OPTIMIZATION OF PRODUCTIVITY AND SUSTAINABILITY OF INTENSIVE CROPPING SYSTEMS THROUGH SYMBIOTIC NITROGEN FIXATION IN AGROFORESTRY PLANTATIONS

Marron N[1,2*], Amiaud B[1,2], Epron D[1,2], Dallé E[1,2], Laflotte A[3], Piutti S[4]

*Correspondence author: marron@nancy.inra.fr

(1) INRA, UMR 1137 'Ecologie et Ecophysiologie Forestières' (EEF), route d'Amance, 54280 Champenoux, France (2) Université de Lorraine, UMR 1137 'Ecologie et Ecophysiologie Forestières' (EEF), 54500 Vandœuvre-lès-Nancy, France (3) Université de Lorraine, Domaine Expérimental de la Bouzule – Ecole Nationale Supérieure d'Agronomie et des Industries Alimentaires (ENSAIA), 54280 Laneuvelotte, France (4) Université de Lorraine, UMR 1121 'Laboratoire Agronomie et Environnement' (LAE), 2, avenue de la Forêt de Haye, 54518 Vandœuvre-lès-Nancy, France

Issues

In temperate areas, intensive timber plantations for energy purposes, such as short rotation coppice (SRC), are currently criticized: they deplete the soils in nutrients, are not environmentally friendly and are not competitive with herbaceous species (Alker *et al.* 2005). However, they are an important asset to reach 20% of energy consumption from renewable resources, objective set by the European Union for 2020 (European Biomass Association 2011). The combination of species capable of fixing nitrogen from the atmosphere to species of economic interest may be a way to overcome many of the disadvantages of short rotation tree plantations (Forrester *et al.* 2006, Epron *et al.* 2013). Actually, biological nitrogen fixation reduces the financial and environmental costs of chemical fertilizers. The nitrogen-fixing species can be woody (e.g. alder) or herbaceous (e.g. alfalfa) in agroforestry systems (Lundgren 1982, Dupraz & Liagre 2011).

Mixture of nitrogen fixing and non-fixing tree species has been widely described in the south hemisphere (see Forrester *et al.* 2006 for a review). Under temperate latitudes, a few studies have been conducted in the eighties about the effect of alder mixture with various tree species. Positive effects were observed on the growth of ashes, liquidambars, tulip trees, spruces, pines, and Douglas-firs (Tarrant & Trappe 1971, Le Tacon *et al.* 1988). In contrast, the fertilizing effect of the mixture of alder trees with a fast growing tree species such as poplar was less obvious: either no effect was observed three years after planting (Teissier du Cros *et al.* 1984), or alder trees were rapidly eliminated by poplar trees (Le Tacon, unpublished data). These contrasting results emphasized the fact that the success of the mixture rely on site conditions. **A fine description of the ecophysiological interaction processes in the mixture, and how they are affected by the environment, is necessary to understand how to tip the balance toward positive interactions and so, to increase the production in the mixture.**

Experimental design

Our experimental instrumented plantation associates nitrogen-fixing species (alder, alfalfa) to species of economic interest (poplar, cereals) and is composed of (1) **"forest" plots** (pure poplar, pure alder, mixture poplar / alder), (2) **agricultural plots** (pure cereals, pure alfalfa), and (3) **agroforestry plots** (poplar / alfalfa mixture, alder / cereal mixture) in order to assess the fertilizer effect of nitrogen-fixing species on non-fixers (**Figure 1**). Planted cereals were wheat during the first two years, then triticale from the third year. The plantation is located on an agricultural plot of the experimental farm of La Bouzule located in Amance, near Nancy, north-eastern France. It has been installed during spring 2014 on an area of 5 ha, and is composed of almost 3500 trees.

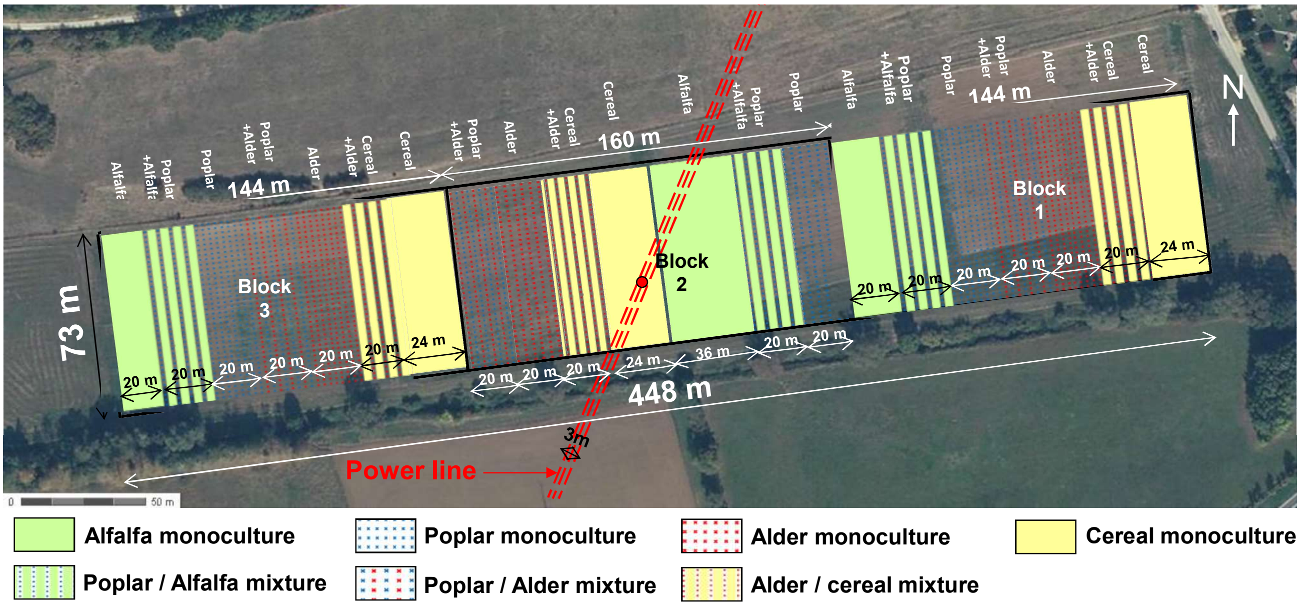

Figure 1: Schema of the experimental plantation. Red dots are alder trees; blue dots are poplar trees; green zones are covered with alfalfa; yellow zones are covered with cereals.

The plantation presents the triple function to be (i) an **experimental research site**, (ii) a site used for **student training**, and (iii) a **showcase for local farmers** who have questions about the technical feasibility of such systems. The plantation is an educational and experimental tool, backbone of future ambitious projects implemented for the long term. The fact that such plantation is all at once, (1) **intensive** (high tree planting density which should quickly lead to interactions between species), (2) **mixed with nitrogen fixing and non-fixing species**, and (3) **agroforestry** is the main originality of the trial. The ecophysiological functioning of such innovative cropping systems is lacking behind in France and in Europe.

Objectives

The description of the ecophysiological processes of species interactions in the mixtures as compared to the monocultures has been initiated in order to answer the following questions: **How species mixture affects carbon and nitrogen allocation and dynamic as compared to monocultures? Is the facilitation effect, linked to nitrogen symbiotic fixation, overriding negative interactions between species (competition), leading to an increased biomass production in the mixture? Are interactions between species comparable in the case of woody and herbaceous fixators?**

Scientific hypotheses

More precisely, our hypotheses about species mixture effects are as follows (**Figure 2**). The growth of the non-nitrogen-fixing species is stimulated by fixing species in the mixture (H1) through an increase of the nitrogen stock in the soil (H2) resulting in increased leaf area and photosynthetic assimilation of non-fixing species (H3). In forest plots, the intra-specific competition is more intense than the interspecific competition (H4). This is due to both a canopy stratification in the mixture allowing a better capture of the light resource (H5) and, similarly, to a stratification of root systems in the mixture allowing a better capture of water and nutrients (H6). The fraction of assimilated carbon allocated to the underground compartment is lower in the mixture (H7). The aboveground production is improved in the mixture (H8). Consequently, the ratio “Net Primary Production” / “Carbon flux to the underground compartment” increases in the mixture.

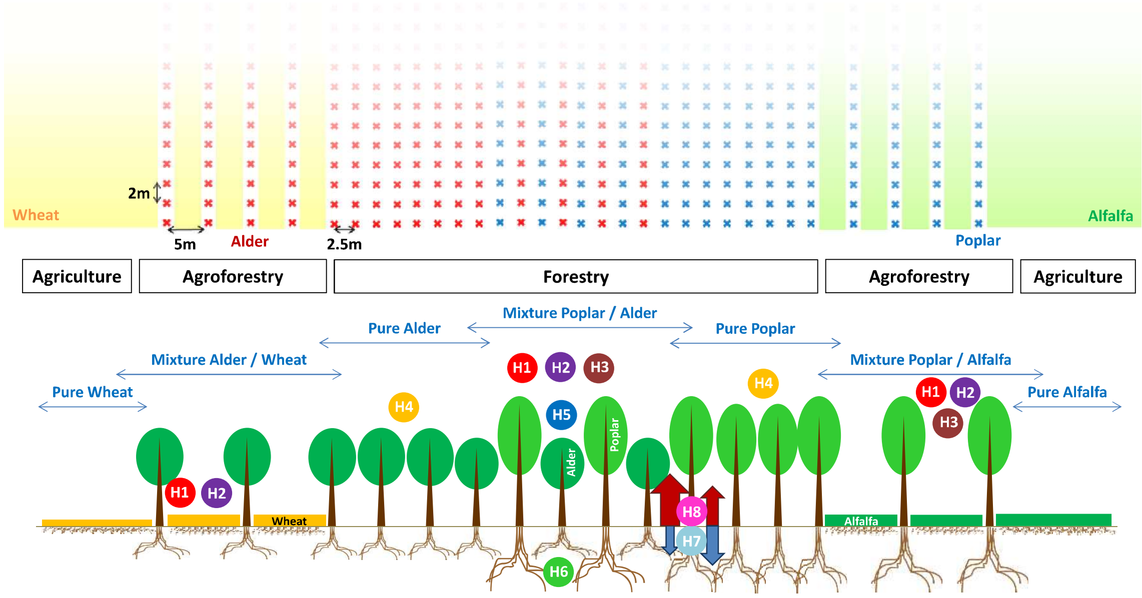

Figure 2: Schema illustrating the scientific hypotheses about species interaction effects in the different mixture treatments as compared with the monocultures. H1 to H8 refer to hypotheses numbers in the text.

Preliminary results

The plantation is still in an "installation" phase, but tree growth was monitored during the second growing season (2015) and strong species and mixture effects are already observed (**Figure 3**). Poplar trees are significantly taller than alder trees, except in the agroforestry treatment. Competition with alfalfa affects very significantly the development of poplar trees. To a lesser extent, alder trees also suffer from the competition with wheat. Poplar trees in monoculture are the tallest. Heights of alder trees are not significantly different in monoculture and in mixture with poplar. From the middle of June 2015 and for the rest of the growing season, a severe drought has drastically slowed down the growth of all plants.

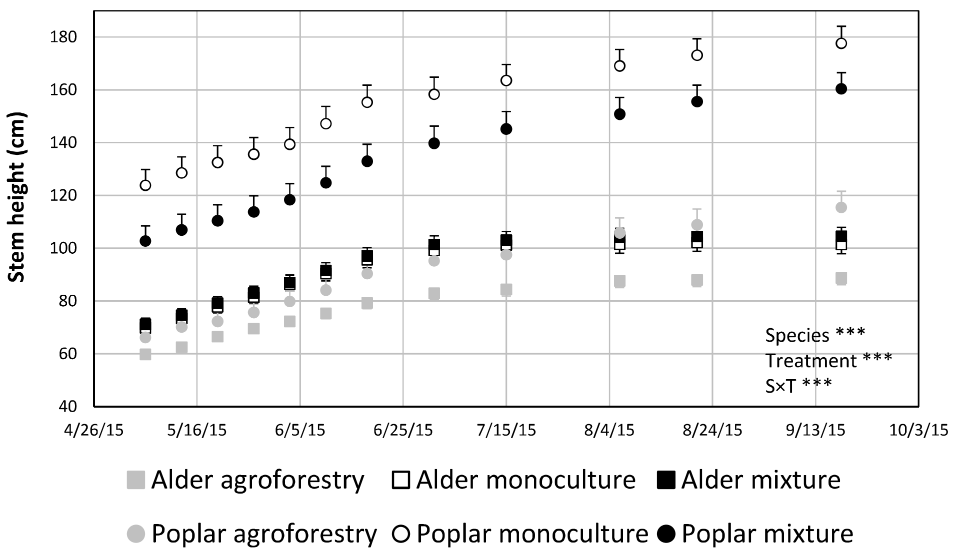

Figure 3: Time course of stem heights during the 2015 growing season for the poplar and alder trees in the monoculture, tree mixture, and agroforestry treatments (*n* = 60). The "species" and "treatment" effects and their interaction were significant at $P \leq 0.001$***.

Discussion

To answer our hypotheses, growth and biomass production of woody and herbaceous species will be evaluated (H1); nitrogen fixation will be estimated with isotopic methods (^{15}N natural abundance and enriched through labelling; H2); leaf gas exchanges will be measured (H3); foliage architecture will be described (H5); root profiles will be established though soil pit and root coring (H6); carbon and nitrogen compositions of above- and belowground biomass samples will be determined (H7 and H8).

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