INTEGRATING AGROFORESTRY INTO AN INNOVATIVE MIXED CROP-DAIRY SYSTEM

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Introduction

To face the new challenges of dairy farming in North-Western Europe, an innovative dairy system was redesigned to produce milk in a context of climate change while saving scarce resources (water, fossil energy) and contributing to a sustainable agriculture. This system, called OasYs, is based on the diversification of forage resources, the development of grazing, larger use of legumes and on a consistent strategy for the livestock system (Novak *et al*., 2015). The main research hypothesis is that the increase of diversity allows to conciliate production levels and environmental performance, this way improving system resilience. Agroforestry practices are introduced to increase the diversity of the cropping system. Agroforestry reinforces the agroecological approach of this dairy system by contributing to diversify the forage resources and to use more efficiently natural resources, either in height by enhancing the possibility of solar radiation absorption by the three-dimensional forage cover, or in depth by improving the absorption of soil nutrient and water resources (Cannell *et al*., 1996). More generally, agroforestry systems offer numerous ecosystem services and environmental benefits (Jose, 2009). Tree rows may also enhance the resilience of the intercrops to climate change by buffering microclimate (Van Noordwijk *et al*., 2014).

In cattle production systems, agroforestry may also improve animal welfare and provide additional fodder from trees and shrubs leaves (Torres, 1983). Agroforestry trees are besides well-known to be more productive than in forestry condition, the leaves and branches production being in some conditions twice more important in agroforestry conditions (Dupraz and Liagre, 2013). But there are currently very few farms in Western Europe where trees or shrubs play a significant role in dairy cattle farming, because of a lack of knowledge in the way to establish a silvopastoral system and on technical and economic references on such systems.

This paper gives an overview of the mixed crop-dairy system and presents the agroforestry practices that are integrated into.

Material and methods

The forage system of OasYs (90 ha) relies on three long term crop-grassland rotations with diversified multispecies grasslands and annual crops, associated with legumes (Novak *et al*., 2014a). In order to save energy and water resources, two of these rotations (5 years of grazed pastures and 2 years of annual crops) are rotationally grazed. One is totally grazed, the two years of annual crops (e.g. fodder beet, millet-clover) having to address the shortages of grass generally observed in summer and winter. The other rotation is mainly grazed and has two years of dual purpose crops (sorghum or cereal-legume mixtures), which can either be grazed or harvested, depending on the livestock needs and climatic hazards. The third rotation (4 years of hay meadow followed by maize, wheat, sorghum and protein-rich plants) is never grazed and provides forage stores, grains and straw. Each crop of these three rotations is present on one field, so that there is a great diversity of crops and of forage resources to be grazed. The reproduction of the 72 dairy cows herd is based on two calving periods centered on spring and autumn, to ensure coherence with the availability of grazed forage resources, and to overcome climatic hazards which could occur at one period (Novak *et al*., 2014b). The increase of the lactation length to 16 months and the crossing of dairy breeds are also tested to improve the durability and resilience of the system. This agroecological dairy system was implemented in June 2013 at an INRA facility located in Lusignan (Poitou-Charentes, France, http://www.poitou-charentes.inra.fr/Outils-et-Ressources/Dispositifs-experimentaux/Oasys/).

The ambition of the OasYs system-experiment is to test and evaluate at field scale and on long-term different coherent ways of integrating agroforestry in a productive dairy cattle farm. The main idea is to integrate the woody fodder production in the annual fodder production, and not to consider it only as a supplement occasionally available during a climatic hazard (*e.g.* drought). Since the beginning of the system-experiment in June 2013, four fields were planted with trees or shrubs (**Table 1**), old hedgerows were included in all the grazed paddocks, one arboretum was established, and one wood is being adapted to be grazed. Most of the innovative agroforestry practices tested here concern the browsing of fodder trees or shrubs. But we also decided to integrate high-value trees into the never grazed rotation, as very few studies have been conducted on agroforestry crop-grassland rotations. These different systems are presented below.

Table 1. Main characteristics of the alley cropping agroforestry fields of the OasYs system-experiment

Tree use	Type of rotation	Field name: surface date of planting	Woody species	Study topic
High value timber	never grazed	V12 : 3.1 ha Feb. 2014	*Prunus avium* *Sorbus torminalis* *Sorbus domestica*	density of plantation cultivar selection soil fertility climatic protection of crop production
Fodder trees	totally grazed	M2: 3.1 ha Feb. 2014	*Fraxinus excelsior* *Morus alba* *Ulmus minor x resista* *Alnus cordata* *Quercus ilex*	tree protection pollards browsing soil fertility
Fodder liana		M3: 3.2 ha April 2015	*Vitis sp*: two vine rootstocks	liana support structure liana protection liana browsing
Multipurpose trees	mainly grazed	G14: 3.0 ha Feb. 2015	*Pyrus communis; Gleditsia triacanthos; Sorbus domestica; Morus alba; Alnus cordata; Salix caprea; Ulmus minor; Robinia pseudoacacia; Alnus incana*	tree protection spatial organization diversification of trees uses

High stem trees

The main vocation of the high stem trees integrated in our mixed crop-dairy system is to produce high-value timber. They are also intended to contribute to soil fertility, to limit the heat stress of the intercrops, to promote beneficial insects (pollinators or predators) and to store carbon. Three species of high stem trees were planted in 2014 (V12, see **Table 1**) in the never-grazed rotation, with three densities (1, 2 or 3 seedlings at each planting location) and at 26 m inter-row spacing. Two selected cultivars of *Prunus avium* are tested.

Fodder trees and liana

Trees and liana (vine rootstock) were planted in the totally grazed rotation in order to be browsed during periods of low grasslands production (summer and autumn). In the M2 field (20 m inter-row spacing), the major part of the trees will be pollarded at 1 m height to increase the foliar biomass available to dairy cattle. Some trees will also be pollarded at 2 m height in order to provide shade for livestock in summer. In the other field (M3, 17 m inter-row spacing), two species of vine rootstock in double-row set and two modes of support structure (trellis) are tested. When the woody plants will be strong enough to be browsed, two browsing managements will be conducted and studied. The trees are currently protected from game with mesh guards and from cattle with an electric fence.

As little is currently known on the nutritive value of woody vegetation for livestock, and the role that pollarding can play on it, we also study that topic (Emile et al., 2016).

Multipurpose trees

The G14 paddock was specifically designed with stakeholders in the frame of the AgForward EU project to answer their needs of technical and economic references in terms of diversification of trees uses, spatial organization and of tree protection from cattle. Diversification of trees uses is tested with various woody resources of different species managed with different pruning techniques, mixed on the same row, as summarized below:

- high stem trees (*Pyrus communis, Gleditsia triacanthos, Sorbus domestica*) to provide timber, fuelwood, wood chips for litter or as soil amendment, shade and fodder,
- pollards (*Morus alba, Alnus cordata*) to provide fodder but also wood chips for litter or as soil amendment, timber or fuelwood,
- coppiced trees (*Salix caprea; Ulmus minor; Robinia pseudoacacia; Alnus incana*), liana and fodder hedge to be used as fodder or wood chips.

Three spatial organizations of trees are tested with single, double or triple-row sets, with an inter-row spacing of 20 m. The tree protections studied to restrict the browsing of the newly established trees are the following: single or double line of electric fence, electric fencing tape, metal or plastic fences, or olfactory repellents. Another option of tree protection consists to exclude the paddock from grazing and to mow the grassland during the first years of the establishment phase.

Boundary hedgerows

Old hedgerows surrounding the grazed paddocks were included in them in order to provide fodder and shelter from wind and sun to the cattle. We will observe the capacity of the hedgerows plants (mainly composed of *Prunus spinosa, Crataegus monogyna, Rubus fruticosus with some Quercus robur or Quercus petraea*) to resist to the cattle trampling and browsing.

Fifty fodder tree species adapted to pollarding were also planted in five rows surrounding five paddocks in December 2014 to constitute an arboretum. It includes nitrogen-fixing species trees such as *Alnus glutinosa* or *Cercis siliquastrum*, and also trees more adapted to the climatic conditions of southern France (e.g. *Morus alba, Acer montspessulanum*) to anticipate climate change.

Groves of trees

One wood (1 ha) located adjacent to a paddock and mainly composed of *Castanea sativa, Corylus avellana, Prunus avium, Robinia pseudoacacia and Quercus robur or Quercus petraea* is currently being adapted to provide shelter and an extra resource of fodder for heifers during summer and winter.

For the same reasons, we also plan to plant groves of trees in a pasture grazed by heifers.

Conclusion and perspective

Depending on objectives, ruminant farmers have many promising possibilities of integrating woody plants in their cropping or livestock system. Since agroforestry is a recent practice for the majority of ruminant farmers in Europe, there is a need to experiment different agroforestry practices so as to lift barriers and guide livestock farmers with best practices as well as economic and technical references.

The study presented here aims to document several agroforestry practices for ruminant farmers, at the establishment phase and also when the woody plants will be harvested or browsed. The overall coherence of the several agroforestry practices tested will also be studied at the scale of the mixed crop-dairy farm. More generally this study aims at increasing knowledge on the effects of woody plants on forage and dairy production, and also on animal welfare, soil fertility, and insect biodiversity.

Scientists of various disciplines (agronomy, animal production, soil science …) are invited to use these experimental plots to broaden the knowledge on agroforestry for ruminants.

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