil, C unfumigated soil) x 3 mesh sizes x 8 replicates) = 6.14 k€

Total: 11.9 k€

For USP site (S3): biochemical and chemical analyses for tree storage compounds (8.5 k€) as well as isotopic 13C analyses for WUE (1.5k€): 10.0 k€

Total: 10.0 k€

For CRDPI site (S4): biochemical and chemical analyses for tree storage compounds (8.5 k€) as well as isotopic 13C analyses for WUE (1.5k€): 10.0 k€

Total: 10.0 k€

- Shipping: 0.7 k€

Total = 94.99 k€

Management cost (4%): 6.5 k€

**Total Partner 3 UMR EEF = 179.39 k €**

## 6.4. PARTENAIRE 4: UMR ECO&SOLS

*Équipement*

Laboratory equipement: fully equipped inverted microscope: 4 k€
Total: 6.97 k€

*Personnel*

Beside the **94 man-months of Eco&Sols permanent staff** involved in the project, student trainees will be recruited to contribute to the implementation of the following activities:

- Four MSc student: 6 months * 420€ /month = 2.52 k€. These students will be involved in the P use efficiency measurement of NFS species (Task 7) and in the study of soil functional ecology and nutrient bioavailability (Tasks 8 and 9).
Total: 10.0 k€
- One assistant engeneer: 18 months * 32 k€ / year = 48 k€. This person will be in charge to proceed to the sampling of soil cores for nematodes studies and chemical analysis, as well the isolation of nematodes, their counting and preparation of samples for species determination. He/she will also be involved in the experiments carried out in mesocosms.
Total: 48 k€

*Prestation de service externe*

*Missions*

- Missions in Nancy for sampling and scientific meetings: 3.0 k€
- Two missions Brazil-Congo for sampling and training for nematodes isolation: 7 k€

Total: 10 k€

*Dépenses justifiées sur une procédure de facturation interne*

*Autres dépenses de fonctionnement*

Pavailability: (4 sites)
10 soil samples * 4 especies (3 treatments: non fixing tree, NFS, non fixing tree + non NFS) * 4 sites = 160 soil samples
- P Olsen, organic and inorganic P: 12 € per analysis * 160 = 1.92 k€
- Production of phytase *A. niger*, phytase *B. subtilis*, phosphatase *H. cylin*: 2k€
- RMN analyses: 40€ per analyse * 160 samples = 6.4 k€
Total = 10.32k€

Nematofauna : 3 €/sample * 4 sites * 200 samples = 2.4 k€
Total = 2.4 k€

N and P cycling (one site)
- Phytase screening = 0.5 k€
- PCR 16S sequences = 1 k€
- Phytase gene cloning = 2.5 k€
- Soil ADN/ARN extraction = 1.25 k€
- PCR + DGGE analyses (4 genes) = 8 k€
- in situ RT-PCR on phytase gene = 1.28 k€
Total =: 14.53k€

Trophic Interactions (site 2)
5 soil treatments * 3 species treaments * 6 individuals / treatment = 90 individuals
- 12 week glass house costs (4 m2): 2.4 k€
- P Olsen, organic and inorganic P of bulk and rhizospheric soil: 12 € per analysis * 160 = 2.16 k€
- Shoot and root mineralization: 4€ per analysis * 180 = 0.72 k€
- N et P analysis: 4€ per analysis * 180 = 1.44 k€
- Soil DNA/RNA extraction: 12.5 € per analysis * 90 = 1.125 k€
- Rootl DNA/RNA extraction: 11.0 € per analysis * 90 = 0.99 k€

- PCR + DGGE (4 genes): 20.0 per analysis * 400 =  8.0 k€
  Total = 16.84 k€

Screening in controlled conditions of N2 fixation depending on P availability (4 sites)
3 P levels * 6 individuals * 4 NFS (1 NFS / site) = 72 individuals
- 12 week glass house costs (8 m2): 4.8 k€
- Shoot and root mineralization: 4€ per analysis * 144 = 0.6 k€

N et P analysis: 4€ per analysis * 144 = 1.15 k€
  Total = 6.53 k€

- For USP site (S3): experiments on P efficiency for N2 fixation: 1.5 k€
- For CRDPI site (S4): experiments on P efficiency for N2 fixation: 1.5 k€

- Small material for field analyses: 1.03 k€

Total: 54.67 k€

Management costs (3.57%):  4631.22 k€

**Total Partner 4 Eco&Sols = 134.357 k€**

## 6.5. PARTENAIRE 5 : UMR INNOVATION

### *Equipement*

None

### *Personnel*

Beside the **28 man-months of UMR - Innovation permanent staff** involved in the project, 2 French MSc students will be recruited for task 12 in Congo and in Brazil in relation with partner 7 - USP and partner - 8 CRDPI : 6 months * 550€/month (salary + accommodation) * 2 = 6.6 k€ .
Total: 6.6 k€

### *Prestation de service externe*

A sub-contract will be established with Ecomidia, a Brazilian research consultancy. Under the supervision of partner 5 – Innovation and partner 7-USP, this sub-contractor will (1) participate to the organization of the inception meeting in Brasil (Task 3.3 - WP1 and Task 11 - WP4), 2)  conduct, for Brazil (Sao-Paulo and Minas Gerais states), the studies (enquiries,…) related to the deliverables D11.1 to D11.2, and D11.4 to D11.6 (WP4 - Task 11) and D12.1 to D12.2 (WP4 – Task 12), and 3) to provide these deliverables.
Total: 14 k€

### *Missions*

WP4 leader - JM Kalms - is located in Montpellier.
Support missions: (basis 3 k€ / mission, including travel, per-diems for 10 day mission + 1 k€ for extra salary costs for Cirad scientists)
- Two missions (Congo) for JM Kalms for inception meeting (WP1 - task 3 and WP4 - task 11) and WP4 coordination: 8.0 k€
- One mission (Brazil) for JM Kalms for WP4 project coordination and 3rd year annual meeting: 4 k€
- One mission in Congo for M Dulcire for task 11 coordination: 4 k€
- One mission (Brazil) for N Sibelet for task 11 and 3rd year annual meeting: 4 k€
- Four missions for MG Piketti (Brazil) for inception meeting (WP1 - task 3 and WP4 - task 11), 3rd year annual meeting and technico-economical analyses in relation with Ecomidia sub-contractor: 16.0 k€
- One mission in Congo and one mission in Brazil for JN Marien (Tasks 11 and 12): 8 k€

- Missions in France for inception meetings (WP1 - task 3 and WP4 - task 11), annual meeting, project animation for M Dulcire, JM Kalms, JN Marien, MG Piketti, N Sibelet : 5.0 k€
- Local transportation in Brazil and Congo: 6 k€
- Participation to international conference (1 scientist): 2 k€

Total: 57.0 k€

### *Internal facturation*

### *Autres dépenses de fonctionnement*

Management costs: 3.1 k€

**Total Partner 5 - Innovation**: **80.7 k€**

## 6.6. PARTENAIRE 6: AFAF

### *Équipement*

None

### *Personnel*

This partner will participate in the assessment of the conceptual model (Task 3), the testing of the "Modelix" model (Task 5), the socioeconomic diagnosis (task 11) and the transfer to end-users (Task 12); **13 man-months** of AFAF members will be allocated to the project. A post-doc scientist with expertise in economic modelling will be contracted for 24 months, particularly to take into account the technical-economical factors and upgrade the Farm-level model: 24 months * 2.9 k€/month = 70.7 k€.

Permanent members of AFA association: model testing, socio-economical diagnosis and result transfer towards potential end-users = 63 k€

Four months of non-permanent ingeneer (no funded by ANR): 11.8 k€

Total: 145.5 k€

### *Prestation de service externe*

The Chambre d'Agriculture des Vosges will be commissionned in relation with partner 5 - Innovation and partner 2 – System to organize the inception meeting (Task 3 - WP1 and Task 11 - WP4) and to provide a report on the bio-energy production potential in the area with VSRC (WP4 - Task 11): 15 k€. A specialised computing society will be contracted to upgrade the Farm-level model with the improved conceptual frame developed for taking into consideration NFS species (Task 3 - WP1 and Task 12 - WP4) : 16 k€.

Total: 31 k€

### *Missions*

Organization of the inception metting for AFS in relation with task 1 of WP1: 4 k€
12 missions inside France for project meetings: 3 k€
1 mission in Brazil for the review meeting of year 3: 2.5 k€
Total: 9.5 k€

### *Dépenses justifiées sur une procédure de facturation interne*

### *Autres dépenses de fonctionnement*

They include the management costs of the project (including the contracted scientist needs), the organisation of inception and evaluation meetings, the conception, design, validation of disemination pamphlets for stakeholders; 5 k€/year * 4 years = 20 k€

The total cost of the project for AFAF is 251.0 k€ with an eligible cost of 239.2k€. The rate of financial support requested is 40%

**Total Partner 6 – AFAF = 95.7 k €**

## 6.7. PARTENAIRE 7 : USP

### *Équipement*

None

### *Personnel*

Beside the **50 man-months of USP permanent staff** involved in the project student trainees will be recruited to contribute to the implementation of the following activities:
- Two MSc students: 2 * 6 months * 250€ /month = 3.0 k€. These students will be involved in i) the *in situ* transfer of N from *Acacia mangium* to *Eucalyptus grandis* (task 9), and ii) the Home Field Advantage for leaf decomposition in mono-specific and mixed-species plantations of *E. grandis* and *Acacia mangium* (task 9)
- For the record 2 **PhD** Brazilian **students** will be recruited (FAPESP or CNPQ grant) to work on N transfer and Litter decomposition (Task 8).
- 13C

Total: 3.0 k€

### *Prestation de service externe*

- Sub-contracting with local companies for field technical support: one full-time field-team head (20 k€) and day-workers (300 days = 10 k€): 30 k€

Total: 30.0 k€

### *Missions*

- Oragnization of the WP1 inception meeting in Brazil: 4k€
- Participation to the kick-off and annual meetings: 5 * 3 k€ (1 annual meeting will be organized in Brazil): 15 k€
- Participation to scientific conference (2 scientists): 7.0 k€

Total: 26 k€

### *Dépenses justifiées sur une procédure de facturation interne*

- Nutrient plant analyses for USP: 6.2k€

Total: 6.2 k€

### *Autres dépenses de fonctionnement*

- Nitrogen 10% $^{15}N$ labelled: $N_2$ fixation, litter decomposition, and 99% $^{15}N$ labelled: N transfer: 3.0k€

- Consumables (litter bags…): 1.5k€
- Analyses
    - Chemical (C, N, P plant): 5k€
    - Isotopic ($^{15}N$ plant): 10.5 k€
    - *in situ* N mineralisation: 2.0 k€

For the record the soil solution analysis (10k€) will be supported by extra funding
Total 22.0 k€

**Total Partner 7 - USP = 87.2 k€**

## 6.8. PARTENAIRE 8: CRDPI

### *Équipement*

None

### *Personnel*

Beside the **76 man-months of CRDPI permanent staff** involved in the project, a post-doctoral researcher and a technician (half time) will be recruited on the Intens&Fix grant:
- One Congolese **post doc**: (10 months* 700€ = 7k€) will work on the variation of wood production among treatments. Annual wood volume and biomass increments will be calculated from tree inventories, biomass sampling and allometric equations, and further converted into biomass, C, N and P increments knowing C, N and P content of plant parts (task 5)
- **Field technical** support: one 1/2-time technician (24*500: 12.0 k€) and day workers: (600 days: 9 k€): 21.0 k€. The technician will supervise the site setup, the management, the maintenance and the performed field measures.
- Two Congolese **MSc** students: (2 * 6 months * 125€ /month): 1.5 k€. These students will be involved in the understanding of the *Eucalyptus* root system dynamics in monoculture plantation compared to mixed plantation and the comparison of *Eucalyptus* root architecture between monoculture plantation and mixed plantation (tasks 5 and 6).
- One Congolese **PhD student** will be recruited by **UR2PI** on its **own budget** to work on the single and mixed litter decomposition (*Eucalyptus*/*Acacia*), evaluation of N transfer between mixed litters ($^{15}N$ labelled litter) and modelisation using the CEM model to describe C and N dynamics in single and mixed litter (task 8). B. Zeller (Partner 3 – EEF) will belong to the thesis committee.

Total: 29.5 k€

### *Prestation de service externe*

None

### *Missions*

- Organization of the WP1 (task 3) inception meeting in Congo: 6 k€
- Participation to the kick off and the annual meetings: 5 * 3 k€ (in France) + 1*4 k€ (meeting in Brazil): 19 k€
- Participation to scientific conference (1 scientist): 3.5 k€
- Travel and missions for WP4 enquiries (task 11 and 12): 5 k€
- One mission of D Epron (Parner 3 – EEF, WP2 coodinator) for TCBA and soil respiration assessement (task 6): 4k€

Total: 37.5 k€

*Dépenses justifiées sur une procédure de facturation interne*

*Autres dépenses de fonctionnement*

- Nitrogen 10% $^{15}N$ labelled: $N_2$ fixation, litter decomposition, and 99% $^{15}N$ labelled: N transfer: 3.3k€
- Consumables (litter bags…): 1.5k€
- Analyses
    - Chemical (C, N, P plant): 5k€
    - *in situ* N mineralisation: 2.0 k€
    - Isotopic ($^{15}N$ plant): 10.5 k€

Total 22.3 k€

Management costs: 3.6 k€

**Total Partner 8 – CRDPI = 92.9 k€**

# 7. ANNEXES

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- UNFCCC, 2002. Report of the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001, addendum, part two: Action taken by the Conference of the Parties, volume II. FCCC/CP/2001/13/Add.2 (21 January).
- Vadez V., Drevon J.J., 2001. Genotipic variability in phosphorus use efficiency for symbiotic N2 fixation in common bean (*Phaseolus vulgaris*). Agronomie, 21 : 691-699.
- Vance C.P., Uhde-Stone C., Allan D.L., 2003. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. /New Phytologist/, 157: 423-447.
- Vandermeer J.H. 1989. The Ecology of Intercropping Cambridge University Press, Cambridge, UK.

- Vincent G., Harja D., 2008. Exploring ecological significance of tree crown plasticity through three-dimensional modelling. Annals of Botany, 101(8): 1221-1231
- Vital M.H.F., 2007. Impacto Ambiental de Florestas de Eucalipto. Revista do BNDES, Rio de Janeiro, 14(28), 235-276
- Vivanco L., Austin AT., 2008. Tree species identity alters forest litter decomposition through long-term plant and soil interactions in Patagonia, Argentina. Journal of Ecology, 96: 4, 727-736
-Wartelle R., Dreyfus J., 2010. Synthèse bibliographique sur la production de biomasse d'origine arborée. Chambre d'Agriculture de Picardie; Programme CASDAR Agroforesterie, p 31.
- West Dean, Perceval, 1991. "The productivity of Maku Lotus as a forest understorey." In Proceedings of the New Zealand Grassland Association 53:169-173.
- Yerokun O.A., 2008. Chemical characteristics of phosphorus in some representative benchmark soil of Zambia. Geoderma, 147: 63-68.

## 7.2. BIOGRAPHIES

**Jean-Paul LACLAU, 44 years**
**CIRAD Scientist**
PERSYST Department, UPR 80 “Functioning and Management of tree-based planted Ecosystems »

***Academic qualification***
PhD in Agronomic Sciences, Institut National Agronomique Paris-Grignon (INA-PG)/Paris/France, 2001
Forest Engineer: Ecole Nationale d’Ingénieurs des Travaux des Eaux et Forêts (ENITEF)/Nogent-sur-Vernisson/France, 1990

***Key qualifications***
Biogeochemical cycles in forest ecosystems, sustainability of plantation forests

***Work experience***
2002-Present: CIRAD-Persyst - University of São Paulo (CIRAD-USP scientific cooperation), visiting professor.
Study of the sustainability of eucalyptus plantations and effects of silvicultural practices on the biogeochemical cycles
1996-2001: CIRAD-Forêt - Pointe-Noire (Congo)
Comparison of the biogeochemical cycles in savana and in *Eucalyptus* plantations. Consequences for the sustainability of the *Eucalyptus* plantations.
1992-1996: CIRAD-Forêt - Pointe-Noire (Congo)
Head of the UAIC Forest Management Department (43 000 ha of *Eucalyptus* plantations in Congo)

***List of the more relevant publications in the last five years***
- **Laclau J.P.**, Almeida J.C.R., Gonçalves J.L.M., Saint-André L., Ventura M., Ranger J., Moreira R.M., Nouvellon Y., 2009. Influence of nitrogen and potassium fertilization on leaf life span and allocation of above-ground growth in *Eucalyptus* plantations. *Tree Physiology*, 29, 111-124.
- **Laclau J.P**., Bouillet J.P., Gonçalves J.L.M., Silva E.V., Jourdan C., Cunha M.C.S., Moreira M.R., Saint-André L., Maquère V., Nouvellon Y., Ranger J., 2008. Mixed-species plantations of *Acacia mangium* and *Eucalyptus grandis* in Brazil. 1. Biomass allocation and net primary production *Forest Ecology and Management, 255, 3905-3917*
- **Laclau J.P**., Ranger J., Deleporte P., Nouvellon Y., Saint-André L., Marlet S., Bouillet J.P., 2005. 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. *Forest Ecology and Management*, 210, 375-391.
- Maquère, V., **Laclau, J.P.**, Bernoux, M., Saint-André, L., Gonçalves, J.L.M., Cerri, C., Piccolo, M., Ranger, J., 2008. Influence of land use (savanna, pastures, *Eucalyptus* plantations) on soil organic matter stocks in Brazil. *European Journal of Soil Science*, 59, 863-877.
- Silva E.V., Gonçalves J.L.M., Coelho S.R.F., Moreira R.M., Mello S.L.M., Bouillet J.P., Jourdan C., **Laclau J.P.**, 2009. Dynamics of fine root distribution after establishment of monospecific and mixed-species plantations of *Eucalyptus grandis* and *Acacia mangium*. *Plant and Soil*, in press.

***Number of papers in referred journals (published or under press): 23***

***Awards, other information***
- Editor of the journal *Forest Ecology and Management*
- Reviewer of the journals *Tree Physiology*, *Plant and Soil*, *Annals of Forest Science*, *Australian Journal of Botany*, *Forest Ecology and Managemen*t.

**Yann NOUVELLON, 40 years**
**CIRAD Scientist**
PERSYST Department, UPR 80 “Functioning and Management of tree-based planted Ecosystems”

***Academic qualification***
PhD in Ecophysiology/Bioclimatology, Institut National Agronomique Paris-Grignon (INA-PG)/ Paris/France, 1999
Engineer and MASTER degrees in Agronomy: Ecole Nationale Supérieure d’Agronomie et des Industries Agro-Alimentaires (ENSAIA), Nancy, France, 1994

***Key qualifications***
Carbon and water cycles in tropical plantations; Modelling soil-plant-atmosphere interactions and tree-growth; Upscaling chamber gas-exchange measurements to the canopy scale; Eddy-covariance measurements of water, $CO_2$, and energy fluxes.

***Work experience***
2006-Present: CIRAD-Persyst - University of São Paulo, Brazil (CIRAD-USP scientific cooperation), visiting professor. Modelling carbon and water-budgets in pure *Eucalyptus* plantations (ULCOS and EUCFLUX projects involving an eddy-covariance site), and in mixed *Eucalyptus*/*Acacia* plantations.
2000-2006: Research scientist, CIRAD-FORET, Pointe-Noire (Congo): Measurement and modelling of water and $CO_2$ fluxes within *Eucalyptus* stands in Congo (ORE eddy-covariance sites; ULCOS and CARBOAFRICA projects).
1999-2000: Research scientist, USDA-ARS, Southwest Watershed Research Center, Tucson, Arizona: SVAT and radiative transfer modelling. Development of a spatially-explicit, hydro-ecological model (SEHEM), and its application over a semi-arid grassland watershed using remotely sensed data (Landsat imagery) and other spatially-distributed data (soil maps, etc.)

***List of the more relevant publications in the last five years***
- Epron, D., **Nouvellon, Y.**, Deleporte, P., Ifo, S., Kazzoti, G., Thongo M’Bou, A., Mouvondy, W., Saint-André, L., Roupsard, O., Jourdan, C., Hamel, O., 2006. Soil carbon balance in a clonal eucalyptus plantation in Congo: effects of logging on carbon inputs on soil CO2 effluxes. *Global Change Biology*, 12, 1021-1031.
- Epron, D., Marsden, C., Thongo m’bou, A., Saint-andré, L., D’Annunzio, R., **Nouvellon, Y.**, 2009. Soil carbon dynamics following afforestation of a tropical savannah with Eucalyptus in Congo. Plant and Soil (in press).
- Marsden, C., **Nouvellon, Y.**, Thongo, Saint-André, L., A., Jourdan, C., Kinana, A., Epron, D., 2008. Two independent estimations of stand-level root respiration on clonal Eucalyptus stands in Congo: up scaling of direct measurements on roots versus the trenched-plot technique. *New Phytologist*, 177:676-687.
- **Nouvellon, Y.**, Epron D., Laclau, J-P., Kinana, A., Mabiala, A., D’Annunzio, R., Deleporte, P., Saint-André, L., Marsden, C., Roupsard, O., Bouillet, J-P., and Hamel, 0., 2008. Soil CO2 efflux and soil carbon balance following savannah afforestation in Congo: comparison of two site preparation treatments. *Forest Ecology and Management*, 255: 1926-1936.
- Roupsard, O., Dauzat, J., **Nouvellon, Y**., Feintrenie, L., Saint-André, L., Mialet-Serra, I., Braconnier, S., Bonnefond, J-M., Berbigier, P., Epron, D., Jourdan, C., Navarro, M., Bouillet J.P., 2008. Cross-validating Sun-shade and 3D models of light absorption by a tree-crop canopy. A*gric. For. Meteorol*. 148: 549-564.

***Number of papers in referred journals (published or under press): 27***

***Awards, other information***
- 2001 USDA Honor Award and USDA certificate of appreciation (January 2000)
- Reviewer for *Agricultural and Forest Meteorology*, *Remote sensing of Environment*, *Geosciences and Remote Sensing Letters*

**Jean-Michel HARMAND, 49 years**
**CIRAD Scientist**
PERSYST Department, UPR 80 “Functioning and Management of tree-based planted Ecosystems »

***Academic qualification***
PhD in Tropical Biology and Ecology, ParisVI-University / France, 1997
Forest Engineer: Ecole Nationale du Génie Rural des Eaux et Forêts (ENGREF) / Nancy/ France, 1984
Agronomist: Ecole Nationale Supérieure d’Agronomie et des Industries Alimentaires (ENSAIA)/Nancy/ France, 1982

***Key qualifications***
Biogeochemical cycling in agroforestry systems and forest plantations, management of soil fertility, agroforestry systems design, environmental evaluation.

***Work experience***
Agro-forester at Cirad since 1985.

2005-Present: (Cirad-Persyst, Montpellier, France): Research and student training on nutrient cycling and soil organic dynamic in agroforestry systems and forest plantations (soil fertility management and environmental services).
1999-2004: (Cirad-Forêt / CATIE -Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica: Associated Researcher developing research on nutrient cycling and tree management in coffee agroforestry systems in the EU-financed INCO-DEV project CASCA (Sustainability of coffee agroforestry systems in Central America) (Responsible for the WPs: Nitrogen cycling and C sequestration)
1989-1998: (Cirad-Forêt, IRAD Cameroun) Head of the forestry research programme of IRAD in Northern Cameroon with a particular focus on 1) Rehabilitation of degraded land, 2) Soil fertility management in agroforestry systems 3) Physical, chemical and biological processes involved in the replenishment of soil fertility by improved tree fallows (PHD thesis).
1985-1988: Cirad-CTFT, Senegal: Head of a forestry development project “Pôles Verts” focusing on the use of tree plantations by farmers in irrigated land in the Senegal River Valley.

***List of the more relevant publications in the last five years***
- **Harmand J.M.**, Avila H., Dambrine E., Skiba U., de Miguel S., Renderos R.V., Oliver R., Jimenez F., Beer J., 2007. Nitrogen dynamics and soil nitrate retention in a *Coffea arabica-Eucalyptus deglupta* agroforestry system in Southern Costa Rica. *Biogeochemistry*, 85 (2): 125-139.
- Hergoualc'h K., **Harmand J.M.**, Cannavo P., Skiba U., Oliver R., Hénault C., 2009. The utility of process-based models for simulating N2O emissions from soils: A case study based on Costa Rican coffee plantations. Soil biology and biochemistry, 41 (11): 2343-2355.
- Hergoualc'h K., Skiba U., **Harmand J.M.**, Hénault C. 2008. Fluxes of greenhouse gases from andosols coffee in monoculture or shaded by Inga densiflora in Costa Rica. Biogeochemistry, 89 (3) : 329-345.
- Hergoualc'h K., Skiba U., **Harmand J.M.,** Oliver R. 2007. Processes responsible for the nitrous oxide emission from a Costa Rican Andosol under a coffee agroforestry plantation. *Biology and fertility of soils*, 43 (6): 787-795.
- Siles P., **Harmand J.M.**, Vaast P. 2009. Effects of Inga densiflora on the microclimate of coffee (Coffea arabica L.) and overall biomass under optimal growing conditions in Costa Rica. Agroforestry Systems; http://dx.doi.org/10.1007/s10457-009-9241-y

***Number of papers in referred journals (published or under press): 11***

***Awards, other information***
- Reviewer for the journals *Agroforestry Systems, Annals of Forest Science*, *Global Change Biology, Journal of Environmental Quality*

**Louis MARESCHAL**, **30 years**
**CIRAD Scientist**
PERSYST Department, UPR 80 “Functioning and Management of tree-based planted Ecosystems »

***Academic qualification***
PhD in Pedology/geoscience, Institut National de la Recherché Agronomique (INRA)/ Nancy/France, 2008
MSc in Soil sciences: Institut National Agronomique Paris-Grignon (INA-PG)/ Paris/France, 2004

***Key qualifications***
Pedogenesis, biogeochemical cycling in forest ecosystems, mineral dissolution and transformation in soil and *in vitro*, X-ray diffraction pattern modelling and weathering flux modelling.

***Work experience***
2008-Present: CIRAD-Persyst / CRDPI, Pointe Noire, Congo (CIRAD-Congo scientific cooperation), visiting scientist. Soil and soil solution changes in eucalyptus chronosequences, mineralogical characterisation, surface charge properties of soil particles, anions and cations exchange.
2005-2008: PhD “Effect of tree species on soils and soil minerals changes: *balance sheet of the Breuil experimental forest site after 28 years (Morvan, France)”*, INRA/ Nancy/France. Collaboration with B. Lanson (Minéralogie & Environnements, LGCA – Maison des Géosciences, CNRS Grenoble). “*X-ray diffraction perspective on structural mechanisms: trial-and-error approach based on the direct comparison between experimental and calculated patterns”*.

***List of the more relevant publications in the last five years***
- Calvaruso C., **Mareschal L**., Leclerc E., Turpault M.P., 2009 Rapid clay weathering in the rhizosphere of Norway spruce and oak in an acid forest ecosystem. *Soil Sciences Society of America Journal.* 73:331-338.
**- Mareschal L**., Ranger J., Turpault M.P., 2009. Stoichiometry of a dissolution reaction of a trioctahedral vermiculite at pH 2.7. *Geochimica Cosmochimica Acta.* 73:307-319.
**- Mareschal L**., Bonnaud P., Turpault M.P., Ranger J., 2009 Impact of common European tree species on fine earth chemical and physico-chemical properties: an unusual pattern. *European Journal of Soil Science,61, 14-21*).
**- Mareschal L**., Ranger J., Turpault M.P., 2010. Relation between weathering of clay minerals and nitrification rate: a rapid tree species effect. *Biogeochemistry,* (in press).
**- Mareschal L**., Ranger J., Turpault M.P., 2009. Forest soil properties derived from two granites (Morvan France). *Geoderma,* (submitted).

***Number of papers in referred journals (published or under press): 4***

**Blandine CAQUET, 28 years**
**CIRAD Scientific National Volonteer**
PERSYST Department, UPR 80 "Functioning and Management of tree-based planted Ecosystems »

***Academic qualification***
PhD in « Biologie Forestière », Université Henri Poincaré Nancy I, 2008
MSc in « Biologie Forestière », Université Henri Poincaré Nancy I, 2004

***Key qualifications***
Ecophysiology, light and gas-exchange, water and carbon cycles, micro-climatology

***Work experience***
From 2009: CIRAD-Persyst/CRDPI, Pointe Noire, Congo (CIRAD-Congo scientific cooperation), International Scientific Volonteer (VIE). Water and Carbon functioning of savana, *Eucalyptus*, and mixed-species *Acacia mangium* and *Eucalyptus* plantations.
2005-2008: PhD "*Réactions de semis naturels de hêtre et d'érable sycomore à l'ouverture du couvert : croissance et ajustements fonctionnels*", Université Henri Poincaré Nancy I, 2008

***List of the more relevant publications in the last five years***
- **Caquet B.**, Barigah S. T., Cochard H., Montpied P, Collet C, Dreyer E, Epron D, 2009. Hydraulic properties of naturally regenerated beech saplings respond to canopy opening. Tree Physiology, 29: 1395 – 1405
- **Caquet B**., Montpied P, Epron D, Dreyer E, Collet C, 2010. Response to canopy opening does not act as a filter to /Fagus sylvatica/ and */Acer/* sp. advance regeneration in a mixed temperate forest. Ann. For. Sci., 67 (1) 105 doi: 10.1051/forest/2009086

***Number of papers in referred journals (published or under press): 2***

**Christian DUPRAZ, 51 years**
**INRA Scientist**
Environment and Agronomy Department, UMR SYSTEM "Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.
Leader of the Metafor (Mediterranean Agroforestry) research team.

***Academic qualification***
PhD in Agronomic Sciences, University of Orléans, ENGREF, 1984; « *Hydrological and biochemical budgets of three watersheds with contrasting vegetation covers*».
Forest Engineer: Ecole Nationale du Génie Rural et des Eaux et Forêts, Paris, 1982
Agronomist : Institut Agronomique Paris-Grignon, 1980

***Key qualifications***
Modelling of tree and crop interactions; Temperate and Mediterranean agroforestry systems;

***Work experience***
Inra Environment and Agronomy Department, UMR SYSTEM "Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.

2006-Present: Scientific coordinator of the French national Agroforestry programme

2001-2005: Coordinator of a European Research Project « Silvoarable Agroforestry for Europe » http://www.montpellier.inra.fr/safe/ (budget: 2.5 M€). Appraisal of the productivity of temperate agroforestry systems and designing new policies adapted to agroforestry

Since 1995: Leader of agroforestry research at INRA; participation to 4 European programmes as WP leader; Coordinator of the PIRAT Agroforestry research project; manager of most French agroforestry field experiments

***List of the more relevant publications in the last five years***
Coutand, C., **C. Dupraz**, G. Jaouen, S. Ploquin, and B. Adam. 2008. Mechanical Stimuli Regulate the Allocation of Biomass in Trees: Demonstration with Young Prunus avium Trees. **Ann Bot** 101:1421-1432.
- Graves A.R., Burgess P.J., Palma J., Keesman K., van der Werf W., Dupraz C., van Keulen H., Herzog F. and Mayus M. 2010. Implementation and calibration of the parameter-sparse Yield-SAFE model to predict production and land equivalent ratio in mixed tree and crop systems. Ecological Modelling In press.
- Malézieux, E., Y. Crozat, **C. Dupraz**, M. Laurans, D. Makowski, H. Ozier-Lafontaine, B. Rapidel, S. de Tourdonnet, M. Valantin-Morison. 2008. Mixing plant species in cropping systems: concepts, tools and models. A review. Agron. Sustain. Dev. 28, 1-20.
- Mulia, R., **C. Dupraz**. 2006. Unusual fine root distributions of two deciduous tree species in southern France: what consequences for modelling of tree root dynamics? Plant and Soil 281, 71-85.
- van der Werf, W., K. Keesman, P. Burgess, A. Graves, D. Pilbeam, L.D. Incoll, K. Metselaar, M. Mayus, R. Stappers, H. van Keulen, J. Palma, **C. Dupraz**. 2007. Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. Ecological Engineering 29, 419-433.

***Number of papers in referred journals (published or under press): 43***

***Awards, other information***
- Elected President of the French National Agroforestry Society since 2007
- First Price in the CNRS contest for the best research video film (1997)
- Associate Editor of the journal *"Agroforestry Systems" since 2008;* Editor of the journal *"Agroforesterie, la revue française des arbres ruraux" since 2008*
- Reviewer of the journals *Agroforestry Systems, Forest Ecology and Managemen*t, *Agriculture, Ecosystems and Environment*

**Marie Ange NGO BIENG, 30 years**
**Cirad Scientist**
Department: Performance of Tropical Production and Processing Systems, UMR SYSTEM "Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.

***Academic qualification***
Ph.D in Forest Sciences and Modelling, AgroParisTech- ENGREF, 2007; «*Building models of structure in order to simulate realistic virtual stands. Application to oak-Scots pine mixed stands.*».

***Key qualifications***
Modelling forest stands: Spatially explicit single tree based model; Simulation methods for spatially explicit initial state with point processes; Spatial statistics
Modelling agrosystems: process-based Vs stochastic models

***Work experience***
Since June 2008: CIRAD young Scientist
Ecologist, specialised in modelling tropical agrosystems
11/2007 to 01/2008: CEMAGREF young Scientist, PhD candidate
Modelling spatial structure of complex stand by point processes. Application to oak-Scots pine mixed stands
02/2004 to 08/2004: CEMAGREF, training
Spatial structure analysis of oak-Scots-pine mixed stands of the Centre region (France)

***List of the more relevant publications in the last five years***
- **Ngo Bieng, M.A**., Ginisty, C., Goreaud, F., Perot, T., 2006. Modelling the spatial structure of complex stands by point processes. Submitted, Environmental modelling and Software
- **Ngo Bieng, M.A**., Ginisty, C., Goreaud, F., Perot, T., 2006. A first typology of Oak and Scots pine mixed stands in the Orleans forest (France), based on the canopy spatial structure. New Zealand Journal of Forestry Science 36 (2/3): 325-346.
- Goreaud, F., Loussier, B., **Ngo Bieng, M.A.,** Allain R., 2004. Simulating realistic spatial structure for forest stands: a mimetic point process. Interdisciplinary Spatial Statistics Workshop, Paris, 22p.
- Goreaud, F., Allain, R., Courbaud, B., **Ngo Bieng, M.A**., Perot, T., Piroche, J.-N., 2007. Simuler des peuplements de structures variées pour faciliter l'utilisation des modèles « arbre » spatialisés. Revue Forestière Française, vol. LIX, n°2, 137-161.
- **Ngo Bieng, M.A.**, Ginisty, C., Goreaud, F., Perot, T., 2005. Spatial structure: a way to understand the dynamics and to model the growth of mixed stands. IUFRO 5.01.04 proceedings, Connection between forest resources and wood quality: modelling approaches and simulation software, fifth Workshop. 20-27 November, 2005. Waiheke Island Resort Auckland, New Zealand.

***Number of papers in referred journals (published or under press): 3***

***Awards, other information***
Main Conferences:
"Modelling the spatial structure of complex stands by point processes".
Complex Stand Structures and Associated Dynamics: measurement indices and modelling approaches. IUFRO 4.01.02 Conference, Growth models for tree and stand simulation July 29 - August 2, 2007 Sault Ste. Marie, Ontario, Canada
"Modelling the spatial structure of heterogeneous stands. Example of sessile oak (Quercus petraea) – Scots- pine (Pinus sylvestris) mixed stands of the Orleans forest in France". IUFRO 1.14.00 Conference, Uneven-aged silviculture conference: Natural disturbance – Based silviculture – Managing for complexity. 14-18 May 2006, Rouyn-Noranda, Québec, Canada.

**Sébastien ROUX, 32 years**
**INRA Research Engineer**
Environment and Agronomy Department, UMR SYSTEM "Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.

*Academic qualification*
Ph.D. in Applied Mathematics, University Joseph Fourier of Grenoble, 2004; Subject: Inversion Methods for Dynamic Image Reconstruction

Computer Science Engineer: Ecole Nationale Supérieure d'Informatique et de Mathématiques Appliquées de Grenoble, Grenoble, 2001

***Key qualifications***
Numerical and Software aspects of Crop Systems Models – Optimization **-** Inversion

***Work experience***
2008-Present: Research Engineer at INRA-EA-SYSTEM
Numerical and software improvement of existing crop systems models: (i) Silvoarable Agroforestry (ii) cover cropped vineyards.

2005-2008: Senior Research Scientist at Philips Healthcare, Paris. R&D on advanced real time algorithms and software for medical image processing.

2001-2004: PhD Student at CEA LETI (Grenoble, France) and TIMC-IMAG (Grenoble, France) on Dynamic Image Reconstruction.

***List of the more relevant publications in the last five years***

- L. Desbat, **S. Roux**, Grangeat P., 2007. Compensation of some time dependent deformation in tomography , IEEE Transaction on Medical Imaging, vol 26(2),pp. 261-269 , Feb 2007
- L. Desbat, **S. Roux,** P. Grangeat and A. Koenig, 2004. Sampling conditions of 3D parallel and fan-beam x-ray CT with application to helical tomography. Physics in Medicine and Biology, vol. 49(11), pp.2377-90-82, June 2004
- **S. Roux,** L.Desbat, A. Koenig, Grangeat P., 2004 Exact reconstruction in 2D dynamic CT : compensation of time-dependent affine deformations », Physics in Medicine and Biology, vol. 49(11), pp.2169-82, June 2004
- **S. Roux**, L. Desbat, A. Koenig and P. Grangeat : « Efficient acquisition for periodic dynamic CT », IEEE Transactions on Nuclear Sciences, vol. 50(5), pp. 1672-77, October 2003
- S. Bonnet, A. Koenig, **S. Roux**, P. Hugonnard , R. Guillemaud and P. Grangeat : « Dynamic x-ray computed tomography », Proceedings of the IEEE, vol. 91(10), pp.1574-87, October 2003

***Number of papers in referred journals (published or under press): 6***

***Awards and other information***
US Patent n°20050238219: « Method for tomographic image reconstruction using an analytical process involving modeling of the movement of the object», October 2005

**Lydie DUFOUR, 52 years**
**INRA Scientist**
Environment and Agronomy Department, UMR SYSTEM “Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.
Responsible of the field experiments of the Metafor (Mediterranean Agroforestry) research team.

***Academic qualification***
PhD in Agronomic Sciences, University of Angers ; 2001 ; *« Yield elaboration of Anthurium andreanum cut flowers in soilless sheltered cultivation and tropical environment».*
Horticulture Engineer: Institut National d’Horticulture, Angers, 1981

***Key qualifications***
Plant physiology ; Measurements of tree and crop interactions ; Temperate and Mediterranean agroforestry systems ; Crop modelling.

***Work experience***
2002-2008 : Participation in the Temperate Agroforestry programmes.
2001-2002 : Study of the mineral nutrition of maize at the “AgroPedoclimatique of Caribean area” research station of INRA in Guadeloupe.
1994-2001 : Responsible of the horticultural research programme at the “AgroPedoclimatique of Caribean area” research station of INRA in Guadeloupe.

***List of the more relevant publications in the last five years***
**Dufour L**., Guérin V., 2003 a.– Growth and development features and flower production of *Anthurium andreanum* Lind. in tropical conditions. Sci. Hort., 98 :25-35.
**Dufour L**., Guérin V., 2003 b.– Low light intensity promotes growth, photosynthesis and yield of *Anthurium andreanum* Lind. in tropical conditions. Adv. Hort. Sci. ,17 (1) :9-14.
Sierra J., Noël C., **Dufour L**., Ozier-Lafontaine H., Welcker C., 2003.- Mineral nutrition and growth analysis of tropical maize as affected by soil acidity. Plant and Soil, 255 :215-226.
**Dufour L**., Guérin V., 2004.– Nutrient solution effects on the development and yield of *Anthurium andreanum* Lind. in tropical soilless conditions. Sci. Hort., 105 :269-282.
Sierra J., Ozier-Lafontaine H., **Dufour L**., Meunier A., Bonhomme, R., Welcker C., 2005.- Nutrient and assimilate partitioning in two tropical maize cultivars in relation to their tolerance to soil acidity. Field Crops Res, 95 (2-3) :234-249.
**Dufour L**., Guérin V., 2006.- Main environmental factors affecting flowering of *Anthurium andreanum* Lind. soilless cultivation in tropical conditions. *In* “Floriculture, Ornamentals and Plant Biotechnology : Advances and Topical Issues (1st Edition), Teixeira da Silva JA (Ed.), Global Science Books, London, UK :172-182.

***Number of papers in referred journals (published or under press): 8***

**Aurélie METAY, 32 years**
**Montpellier Supagro Lecturer in agronomy**
Environment and Agronomy Department, UMR SYSTEM "Functioning and management of Tropical and Mediterranean cropping systems », Montpellier.

*Academic qualification*
2005: Ph.D. in Agronomic Sciences, INA P-G "Carbon sequestration and greenhouse effect gases fluxes - Comparison between no-tillage system and conventional system in the Brazilian *Cerrados*", directed by Christian Feller (IRD).
2001: Master "Chemical, physical and biological functionning of natural and cultivated ecosystems" (Paris VI, ENS Ulm, INA P-G), 2001.
2000: INA P-G engineer.

***Key qualifications***
Cropping systems evaluation; soil resources cycles (water, nitrogen and carbon); modelling of perennial and annual crop interactions; cover cropped vineyards; temperate and mediterranean agroforestry systems.

***Work experience***
2008-Present: lecturer in agronomy at Montpellier Supagro, research program developed at UMR System, focused on environmental evaluation of mixed species cropping systems and resources sharing (nitrogen and water mainly)
2004-2008: lecturer in agronomy at ISTOM (www.istom.net), research program developped at UMR Eco&Sols (formerly UR SeqBio) as associated scientist focused on organic fertilization of cropping systems (crop residues or organic waste) and experimentation or modelling assessment of $N_2O$ fluxes

***List of some relevant and recent publications***
- **Metay A.,** Martin M., Mary B., Arrouays D., Germon J-C, 2009. Effets des techniques culturales sans labour sur le stockage de carbone dans le sol en contexte tempéré, *Canadian Journal of Soil Science (*accepted).
- **Metay A.**, Oliver R., Scopel E., Douzet J.M., Alves Moreira J.A., Maraux F., Feigl B.E., Feller C., 2007. $N_2O$ and $CH_4$ emissions from soils under conventional and direct seeding cropping systems in Goiânia (Cerrados, Brazil). *Geoderma*, 141, (1-2) 15, 78-88.
- **Metay A.**, Alves Moreira J.A., Bernoux M., Boyer T, Douzet J-M., Feigl B., Feller C., Maraux F., Oliver R., Scopel E., 2007. Storage and forms of organic carbon in a no-tillage under cover crops system on clayey Oxisol in dryland rice production (Cerrados, Brazil). *Soil & Tillage Research*, 94, 1, 122-132.
- **Metay A.**, Gary C., Casellas E., Ripoche A., Kansou K.,Wery J., Modelling of cover cropped vineyards with APES, a modular simulation platform, AgSAP Conference 2009, Egmond aan Zee, the Netherlands oral communication.
- **Metay A**. Chevallier T., Germon J-C, Soil carbon contents and $CO_2$ fluxes measurements: how to assess carbon storage under no-tillage systems in temperate conditions. Poster presented at European Society for Agronomy, 2008 Congress – Bologna, Italy, September 15-19 2008.

***Number of papers in referred journals (published or under press): 11***

**Daniel EPRON**, **43 years**
**EEF scientist**, Professor at the University of Nancy I

***Academic qualification***
Habilitation à Diriger des Recherches (Besançon), 1999
PhD in Biologie Végétale et Forestière (Nancy), 1993
Magistère « Biologie-Biochimie » (Paris VI, Paris XI et E.N.S. Ulm), 1989
MSc « Biologie Végétale et Forestière », 1989

***Key qualification***
Ecophyiology, Plant functioning, Carbon cycle, $CO_2$ fluxes, Soil respiration

***Work experience***
2003- Present: Professor at the University of Nancy I (66e section),
2000-2003: Professor at the University of Franche-Comté (67e section)
1994-2000: Maître de Conférences at the University of Franche-Comté (66e section)
1993-1994: Post-doc (laboratoire d'Ecologie Végétale, University of Paris XI)
1992-1993: Attaché temporaire d'Enseignement et de Recherche (Metz University)

***List of the more relevant publications in the last five years***
- **Epron D**, Marsden C, Thongo M'Bou A, Saint-André L, d'Annunzio R, Nouvellon Y, 2009. Soil carbon dynamics following afforestation of a tropical savannah with *Eucalyptus* in Congo. *Plant Soil*, 323, 309-322.
- Marron N, Plain C, Longdoz B, **Epron D.**, 2009. Seasonal and daily time course of the $^{13}C$ composition in soil CO2 efflux recorded with a tunable diode laser spectrophotometer (TDLS). *Plant and Soil*, 318, 137-151.
- Marsden C, Nouvellon Y, **Epron D**., 2008. Relating coarse root respiration to root diameter in clonal Eucalyptus stands in the Republic of the Congo. *Tree Physiology* 28, 1245-1254
- Nouvellon Y, **Epron D**, Kinana A, Hamel O, Mabiala A, D'Annunzio R, Deleporte P, Saint-André L, Marsden C, Roupsard O, Bouillet JP, Laclau JP., 2008. Soil $CO_2$ effluxes, soil carbon balance, and early tree growth following savannah afforestation in Congo: comparison of two site preparation treatments *Forest Ecology and Management*, 255, 1926-1936.
- Marsden C, Nouvellon Y, Thongo M'Bou A, Saint Andre L, Jourdan C, Kinana A, **Epron D**., 2008. Two independent estimations of stand-level root respiration 1 on clonal Eucalyptus stands in Congo: up scaling of direct measurements on roots versus the trenched-plot technique. *New Phytologist* 177, 676-687.

***Number of papers in referred journals (published or under press): 58***

***Awards, other information***
- Director of 11 PhD Theses (9 defended, 2 ongoing)
- Research Projects:
    a. On going: 2 ANR project (programme blanc et VMC), 2 project in bilateral cooperation (INRA-JSPS and USP-COFECUB)
    b. Terminated: 3 EU projects (5e PCRD), 4 national projcts (ACI), 4 projects in bilateral cooperation (Galileo, Fast, COFECUB, A.U.F.), 6 others (GIP ECOFOR, ATP CIRAD, GIS SILVOLAB, PNSE, GDR)
- Head of the Master FAGE at the University of Nancy (Forêt, Agronomie, Environnement)
- Associated Editor of “Tree Physiology” (from January 2000)
- Deputy Director of the Ecole Doctorale « Homme Environnement Santé » at the University of Franche Comté up to 2003

**Nicolas MARRON, 32 years**
**INRA Scientist**
UMR 1137 INRA Nancy – University, Forest Ecology and Ecophysiology (EEF)

***Academic qualification***
PhD in Physiology, Biology of Organisms, Populations, Interactions “Poplar ecophysiology under drought conditions” – University of Orléans/ France, 2003
Master degree in Forest Biology - University Henri Poincaré/Nancy/France, 2003

***Key qualifications***
Short rotation coppice plantations, resource use efficiencies, physiology of growth and productivity

***Work experience***
2007-present: UMR 1137 INRA Nancy - University – Forest Ecology and Ecophysiology, CR1 scientist
2006-2007: Postdoctoral stay - UMR 1137 INRA Nancy - University – Forest Ecology and Ecophysiology
2006: Postdoctoral stay - Università degli Studi della Tuscia, Department of Forest Environment and Resources, University of Viterbo, Italy.
2003-2006: Postdoctoral stay - Research Group of Plant and Vegetation Ecology, University of Antwerp, Belgium. Coordinator of the ecophysiological task of the European project POPYOMICs (QLK5-CT-2002-00953)

***List of the more relevant publications in the last five years***
- **Marron N.**, C. Plain, B. Longdoz, D. Epron., 2009. Seasonal and daily time course of the 13C composition of soil $CO_2$ efflux recorded with a tunable diode laser spectrophotometer (TDLS). Plant and Soil. 318: 137-151.
- **Marron N.**, S.Y. Dillen, R. Ceulemans., 2007. Leaf determinants of productivity in poplar depend on environmental conditions and genetic background. Environmental and Experimental Botany. 61: 103-116.
- **Marron N.,** Ceulemans R., 2006. Genetic variation of leaf traits related to productivity in a *Populus deltoides* x *P. nigra* family. Canadian Journal of Forest Research. 36: 390-400.
- **Marron N.**, C. Bastien, M. Sabatti, G. Taylor, R. Ceulemans., 2006. Plasticity of growth and sylleptic branchiness in two poplar families grown at three sites across Europe. Tree Physiology. 26: 935-946.
- **Marron N.**, M. Villar, E. Dreyer, D. Delay, É. Boudouresque, J.-M. Petit, F.M. Delmotte, J.-M. Guehl, F. Brignolas,. 2005. Diversity of leaf traits related to productivity in 31 *Populus deltoides* x *P. nigra* clones. Tree Physiology, 25: 425-435.

***Number of papers in referred journals (published or under press): 18***

***Awards, other information***
- Reviewer of the journals *Silvae Genetica*, *Environmental Management*, *Forest Ecology and Management*, *International Journal of Plant Sciences*, *Annals of Forest Science*, *Environmental and Experimental Botany*, *Tree Physiology*, *Physiologia Plantarum*, *Functional Plant Biology*, *Environmental Pollution*, *Ecology* and *New Phytologist*

**Dominique GERANT SAUVAGE, 52 years**
**Assistant Professor, UHP Nancy 1**
UMR 1137 Forest Ecology and Ecophysiology (EEF), Team ARBECO INRA Nancy University

***Academic qualification***
PhD in Plant Physiology, Nancy 1-University / France, 1985
Carbon and nitrogen interactions between the symbiotic partners *Rhizobium meliloti* and *Medicago sativa*.
« Structure, biogenèse et rôles fonctionnels des poly-γ-aminobutyrates élaborés sous contrôle bactérien dans les nodosités de *Medicago sativa* L. »
Assistant Professor in Plant Physiology / Nancy/ France, since 1988

***Key qualifications***
Plant biochemistry, cellular ecophysiology, C and N metabolisms and storage, organ and tree level, vegetative storage proteins.

***Work experience***
1990-1996: scientific participant to European programs STEP (EV5V CT0117 and EV5V CT0263) « Interactions between air pollutants, climatic and nutritional factors on coniferous tree physiology ». Coordinator: Prof. P. Dizengremel, Nancy University
1988-present:

Ozone and/ or double CO2 effects on carbon metabolism (key enzymes of photosyntethic and respiratory processes) of different tree species (oak, beech, *Pinus halepensis*)
High CO2 effects on mitochondrial activity of pedunculate oak leaves
Interactive effects of elevated CO2 and nitrogen on carbon and nitrogen metabolism in pedunculate oak
Interactive effects of elevated $CO_2$ and nitrogen on carbon and nitrogen storage in pedunculate oak
Intra-tree distribution and seasonal dynamics of C and N storage compounds in adult trees and young seedlings of oak (*Quercus petraea* L.) and common beech (*Fagus sylvatica* L.)
Biochemical characterization of N storage compounds: soluble proteins, amino acids and nitrate.
Seasonal dynamics of VSP storage in oak and beech trees.
Purification, characterization and organ/tissue distribution of the storage proteins of oak and beech

2007-present: Dual $^{15}N$ and $^{13}C$ labelling for tracing storage and remobilisation of carbon and nitrogen in trees

Participation to the project ANR CATS 2007-2011 (Prof. D. Epron): the fate of $^{13}CO2$ pulse absorbed by adult beech foliage in the storage compounds: from the accumulation during the dormant season to the remobilization in the following spring.

***List of the more relevant publications in the last five years***
- **Gérant** D, Valenzuela Nunez L, Maillard P, Bréda NJJ, 2010. Characterization of a 26 kDa vegetative storage protein in the stem sapwood of mature pedunculate oak**.** Submitted to New Phytologist
- Valenzuela Nunez L, **Gérant** D, Maillard P, Bréda NJJ., 2010 Intra-tree distribution and seasonal dynamics of total soluble proteins in adult sessile oak (*Quercus petraea* L.) and common beech (*Fagus sylvatica* L.) Submitted to Tree Physiology
- Vizoso S, **Gérant** D, Guehl JM, Joffre R, Chalot M, Maillard P,. 2008. Do elevation of $CO_2$ concentration and nitrogen fertilization alter storage and remobilization of carbon and nitrogen in pedunculate oak saplings? Tree Physiology 28: 1729-1739
- Plain C, **Gérant** D, Maillard P, Dannoura M, Dong Y, Zeller B, Priault P, Parent F, Epron D, 2009. Tracing of recently assimilated carbon in respiration at high temporal resolution in the field with a tuneable diode laser absorption spectrometer after in situ 13CO2 pulse labelling of 20-year-old beech trees. Tree Physiology, 29: 1433-1445.

***Relevant papers in referred journals (published or under press): 12***

***Awards, other information***
Reviewer for the journals *Annals of Forest Science, New Phytologist, J. Exp. Bot.*

**Pascale MAILLARD, 50 years**
**INRA Researcher,**
UMR 1137 Forest Ecology and Ecophysiology (EEF), Team ARBECO INRA Nancy University

***Academic qualification***
PhD in Plant Physiology, Paris 6-University / France, 1987
"Study of vegetative development of *Terminalia superba* Englers & Diels in controlled conditions: Evidence of rhythmical growth patterns"
Master in Plant Physiology, Paris 6-University / France, 1984
"Study of rhythmical growth of the internode of *Chenopodium rubrum* L., highlighting of a biochemical marker of growth"

***Key qualifications***
Reforestation, transplanting stress, tree physiology, climate change, C and N balance, biochemical and isotopic labelling approaches.

***Work experience***
INRA researcher I Agronomical Sciences (Paris/Clermont-Ferrand-Nancy, France) since 1987 specialized in biochemistry and isotopic labelling.

Interests: understanding effects of various biotic and abiotic factors on tree physiology (from young to adult stages in forest, nurseries, or controlled conditions) and seasonal C and N balances (acquisition, storage, remobilisation).

***List of the more relevant publications in the last five years***
- Vizoso S, Gérant D, Guehl JM, Joffre R, Chalot M, **Maillard P**. 2008. Do elevation of $CO_2$ concentration and nitrogen fertilization alter storage and remobilization of carbon and nitrogen in pedunculate oak saplings? Tree Physiology 28: 1729-1739.
- **Maillard P**., Garriou D., Deléens E., Gross P., Guehl, J.M., 2004. The effects of lifting on mobilisation and new assimilation of C and N during regrowth of transplanted Corsican pine seedlings. A dual $^{13}C$ and $^{15}N$ labelling approach. Ann. For. Sci., 61: 795-805.
- Guérard N., **Maillard P**., Bréchet C., Lieutier F., Dreyer E., 2007. Do trees use reserve or newly assimilated carbon for their defense reactions? A $^{13}C$ labeling approach with young Scots pines inoculated with a bark-beetle-associated fungus (*Ophiostoma brunneo ciliatum* ), Ann. For. Sci., 64: 601-608.
- Cerasoli S., **Maillard P**., Scartazza A, Brugnoli E., Chaves M.M., Pereira J.S., 2004. Carbon and nitrogen winter storage and remobilisation during seasonal flush growth in two-year-old cork oak (*Quercus suber* L.) saplings, Ann. For. Sci., 61: 712-729.

***Number of papers in referred journals (published or under press): 20***

***Awards, other information***
Medal of vermeil delivered by Académie d'Agriculture, France, 1988, December 7th,
Reviewer from 2001 for *Plant Biology, Tree Physiology, Annals of Botany, Annals of Forest Sciences and Plant and Soi*l. Member of several scientific councils (UMR INRA-UHP 1137,INRA Department "Environnement et Agronomie") and of two specialist committees (Université Henri Poincaré Nancy, France : CS 67-68 et CS 68-69).
Supervisor of students (master, PhD, post-doctorates).
Participation to national and international projects (ex.: NETCARB, CATS 2007-2011, …)

**Claude PLASSARD, 54 years**
**INRA scientist**
UMR Eco&Sols, INRA/IRD/SupAgro "Ecologie fonctionnelle & Biogéochimie des Sols "

***Academic qualification***
PhD in Plant Physiology, Ecole Nationale Supérieure Agronomique Montpellier/Université de Montpellier II, 1983.

***Key qualifications***
Ectomycorrhizal functioning, N and P uptake, Mineral and organic P mobilisation by organic anions and phosphatasereleased by the fungi.

***Work experience***
1987-Present: INRA, Montpellier
2009-present: UMR Eco&Sols.. Leader of the group studying the interactions between organisms in the root environment
2002-2008: UMR BSR (Biogeochemistry of Soil and Rhizosphere).
Effect of ectomycorrhizal symbiosis on P uptake by the host plant and regulation of P exchanges between partners.
1999-2002: Unité Science du Sol, Montpellier.
Rhizosphere mobilisation of unavailable P by organic anions and phosphatase released by the fungal partner associated with the ectomycorrhizal plants. Effect of N source.
1992-1993: University of Adelaide, Australia: visiting scientist. Proton concentration in cell walls of ectomycorrhizal roots studied with double-barrelled ion-selective microelectrodes
1987-1999: Laboratory of research on root symbionts
Effect of ectomycorrhizal symbiosis on host N-nutrition

***List of the more relevant publications in the last five years***
- Tatry M.-V., El Kassi E., Lambilliotte R., Corratgé C., van Aarle I., Amenc L.K., Alary R., Zimmermann S., Sentenanc H., **Plassard C.,** 2009. Two differentially regulated phosphate transporters from the symbiotic fungus *Hebeloma cylindrosporum* and phosphorus acquisition by ectomycorrhizal *Pinus pinaster*. *Plant Journal*, **57**: 1092–1102
- Gobert A., **Plassard C.,** 2008. The Beneficial Effect of Mycorrhizae on N Utilisation by the Host-Plant: Myth or Reality? In *Mycorrhiza: Genetics and Molecular Biology, Eco-function, Biotechnology, Eco-Physiology, Structure and Systematics.* 3rd edition, A. Varma ed., Springer-Verlag Berlin Heidelberg, 209-240.
- Araújo A.P., **Plassard C.,** Drevon JJ**,** 2008. Phosphatase and phytase activities in nodules of common bean genotypes at different levels of phosphorus supply. *Plant Soil*, **312**:129–138
- Gobert A., **Plassard C.** 2007**.** [$NO_3^-$]-dependant kinetics of $NO_3^-$ net fluxes in *Pinus pinaster*, *Rhizopogon roseolus* and their ectomycorrhizal association, as affected by the presence of $NO_3^-$ and $NH_4^+$. *Plant Cell Environment***, 30** : 1309-1319.
**-** van Aarle I., Viennois G., Amenc L., Tatry M-V., Luu D.T., **Plassard C.** 2007. Fluorescent *in situ* RT-PCR to localise gene expression in the ectomycorrhizal fungus *Hebeloma cylindrosporum. Mycorrhiza*, **17:** 487-494.

***Number of papers in referred journals (published or under press): 46***

***Other information-*** Reviewer of the journals *Tree Physiology*, *Plant and Soil*, *The New Phytologist*, *Phytochemistry, Annals of Botany*

**KALMS Jean-Marie, 62 years**
**INRA – SAD Researcher CR1/ CIRAD-ES**
UMR85: Innovation & Development for Agriculture & Agrifood, SPACTO (Organizational & Technical changes in farmer production system) Team / SAF group (innovation in agroforestry and tree crops based production system)

***Academic qualification***
Agronomy Engineer : Ecole Nationale Supérieure Agronomique Montpellier, 1970
Master in Soil Sciences and Management : Université de Montpellier USTL, 1970

***Key qualifications***
Systemic Agronomy, Scientific adviser of CIRAD's South Partners for research & development project
Scientific agroforestry research in humid forest zone of West & Center Africa
Action-research in partnership approach

***Work experience***
2009- Present: CIRAD-ES / INRA-SAD, Montpellier/ UMR 85: SPACTO-SAF group
2008-2009: Advisor of the scientific director of IRAG Guinea /MAEE Technical Adviser, and RTRA/MIA (Méthodes d'innovations en agroforesterie): A. Camara post-doc director- Comparative study of agroforests spatio-temporal dynamiics in 3 countries: Cameroun, Ghana, Guinea
2003-2008: CIRAD-ES / INRA-SAD, Montpellier/ UMR 85: SPACTO: diversification and innovation of tree crops based farmers in West & Center AFRICA
DURAS PROJECT N°18-2: Scientific advisor for Cameroon, Ghana and Guinea teams (2005-2008).
1998-2002: MAE Technical advisor for CIAT/Sao Tome & Principe/CIRAD: R&D project for cocoa farmers
1981-1997: R&D team project advisor in various countries: Venezuela (1981-1987), Brazil (Embrapa/CPAC) 1989-1993, Zaïre/PNUD (1994-1995), Colombia/EU-TCA regional parks management project (1996-1997).
1970-1980: IRAT, soil water dynamics under food crops team leader in IDESSA, Savannah Research Centre of Ivory Coast

***List of the more relevant publications in the last five years***
- Camara A., Dugué P., **Kalms JM**, J-P Cheylan, 2009. De la forêt naturelle aux agroforêts cultivées en Guinée forestière= From natural forests to agroforests in the Guinea forest region. *Cahiers Agriculture,* **18** (5): 425-431.
- Lamanda N., Michel-Dounias I., Canet M., **Kalms J.M**., 2008. Les pratiques de gestion des agroforêts à base de café de Guinée forestière sur le temps long. *Atelier international de réflexion à partir de visites de terrain « Les agroforêts d'Afrique de l'Ouest et du Centre : dynamiques, performances et avenir ?* 11-15 novembre 2008, Sérédou, Guinée, 10p.
- Triomphe B., Béavogui F., **Kalms J.-M**., Dugué P. 2009. Actes de l'atelier de formation et d'échanges autour des démarches et méthodes de recherche-action et de construction des innovations en partenariat. Foulaya, Guinée, 25 février – 1er mars 2008. CIRAD-ES Ed. Montpellier (CD-ROM).
- Lamanda N., Camara A., Diabaté M., Kolié D**., Kalms J.M.,** Malezieux E., de Foresta H., Cheylan J.P. Spatio-temporal extension of agroforestry systems in "Guinée Forestière" (Guinea, West Africa). *In:* Symposium "Agroforestery with Perennial Crops: Making Ecosystem services count for farmers, consumers and the environment", 17-21 September 2007, Turrialba, Costa-Rica, CATIE, 5 p.
**- Camara A.,** Lamanda N., Jagoret P., **Kalms J.-M**., 2008. Une approche géo-agronomique pour l'analyse comparative des dynamiques spatio-temporelles des systèmes agroforestiers d'Afrique de l'Ouest et du Centre : Guinée – Cameroun ». International research workshop « Les agroforêts d'Afrique de l'Ouest et du Centre : dynamiques, performances et avenir ? 11-15 November 2008, Sérédou, Guinée, 9p.
- **Kalms, J. M.**, Michel Dounias I., Steer L., Jannot C., 2005. Diversification et stratégies des planteurs de cacao en région Est du Ghana. *Les institutions du développement durable des agricultures du Sud*, Montpellier, France, SFER.

***Number of papers in referred journals (published or under press): 24***

***Other information***- Reviewer of ARDESSAC 2008

**José Leonardo de Moraes GONCALVES, 49 years**
**Professor**
University of São Paulo-ESALQ, Department of Forest Science, Brazil

***Academic qualification***

1990 PhD in Science (Soil and Forest Nutrition), University of São Paulo, Brazil
1987 Master in Science (Soil and Plant Nutrition), Federal University of Viçosa, Brazil
1983 Degree in Agronomy, Federal University of Viçosa, Brazil

***Key qualifications***

Soil and Forest Nutrition; Forest establishment; Forest managameent; nutrient cycles

***Work experience***

1988- present: Professor, Forest Soil and Plant Nutrition), University of São Paulo (USP), "Luiz de Queiroz" College of Agriculture (ESALQ), Piracicaba
1992-1993: Sabbatical year in C.S.I.R.O. / Plantation Forest Research Centers / Australia
1987 1988: Soil Scientist/Plant Nutritionist (Consultant) - Institute of Forestry Research and Study, Piracicaba (Brazil)
1985 1987: Soil Scientist/Plant Nutritionist, Ripasa Pulp and Paper Ltd, Americana (Brazil)

***List of the more relevant publications in the last five years***

- Silva, E.V., **Gonçalves, J.L.M**, Coelho S.R, Moreira, R..M.; Mello, S.L.M, Bouillet J.P., Jourdan C., Laclau, J.P., 2009. Dynamics of fine root distribution after establishment of monospecific and mixed-species plantations of *Eucalyptus grandis* and *Acacia mangium*. Plant and Soil, 318: 325:305.
- Laclau, J.P, Almeida, J.C.R, **Gonçalves, J.L.M.**; Saint-Andre, L., Ventura M., Ranger, J., Moreira, R.M., Nouvellon, Y., 2009. Influence of nitrogen and potassium fertilization on leaf lifespan and allocation of above-ground growth in *Eucalyptus* plantations. Tree Physiology, 29: 111-124.
- **Gonçalves J.L.M**., Stape J.L., Laclau J.P., Bouillet J.P., Ranger, J., 2008. Assessing the effects of early silvicultural management on long-term site productivity of fast-growing eucalypt plantations: the Brazilian experience. Southern Forests, 70: 105-118.
- Gava J.L., **Gonçalves J. L. M.**, 2008. Soil attributes and wood quality for pulp production in plantations of Eucalyptus grandis clone. Scientia Agricola, 65: 306-313.
- **Gonçalves J.L.M**., Wichert M.C.P., Gava J.L., Masetto A.V., Arthur Junior J.C., Serrano M.I.P., Mello S.L.M., 2007. Soil fertility and growth of *Eucalyptus grandis* in Brazil under different residue management practices. Southern Hemisphere Forestry Journal, 69: 95-102.
- Sasaki C.M., **Gonçalves J.L.M**., Silva A.P., 2007. Ideal subsoiling moisture content of Latosols used in forest plantations. Forest Ecology and Management, 243: 75 - 82.

***Number of papers in referred journals (published or under press): 59***

***Awards, other information***

Since 2008: Head of the department of Forest Sciences USP, ESALQ, Piracicaba, Brazil
Since 2003: Coordinator of the Post-graduation Program in Forest Sciences (PhD and master's degree) USP, ESALQ, Piracicaba
Since 1994: Coordinator of the Laboratory of Applied Ecology, University of São Paulo, ESALQ, Piracicaba
Since 1998: Assistant Editor of the Journal of Brazilian Society of Soil Science, Federal University of Viçosa
Since 1994: Scientific Coordinator of the Cooperative Program of Research in Silviculture and Forest Management – Seventeen Brazilian forest industries are associated, including about 3.5 million hectares of planted forests in the States of São Paulo, Minas Gerais, Bahia, Parana, Rio Grande do Sul, Pará; Institute of Forest Research and Study (IPEF), linked do USP/ESALQ, Piracicaba

**Méthode NKOUA, 39 ans**
**Chercheur CRDPI**
« Gestion Sociale et Environnementale » Research Unit

*Academic qualification*
- PhD in geography,, Université Marien Ngouabi, Brazzaville/République du Congo, 2008-2010
- Engineer in agronomy: Institut de Développement Rural (IDR) / Brazzaville/ Congo, 1995

*Key qualifications*
Socio-economy, rural development, rural forest plantations, agroforestry

*Work experience*
2007- present: Centre de Recherche sur la Durabilité et la Productivité des Plantations Industrielles (CRDPI – Pointe-Noire) – Head of the « Gestion Sociale et Environnementale » research unit
2000-2007: Minoterie du Congo (MINOCO S.A) – Agence head – Nkayi
1995 - 2000: Grands Elevages du Congo (GRELCO S.A) – Operational and technical head – Brazzaville
1993 - 1995:Institut de Recherche pour le Développement (IRD ex ORSTOM) – Research traing in the Laboratoire d'Etude des Sols Cultivés (LESC) – Brazzaville

*List of the more relevant publications in the last five years*
- **Nkoua M.**, Besse F., Hervé G., Matondo R., 2009. Rapport d'enquête sur le trafic d'approvisionnement en bois d'usage local à Pointe-Noire. Rapport UR2PI, 29 p.
- **Nkoua M.**, Mponguily G. S. W., Missamba Lola A. P., Founa Toutou E. C., Kinouani G., 2009. Rapport d'étude sur l'identification et l'analyse des besoins et ressources de formation professionnelle dans la zone d'intervention de la société Magalloy Congo S.A., 100 p.
- Marien J. N., **Nkoua M.**, 2008. Foresterie périurbaine : approvisionnement en bois énergie de la ville de Pointe – Noire, Annales de la FAO, p 25-30.
- Rivals C., **Nkoua M.**, 2007. Filière viande de brousse au Kouilou et ses répercussions sur la faune. 4è volet du projet GECKO. Rapport d'étude, 45 p.

**Armel THONGO M'BOU, 35 years**
**CRDPI Research scientist**
« Plantes et Milieu » Research Unit

***Academic qualification***
PhD in Forestry, Henri Poincaré University/France and Marien Ngouabi University/Congo, 2008.
Master of Science in vegetable biology: Marien Ngouabi University/Brazzaville/Congo, 2003
Engineer in agronomy: Institut de Développement Rural (IDR) / Brazzaville/ Congo, 2000

***Key qualifications***
Root growth and modelling, respiration, sustainability of plantation forests

***Work experience***
2006-Present: CRDPI research scientist on root system growth and modelling, soil respiration, silviculture
2000-2005: CRDPI Ingeneer on root growth, photosynthesis measurement, aerial and root architecture.

***List of the more relevant publications in the last five years***
- Epron, D., Marsden, C., **Thongo M'bou**, A., Saint-andré, L., D'Annunzio, R., **Nouvellon, Y.**, 2009. Soil carbon dynamics following afforestation of a tropical savannah with *Eucalyptus* in Congo. Plant and Soil (in press).
- Laclau J.P., Toutain F., **Thongo M'bou A**., Arnaud M., Joffre R., Ranger J., 2004. The function of the superficial root mat in the biogeochemical cycles of nutrients in Congolese *Eucalyptus* plantations. Annals of Botany 93: 249-261.
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- Saint-André L., **Thongo M'bou A**., Mabiala A., Mouvondy W., Jourdan C., Roupsard O., Hamel O., Nouvellon Y., 2005. Age related equations for above- and below-ground biomass of a *Eucalyptus* hybrid in Congo. Forest Ecology and Management 205: 199-214 .
- **Thongo M'bou A**., Jourdan C., Deleporte P., Nouvellon Y., Saint-André L., Bouillet J P, Mialoundama F, Mabiala A, Epron D, 2008. Root elongation in tropical *Eucalyptus* plantations: effect of soil water contents. Annals of forest science 65: 609.

***Number of papers in referred journals (published or under press): 9***

## 7. 3 IMPLICATION DES PERSONNES DANS D'AUTRES CONTRATS

| Partner | Name | Man-month / year | Funding agency Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 1-UPR 80 | Bouillet JP | 1 | Integrated Project European Commission 6th PCRDT 365 k€ | ULCOS *"Ultra Low CO2 Steel Making"* 2nd Phase | JP Birat Arcelor-Mittal | 2006-2010 |
| 1-UPR 80 | Nouvellon Y | 3 | Integrated Project European Commission 6th PCRDT 365 k€ | ULCOS 2nd Phase | JP Birat Arcelor-Mittal | 2006-2010 |
| 1-UPR 80 | Nouvellon Y | 0.5 | Union Européenne - ENV.2009.1.1.5.1 170 k€ | ClimAfrica *Climate change predictions in Sub-Saharan Africa: impacts and adaptations* | Tuscia Univ. | 2006-2009 |
| 1-UPR 80 | Nouvellon Y | 2 | ANR Systerra (submitted) 175 k€ | EuPopScale | C Barbaroux Orleans Univ | 2010-2014 |
| 1-UPR 80 | Laclau JP | 3 | Integrated Project European Commission 6th PCRDT 365 k€ | ULCOS *"Ultra Low CO2 Steel Making"* 2nd Phase | JP Birat Arcelor-Mittal | 2006-2010 |
| 1-UPR 80 | Laclau JP | 1 | ANR Systerra (submitted) 175 k€ | EuPopScale | C Barbaroux Orleans Univ | 2010-2014 |
| 1– UPR 80 | Harmand JM | 1 | INCO European Commission 6th PCRDT 450 k€ | Acaciagum *"Innovative management of Acacia senegal trees to improve resource productivity and gum arabic production in arid and semi-arid sub-Saharan Africa"* | D Lesueur CIRAD | 2007-2011 |
| 1 - UPR 80 | Harmand JM | 1 | European Commission EuropAid – Line « Environnement & Tropical Forest » 800 k€ | Cafnet *« Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India."* | P Vaast CIRAD | 2007-2010 |
| 1 - UPR 80 | Le Maire G | 1 | Integrated Project European Commission 6th PCRDT 365 k€ | ULCOS 2nd Phase | JP Birat Arcelor-Mittal | 2006-2010 |
| 1 - UPR 80 | Le Maire G | 0.5 | Union Européenne - ENV.2009.1.1.5.1 170 k€ | ClimAfrica | R Valentini Tuscia Univ | 2010-2013 |
| 1 - UPR 80 | Le Maire G | 1 | ANR Systerra (submitted) | EuPopScale | C Barbaroux INRA | 2010-2014 |
| 1 – UPR 80 | Saint-André L | 2 | Integrated Project European Commission 6th PCRDT 365 k€ | ULCOS 2nd Phase | JP Birat Arcelor-Mittal | 2006-2010 |
| 1 – UPR 80 | Saint-André L | 3 | Strep European Commission 6th PCRDT 400 k€ | CarboAfrica | R Valentini Tuscia Univ. | 2006-2009 |
| 1 - UPR 80 | Saint-André L | 3 | ANR Bioenergie 145 k€ | EMERGE Elaboration de Modèles pour une Estimation Robuste et Générique du bois Energie | C Deleuze ONF | 2010-2012 |
| 1 - UPR 80 | Saint-André L | 1 | Union Européenne - ENV.2009.1.1.5.1 170 k€ | ClimAfrica | R Valentini Tuscia Univ | 2010-2013 |

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|---|---|---|---|---|---|---|
| 1 - UPR 80 | Saint-André L | 1 | ANR Bioenergie<br>100 k€ | SYLLABE<br>Sylvi – Laser Bois Energie<br>submitted | F Berger<br>Cemagfre | 2010-2012 |
| 1 - UPR 80 | Jourdan C | 1 | European Commission<br>FP6 Strep N°032037<br>350 k€ | *INNOVKAR*<br>*« Innovative Tools and Techniques for Sustainable Use of the Shea Tree in Sudano-Sahelian zone »* | JM Bouvet<br>CIRAD | 2007-2010 |
| 1 - UPR 80 | Jourdan C | 3 | ANR Systerra<br>(submitted)<br>124 k€ | Ecosfix | A Stockes<br>CIRAD | 2010-2013 |

| Partner | Name | Man-month / year | Funding agency<br>Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 2 – UMR System | Christian Dupraz | 0.5 | CASDAR<br>20 k€ | Agroforesterie avec grandes cultures | P. Boucheny, APCA | 2009-2010 |
| 2 – UMR System | Christian Dupraz | 1 | CG34 – PIRAT<br>23 k€ | PIRAT<br>Programme integeré de recherches en agroforesterie à Restinclières | C. Dupraz | 2001-2013 |
| 2 – UMR System | Christian Dupraz | 1 | Agence de l'Eau Rhône-Méditerranée-Corse<br>90 k€ | Bilan environnemental des parcelles agroforestières | C. Dupraz | 2009-2010 |
| 2 – UMR System | Christian Dupraz | 2 | ANR-Systerra-Appel d'offre 2009<br>140 k€ | DROOPY<br>Deep ROOts as a means to enhance the Productivity and sustainabilitY of agricultural systems<br>Submitted | A. Pierret | 2010-2013 |
| 2 – UMR System | Lydie Dufour | 3 | CG34 – PIRAT<br>23 k€ | PIRAT<br>Programme integeré de recherches en agroforesterie à Restinclières | C. Dupraz | 2001-2013 |
| 2 – UMR System | Aurélie Metay | 1 | Agence de l'Eau Rhône-Méditerranée-Corse<br>90 k€ | Bilan environnemental des parcelles agroforestières | C. Dupraz | 2009-2010 |

| Partner | Name | Man-month / year | Funding agency<br>Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 3 – EEF | Maillard P | 4 | ANR Blanche 2007<br>182 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron<br>EEF | 2008 – 2011 |
| 3 – EEF | Maillard P | 1 | ANR – Programme VMC 2007<br>87.2 k€ | Impact du réchauffement climatique sur la fonction de puits de carbone de l'écosystème tourbières à sphaignes (PeatWarm) | F Laggoun-Défarge<br>CNRS Orléans | 2008 – 2012 |
| 3 – EEF | Gérant D | 3 | ANR Blanche 2007<br>182 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron<br>EEF | 2008 – 2011 |
| 3 – EEF | Gérant D | 1 | ANR – Programme VMC 2007<br>87.2 k€ | Impact du réchauffement climatique sur la fonction de puits de carbone de l'écosystème tourbières à sphaignes (PeatWarm) | F Laggoun-Défarge<br>CNRS Orléans | 2008 – 2012 |

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|---|---|---|---|---|---|---|
| 3 – EEF | Marron N | 5 | ERA-Net Bioenergy Funding ADEME (for France) 290 k€ | Cost reduction and efficiency improvement of Short Rotation Coppice (CREFF) | N Marron EEF | 2008-2011 |
| 3 – EEF | Marron N | 3 | ANR Bioenergy 185 k€ | Nouveaux concepts de cultures ligneuses durables pour la production de biomasse à des fins énergétiques (SYLVABIOM) | JC Bastien INRA AGPF Orléans | 2008-2012 |
| 3 – EEF | Epron D | 6 | ANR Blanche 2007 182 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron EEF | 2008 – 2011 |
| 3 – EEF | Epron D | 3 | ANR – Programme VMC 2007 87.2 k€ | Impact du réchauffement climatique sur la fonction de puits de carbone de l'écosystème tourbières à sphaignes (PeatWarm) | F Laggoun-Défarge CNRS Orléans | 2008 – 2012 |
| 3 – EEF | Epron D | 4 | ANR Systerra 2009 | RESTOSOLS Dégradation et Restauration des fonctions des sols forestiers suite à l'application de contraintes mécaniques submitted | J Ranger INRA BEF | 2010 – 2012 |
| 3 – EEF | Gross P | 1 | ANR Blanche 2007 225 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron EEF | 2008 – 2011 |
| 3 – EEF | Gross P | 1 | Gestion et Impacts du Changement Climatique (GICC) | Carbo France | P Peylin LSCE | 2008-2009 |
| 3 – EEF | Gross P | 0.5 | FP6 – Integrated Infrastructure Initiative | Infrastructure for Measurement of the European Carbon Cycle (IMMEC) | D Papale Tuscia Univ. | 2008 – 2011 |
| 3 – EEF | Clerc B | 2 | ANR Blanche 2007 182 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron EEF | 2008 – 2011 |
| 3 – EEF | Clerc B | 0.5 | FP6 – Integrated Infrastructure Initiative | Infrastructure for Measurement of the European Carbon Cycle (IMMEC) | D Papale Tuscia Univ. | 2008 – 2011 |
| 3 – EEF | Courtois P | 1 | FP6 – Integrated Infrastructure Initiative | Infrastructure for Measurement of the European Carbon Cycle (IMMEC) | D Papale Tuscia Univ. | 2008 – 2011 |
| 3 – EEF | Zeller B | 5 | ANR Blanche 480 k€ | DYNAMOS | C Hatté | 2007-2010 |
| 3 – EEF | Zeller B | 1 | ANR Systerra 2009 25 k€ | RESTOSOLS Dégradation et Restauration des fonctions des sols forestiers suite à l'application de contraintes mécaniques submitted | J Ranger INRA BEF | 2010 – 2012 |
| 3 – EEF | Zeller B | 1 | ANR Systerra 2009 30 k€ | SYSTRUF An integrated approach for sustainable management of ecosystems producing black truffle (*Tuber melanosporum*) | MA Selosse University of Montpellier | 2010 – 2013 |
| 3 – EEF | Plain C | 6 | ANR Blanche 2007 182 k€ | CATS – Integrated monitoring of carbon allocation in tree and soil | D Epron EEF | 2008 – 2011 |
| 3 – EEF | Plain C | 2.5 | ANR – Programme VMC 2007 87.2 k€ | Impact du réchauffement climatique sur la fonction de puits de carbone de l'écosystème tourbières à sphaignes (PeatWarm) | F Laggoun-Défarge CNRS Orléans | 2008 – 2012 |

| Partner | Name | Man-month / year | Funding agency Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 4-Eco&Sols | Brauman A. | 2 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | Performing Plant Communities in Low input Agriculture-Multitrophic interactions and Intergenotypic Interactions<br>PERFCOM | P Hinsinger. UMR Eco&Sols | 2008 - 2012 |
| 4-Eco&Sols | Brauman A. | 1 | ANR Métagénome<br>150 k€ | Biospaning for biocatalyst in the litter of invertebrates : analysis of microbia in soil inverytebrates from the Malagasy forest<br>BAMBI | O'Donohue M. | 2008 - 2011 |
| 4-Eco&Sols | Brauman A. | 1 | ANR SYSTERRA 2008<br>85 k€ | "Processus Ecologiques et Processus d'Innovation Technique et Sociale en agriculture de conservation"<br>PEPITES | S De Tourdonnet Inra. | 2009 - 2012 |
| 4-Eco&Sols | Drevon JJ | 3 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | PERFCOM | P Hinsinger. UMR Eco&Sols | 2008 - 2012 |
| 4-Eco&Sols | Drevon JJ | 1 | Egide<br>27 k€ | P Imoteph | Magdi<br>NRC Egypt | 2008 – 2010 |
| 4-Eco&Sols | Drevon JJ | 1 | Egide<br>25 K€ | P Tassili | Ounane<br>INA Alger | 2008 – 2010 |
| 4-Eco&Sols | Drevon JJ | 3 | ANR Systerra 2009<br>50 K€ | Eco-Culture de l'olivier comme une nouvelle fonctionnalité pour les reconquêtes écologique et sociétale des milieux méditerranéens à l'abandon et inflammables (ECCOLIV)<br>submitted | S Roussos<br>IRD | 2010-2012 |
| 4-Eco&Sols | Hinsinger P. | 5 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | PERFCOM | P Hinsinger. UMR Eco&Sols | 2008 - 2012 |
| 4-Eco&Sols | Hinsinger P. | 2,33 | ANR CES 2009<br>76,4 k€ | Vers la Normalisation du RHIZOtest pour l'évaluation de la phytodisponibilité des éléments traces en sols contaminés (NormaRHIZO)<br>submitted | E Doelsch<br>CIRAD | 2010-2012 |
| 4-Eco&Sols | Pansu M. | 3 | ECOS-Nord, coopération universitaire France-Venezuela | Modélisation de la matière organique du sol dans les écosystèmes vénézuéliens et application à la gestion de la fertilité et la séquestration de carbone | Pansu M. | 2007-2011 |
| 4-Eco&Sols | Pansu M. | 1 | Programme ANR STRA, .CIRAD, INRA, IRD, Universités Montpellier, ISRA Burkina Faso, Université d'Antananarivo, Madagascar | ISARD, 2009 Intensification écologique des Systèmes de production Agricoles par le Recyclage des Déchets | Hervé Saint Macary<br>Cirad | 2009-2013 |
| 4-Eco&Sols | Pansu M. | 3 | ECOS-Nord, coopération universitaire France-Venezuela | Modélisation de la matière organique du sol dans les écosystèmes vénézuéliens et application à la gestion de la fertilité et la séquestration de carbone | Pansu M<br>UMR Eco&Sols. | 2007-2011 |
| 4-Eco&Sols | Pansu M. | 2 | Collaborative Project, Large scale integrated project, Topic ENV.2009.2.1.3.1 Soil processes and modelling, FP7 European program<br>SOILIFE 2009<br>120 k€ | Climate and management effects on life cycles in soils of mountainous ecosystems,<br>Submitted | Marchetti M. | 2010-2012 |

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|---|---|---|---|---|---|---|
| 4-Eco&Sols | Pernot C | 3 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | PERFCOM | P Hinsinger.<br>UMR Eco&Sols | 2008 -<br>2012 |
| 4-Eco&Sols | Plassard C. | 1 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | PERFCOM | P Hinsinger.<br>UMR Eco&Sols | 2008 -<br>2012 |
| 4-Eco&Sols | Plassard C. | 1 | ANR SYSTERRA 2008<br>85 keuros | PEPITES | S De<br>Tourdonnet.<br>Inra | 2009 -<br>2012 |
| 4-Eco&Sols | Plassard C. | 3 | ANR biodiversité 2006<br>106,8 k€ | "Conserving and exploiting the functional diversity of ectomycorrhizal fungi in forest ecosystems" | J Garbaye<br>Inra. | 2007 –<br>2010 |
| 4-Eco&Sols | Plassard C. | 2,4 | ANR Blanc 2009<br>119 k€ | Trophic exchange between ectomycorrhizal fungi and host plant and differentiation of the fungal plasma membrane between sites of uptake and secretion<br>TRECTOSYM<br>Submitted | S Zimmermann<br>Cnrs | 2010 -<br>2012 |
| 4-Eco&Sols | Villenave C. | 1,75 | ANR SYSTERRA 2008<br>225, 8 k€ (INRA)<br>+ 170,4 k€ (IRD) | PERFCOM | P Hinsinger.<br>UMR Eco&Sols | 2008 -<br>2012 |
| 4-Eco&Sols | Villenave C. | 1 | ADEME | Bioindicateurs phase II | Bispo A. | 2009 -<br>2011 |
| 4-Eco&Sols | Villenave C. | 1,5 | GESSOL<br>189 k€ | Biotechnosol<br>(Submitted) | J Cortet. | 2010-<br>2012 |
| 4-Eco&Sols | Villenave C. | 1 | GESSOL<br>107 k€ | SpecBio<br>(Submitted) | B Barthes<br>UMR Eco&Sols | 2010-<br>2012 |

| Partner | Name | Man-month / year | Funding agency Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 5 - Innovation | Sibelet N. | 6 | RTRA<br>Agropolis foundation<br>148 k€ | IAM | Sibelet N. | 2008 -<br>2010 |
| 5 - Innovation | Kalms JM | 6 | RTRA<br>Agropolis foundation<br>148 k€ | IAM | Sibelet N. | 2008 -<br>2009 |
| 5 - Innovation | Sibelet N | 1 | ANR<br>40 k€ | SEPIA | - | 2010-<br>2013 |
| 5 - Innovation | Sibelet N | 1 | EU<br>300 k€ | FUNCITREE | - | 2009-<br>2013 |
| 5 - Innovation | Dulcire M. | 1 | PSDR<br>45 k€ | INTERSAMA | - | 2008-<br>2011 |

| Partner | Name | Man-month / year | Funding agency Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 7 – USP | Gonçalves L | 1.5 | Institute of Forest Research an Study 415 k€ | Soil, eucalypt nutrition and management under minimum tillage | L Gonçalves USP | 2005-2015 |
| 7 – USP | Trivelin PC | 1 | Foundation for Research Support of São Paulo 150 k€ | Enrichment of stable isotopes and synthesis of labeled compounds | PC Trivelin USP | 2007-2011 |
| 7 – USP | Silva LD | 0.5 | Institute of Forest Research an Study 415 k€ | Soil, eucalypt nutrition and management under minimum tillage | L Gonçalves USP | 2005-2015 |
| 7 – USP | Meirelles ST | 1 | Foundation for Research Support of São Paulo 100 k€ | Ecophysiology of plants tolerant to desiccation | Sergio Tadeu Meirelles | 2009-2011 |
| 7 – USP | Moreira M | 1 | Foundation for Research Support of São Paulo 150 k€ | The Role of Lakes and Rivers as Sources of Evaporated Water to the Atmosphere in the Amazon Basin | Marcelo Zacharia Moreira | 2009-2012 |
| 7 – USP | Piccolo MC | 1.5 | Foundation for Research Support of São Paulo 250 k€ | Carbon, nitrogen and soil nutrient cycling in tropical forest | Marisa de Cassia Piccolo | 2008-2013 |
| 7 – USP | Tsai SM | 0.5 | National Center of Science and Technological Development 150 k€ | Molecular microbial ecology | Siu Mui Tsai | 2008-2012 |

| Partner | Name | Man-month / year | Funding agency Partner grant | Project title | Coordination | Start/ end |
|---|---|---|---|---|---|---|
| 8-CRDPI | Thongo A. | 1.5 | Union Européenne - ENV.2009.1.1.5.1 40 k€ | ClimAfrica Climate change predictions in Sub-Saharan Africa: impacts and adaptations submited | R Valentini Tuscia Univ | 2010-2013 |