Setting the Scene of Alfalfa Ecosystem Services at Rotation & Territory Levels: Toward a Better Use of Alfalfa

Christian Huyghe, INRAE - Paris, France

Doctor of Agricultural Engineering from the École Nationale Supérieure Agronomique de Rennes and Director of Research in "Plant Genetics and Improvement" at INRA, Christian Huyghe has conducted research programs on the genetic improvement of the seed yield of a protein crop, the Lupin, on the genetic improvement of the digestibility and production of alfalfa seeds and on the analysis of the genetic evolution of the sown grasslands and the underlying mechanisms. He has published more than 80 scientific articles and written about 20 scientific and popular books. He was Director of the INRA's Research Unit in Genetics of Forage Plants in Lusignan from 2001 to 2007 and then President of the INRA Poitou-Charentes center from 2008-2010. He chaired the French Grassland Society (AFPF) and the European Grassland Society when preparing to host the European Grassland Conference in France in 2002.

He is currently Scientific Director of Agriculture at INRAE, where he is in charge of issues related to the changes of production systems towards multi-performance, partnerships with technical institutes and cooperatives and the general issue of innovation in agriculture. Climate change and plant protection related to pesticide issue are high in his agenda. He contributes to the implementation of the Priority Research Program "Cultivate and Protect Alternatively" coordinated by the ANR and whose scientific management is ensured by INRAE. He is particularly involved in plant variety issues. He has been Chairman of the CTPS's Scientific Committee, i.e. for all plant and forest species, since June 2009. He was also Chairman of GIP GEVES's Board of Directors. In the field of support to public policies, he chairs the independent evaluation commission for CEPPs (Certificates of Economy of Plant Protection Products), a key element of the Ecophyto 2+ system. At the national level, he has been President of the Acta's COST (Scientific and Technical Steering Committee), a structure that coordinates and guides the network of Agricultural Technical Institutes, from 2011 and chairs the French public – private consortium on biocontrol. At the European level, he is a member of the Scientific Council of the Public-Private Partnership program entitled CBE-JU (Circular Bio-Based Europe - Joint Undertaking).

Ecosystem services as defined by the Millenium Ecosystem Assessment in 2005 include provisioning, supporting, regulating and cultural services. Most of these services are relevant to alfalfa-based cropping systems. Indeed, production of high-protein forage is part of provisioning services. Contribution to nitrogen budget through symbiotic fixation and high quality of soils are major supporting services, while preservation of biodiversity and mitigation of climate change are regulating services.

White et al (2021) demonstrated that ecosystem services, alongside with technological services and human labor ensure the production of all required outcomes and that the share of ecosystem services makes it possible to measure the degree to which a solution or a system is nature-based. In alfalfa-based cropping systems, this share may be very high if the cropping system and the surrounding landscape are well-designed.

Alfalfa services may be provided either per se, or through the rotations, while a peculiar attention must be paid to the alfalfa termination where services may be lost.

High biomass and high-quality and high-protein forage are produced by alfalfa stands. This must be regarded in regards of the total nitrogen world budget, where massive N quantities are lost because of low N use efficiencies of plant and animal production, of local disequilibrium and long distance transports (Billen et al, 2014). Legumes in general and alfalfa in particular are the only options to reduce these losses that are sources of costs, of N pollution and of massive N_2O emissions, one of the most severe greenhouse gases, contributing 40% of the GHG of the European agriculture.

Alfalfa does not produce any N_2O during the growth and it was shown by Zhang et al (2021) that if an appropriate symbiosis with arbuscular mycorrhizae was established, the low emission was maintained even under high temperature increase.

Beneficial effects on soil properties have been demonstrated.

Preserving or restoring biodiversity is a major challenge for the present agriculture, considering the massive losses experienced over the last three decades (Hallmann et al, 2017) and the responsibility of agricultural practices and agricultural systems in these losses (Sanchez-Bayo and Wijkhuis, 2019). Alfalfa offers several opportunities to contribute to this challenge. It has been demonstrated that alfalfa may be a major source of pollen and nectar for honey bees and wild bees (Haedo et al, 2022) especially if an adapted management is implemented with a strip of alfalfa being not harvested at each cut in order to increase the flower abundance.

Several studies have shown that the presence of alfalfa in the landscape is very beneficial to increase the regulation of pests by increasing the abundance of predators. This was illustrated by Costamagna et al (2015) for the control of *Aphis gossypii* in cotton in Australia, with a positive effect of an increasing proportion of alfalfa in the neighborhood. Clemente-Orta et al (2020) showed that alfalfa was more efficient than orchards in controlling pest damage in neighboring maize fields.

Services of alfalfa to biodiversity depend on the surrounding landscapes as shown by Kross et al (2016) who demonstrated that alfalfa had beneficial effects on avian conservation and avian-mediated pest control, and that these effects were boosted by presence of complex edge habitats in the neighborhood. This is relevant with the collective scientific expertise recently released by Inrae, France on the positive effect of increasing functional diversity at field and landscape scale on the biological regulations (Vialatte et al, 2022).

Multi-criteria assessment has been implemented to describe all benefits. At the scale of a crop and based on the US LTER network, Syswerda et al (2014) showed the services provided by alfalfa stand in comparison to several managements of annual rotations. The services are even more obvious when assessment is performed at the rotation scale, as done by Baldwin-Kordick et al (2022) who showed beneficial effects through a reduction in soil resistance to root growth, an increase in cation exchange capacity, a very large increase in salt-extractable soil carbon and in soil microbial biomass.

However, it has recently been demonstrated that the termination of alfalfa stands play an important role in preserving these benefits. Toderi et al (2021) showed that a destruction with herbicide and no-tillage was releasing less greenhouse gases than a destruction through tillage, even though massive quantities of CO_2 were released. It was also demonstrated by Francioni et al (2022) that the use of biochar at the time of alfalfa destruction followed by two wheat crops was making it possible to preserve some supporting services.

All these elements regarding possible ecosystem services from alfalfa and alfalfa-based cropping systems are relevant with the analyses from Martin et al (2020) on the role of grasslands and leys for sustainable agriculture and food systems and underline the need to design the cropping systems and cropping landscape while considering all services to be provided and especially the need to restore biodiversity and to adapt to and mitigate climate change. This defines safe operating spaces for those components of cropping systems.