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Agroforestry: benefits and considerations to meet the challenges of organic livestock production

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■ Agroforestry is an age-old agroecological practice with a promising future, and it has the potential to be a major ally in the development of organic farming. Animals have much to gain from living in the shade of trees and eating their leaves and fruit. Conversely, trees can benefit from the presence of animals. Nevertheless, certain adaptations may be necessary, and the increased complexity of farming systems raises new challenges.

Introduction

The "Green Revolution" was driven by public incentives and subsidies to achieve food self-sufficiency after World War II. It profoundly transformed the profile of farms, leading to the standardisation and compartmentalisation of both landscapes and know-how. In particular, this has led to the degradation or elimination of semi-natural habitats such as hedgerows and permanent grasslands, significantly contributing to a major biodiversity loss (Reidsma *et al.*, 2006). Furthermore, farmers receive only a small proportion of the added value generated by their work, and many farms are weakened by high levels of debt and a strong dependence on fluctuating global agricultural commodity and input prices.

Organic agriculture has developed partly as a response to the negative impacts of this intensification and specialisation, in particular by underlining the importance of crop/livestock combinations. The "principles of organic agriculture" emphasise the notions of holistic health ("sustain and improve the health of soils, plants, animals, people and the planet, as one and indivisible") and ecology ("[base] oneself on living ecological cycles and systems, work with them, imitate them and help sustain them") (IFOAM, 2005).

Livestock farming systems have a large footprint on our planet: in 2006, they occupied 33% of the Earth's land surface, of which 30% of arable land was used to produce animal feed (Steinfeld *et al.*, 2006). This sector accounts for 8% of global water consumption, and its effluents cause significant pollution of aquatic environments (Steinfeld *et al.*, 2006; Schlink *et al.*, 2010). According to the FAO, greenhouse gases emitted by livestock farming, mainly in the form of CH_4 and NO_2, account for 14.5% (in CO_2 equivalent) of anthropogenic emissions (Gerber *et al.*, 2013).

In this context, agroforestry – the farming practice of combining trees with crops and/or livestock – is emerging as a possible response to current and future health, climate, economic and social crises. A modern reworking of ancestral practices, agroforestry is an attempt to maintain or even improve agricultural yields by benefiting from the ecosystem goods and services provided by the presence of trees. In an agroforestry system, the management of incoming flows (sunlight, water, nutrients, etc.) and outgoing flows (animal waste, crop residues, residual agricultural inputs, etc.) can be optimised compared to conventional systems with separate plots of cropland and woodland (Dupraz & Liagre, 2008). Habitats are created for wild micro and macro fauna, large quantities of atmospheric carbon are stored, and benefits can be expected in terms of crop health and/or animal welfare (Veldkamp *et al.*, 2023). Agroforestry can therefore be seen as a form of agroecology capable of supporting the transition of farms to organic farming (Dupraz & Liagre, 2008), but also as a potential pathway for the future of organic farming (Rosati *et al.*, 2021). Nevertheless, the presence of trees creates a number of constraints that can have an impact on working time, yield, and the farmer's perception of his work.

Agroforestry systems involving livestock (silvopastoral systems, Box 1) have been defined in various ways. These complex systems include not only animals (of different species and breeds) and trees (of different species and varieties), but also the soil, climate, plant cover, existing farming practices, as well as the farmers and the social, economic and political context in which they operate. The motivations for adopting silvopastoralism are linked to the synergies it can generate between animal feed, maintenance of the plant cover, animal welfare, etc. However, trade-offs between system components may also arise. These can be mitigated through careful system management.

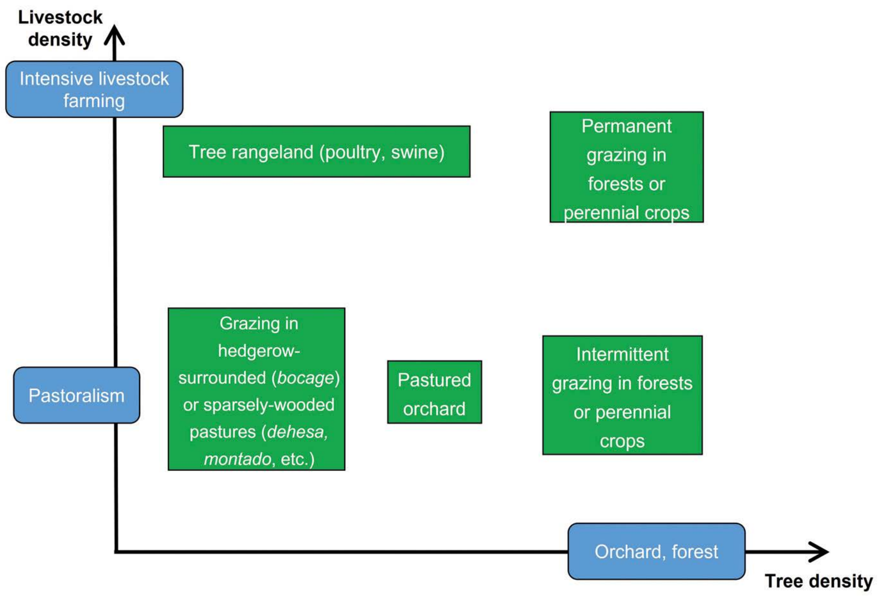
This article aims to document the diversity of silvopastoral systems and the potential synergies they produce, as well as their limitations and the new issues they raise, by considering different perspectives (tree, animal, farmer) and exploring the spectrum of tree-animal integration. This review is based on English-language scientific literature, grey literature (mainly in French), and preliminary results from ongoing projects. In the first part, it reviews the different challenges facing livestock farming, asking how silvopastoralism can contribute to coping with global change (mass extinction of species, climate crisis, etc.). Then, it tackles the management and performance of agroforestry livestock farming, before addressing the economic, social and regulatory issues about this practice.

The article focuses on silvopastoralism in temperate regions, with occasional references to the more abundant literature in tropical conditions. Some examples draw on data from silvo-arable systems, which are also important in livestock systems (production of concentrate), and particular attention is given to the association of livestock with specialised perennial crops (orchards, vineyards).

Box 1. ***Lifestock agroforestry terminology.***

Agroforestry applied to livestock systems ("*silvopastoralism*") can be defined as the *"combination of trees, forage plants, and livestock in an integrated and intensively managed system"* (Jose & Dollinger, 2019). These agroforestry systems that involve livestock can refer to grazing practices in forested or sparsely wooded areas, but also to the presence of animals in perennial crops (vineyards, orchards), or the creation of tree rangelands on a livestock farm (Figure 1). The term "*agro-silvo-pastoralism*" additionally implies that grazing can be extended to arable crops and/or that the arable crops used for animal feed originate from agroforestry systems. As to the notion of "*crop-livestock integration*", it tends to encompass all possible associations, therefore also including systems where trees are absent (grazing of intercultural cover crops, for example).

Figure 1. ***Agroforestry methods in livestock farming (Silvopastoralism).***



Dehesa and *montado* are traditional Mediterranean systems of extensive grazing in areas of intermediate tree density between grassland and woodland, with equivalents in various European countries.

1. Agroforestry as a response to the environmental and climatic challenges facing livestock farming

1.1 Maintaining the productive capacity of farmlands

Although often perceived as a hindrance to agricultural productivity, trees are now recognised for their contribution to fodder self-sufficiency and the maintenance of soil quality and fertility.

a. More diversified forage production

Good fodder management is crucial in organic farming, since the standards require a large proportion of feed to be produced on the farm, for both ruminants and monogastric animals. The fodder purchased must be certified organic and come as much as possible from the farm area, which can involve considerable expenditure. Aiming for forage autonomy is therefore essential, not only for economic reasons, but also to cope with drought and summer heatwaves.

b. Changes in forage productivity and quality

The risk of reduced fodder yields can be a limiting factor to planting trees in agricultural environments.

However, the effect of trees on crops varies according to planting density, soil and climate conditions and the species grown, making it difficult to draw any general conclusions about their impact on productivity (Torralba, 2016). Regarding grassland, the main effect of trees is the shade they produce, while competition for water and nutrients is minimal or even absent (DeBruyne *et al.*, 2011).

In France, a canopy that is at least 60% open may not significantly affect grassland productivity, except for the grass at the foot of the tree (Béral & Moreau, 2020), but decreases have been observed in other temperate grasslands. Trees delay grass growth, allowing later grazing or mowing, thanks to the creation of microclimates (Karki & Goodman, 2015). Although the shade created by trees can reduce legume production (Béral & Moreau, 2020), grasses can be of better forage quality under the tree canopy (Kallenbach *et al.*, 2006), which could lead to forages of equivalent quality between agroforestry and open grassland. Models for calculating the optimal tree density to maintain adequate productivity of the herbaceous resource have been produced (García de Jalón *et al.*, 2018b), but they still need to be extensively tested against field data.

c. Better use of the herbaceous layer

The presence of trees also has an impact on the behaviour of animals, which are likely to make a better exploitation of the herbaceous layer.

An appropriate design of the grazing area is essential to encourage poultry to leave their rearing building (Béral *et al.*, 2014). Chickens grazing on tree-planted areas consume more grass (Dal Bosco *et al.*, 2014), promoting better weight gain (Germain, 2014). However, access to a run can also result in increased soil ingestion (Jurjanz *et al.*, 2015). Therefore, maintaining the quality of the herbaceous cover is crucial to limit this effect and guarantee an adequate feed intake. This requires identifying palatable herbaceous species with interesting protein contents (Germain, 2014), while considering the light competition with trees. Trees protect pigs from the sun, making it easier for them to move around the grassland (Jakobsen, 2018). In addition, the consumption of on-the-hoof forage by pigs reduces the proportion of concentrate feed distributed and enhances the value of the carcass (Maupertuis & Desaint, 2023).

d. Trees as a source of fodder

Many tree species have been used since the Neolithic as livestock fodder (Rasmussen, 1989). Three factors need to be considered when evaluating their benefits for ruminants: yield, fodder quality and palatability.

Fodder yields remain poorly documented and vary depending on the species, age and management methods (pollard or high-stem[1], frequency of pollard pruning, etc.). Preliminary studies show that average leaf production per tree can exceed 800 g of dry matter per year for low pollards (Mesbahi & Novak, 2022). Measuring the yield from tall pollards, high-stem trees, and hedges is more difficult because these trees are larger, only partially accessible to animals and often densely interwoven. There is therefore very little data available to date, despite their greater presence in Europe.

Woody species show considerable variability in their nutritive values: they are often of higher quality than grasses in summer, but remain inferior to chicory (Novak *et al.*, 2020a) (Table 1). Partially replacing alfalfa with white mulberry in goat rations increases milk fat production by 9 g per kg of milk (Boyer, 2022). Similarly to herbaceous species, the forage quality of woody species declines as the season progresses (Mesbahi *et al.*, 2022a). Woody species can contain numerous secondary compounds with potential medicinal properties and/or that may reduce greenhouse gas emissions, but they may also have an anti-nutritional effect (see § 2.1.b). In addition to ruminants, preliminary studies have shown that finishing phase pigs consume available tree fodder (willow), but it does not fully offset the growth loss caused by a 30% reduction in the feed ration (Kongsted, 2022).

1 The term "high-stem" refers to a tree intended for timber production, where the trunk is free of branches and the crown develops freely. A "pollard" is a tree that is regularly pruned ("pollarded") at various heights on the trunk or branches, in order to produce kindling and fodder. Its name can vary depending on the region and the pruning methods used: pollard, pleaching, coppicing, etc.

Cultivated (e.g apples, cherries) and wild fruits (e.g. acorns, chestnuts) can also be consumed by livestock (Solagro, 2016). In the Lapoesie project, rabbits grazing in an orchard consumed 23% less feed than those raised indoors, thanks to their use of plant cover and fallen fruits (Savietto, 2023). In extensive Mediterranean pig production systems (*dehesa*, *montado*), the consumption of fruit during finishing improves the intramuscular fat and fatty acid profile of the meat, leading to a better evaluation by consumers (Lebret, 2008).

Assessing leaf palatability of woody species is essential, as a productive species with good forage quality is of no use if livestock does not consume it. Ash is traditionally used as fodder, yet various studies have shown that it is grazed very little by cattle if other resources are available (Vandermeulen *et al.*, 2018; Mesbahi *et al.*, 2022b), but that sheep readily consume it at the trough when it is presented alone (Bernard *et al.*, 2020). Among the species regularly observed in Western Europe, hawthorn, dogwood, elm, hazel, black locust, and certain willows are particularly popular with ruminants (Vandermeulen *et al.*, 2018) (Figure 2). The more Mediterranean white mulberry is also highly palatable to cattle, sheep and goats. These results on palatability need to be completed, however, as few studies have been carried out to date, and the determinants of food preferences have yet to be identified according to species, breeds, habits or even the balance of the animals' feed ration.

e. Healthy agroforestry soils

Agricultural soils generally benefit from the introduction of trees in fields: in arable farming, agroforestry improves soil structure, increases aggregate stability and water infiltration capacity, leading to greater resistance to erosion (Fahad *et al.*, 2022). In traditional Mediterranean silvopastoral systems, a reduction in water erosion has also

Table 1. ***Leaf* in vitro *dry matter digestibility and average crude protein content in August of selected woody species attractive to cattle, compared with chicory and perennial ryegrass (Novak* et al.*, 2020a).***

English name	Latin name	*in vitro* digestibility (%)	Total nitrogen (g/kg DM)
Common hawthorn	*Crataegus monogyna*	73.1	126
Bloody dogwood	*Cornus sanguinea*	89.4	90
White mulberry	*Morus alba*	84.8	164
Hazel	*Corylus avellana*	51.1	133
Field elm	*Ulmus minor*	60.8	131
Black locust	*Robinia pseudoacacia*	50.1	216
Basket willow	*Salix viminalis*	58.7	167
Goat willow	*Salix caprea*	70.4	159
Chicory	*Cichorium intybus*	87.3	207
Perennial ryegrass	*Lolium perenne*	62.4	120

been observed, although this depends on grazing practices (Shakesby *et al.*, 2002). Trampling by animals, but also the radial growth of tree roots, can compact the soil, although this effect is limited and reversible (Sharrow, 2007).

Part of the tree biomass ultimately becomes available to other components of the agroecosystem *via* the decomposition of fine roots and the annual fall of deciduous aerial organs. Trees facilitate the redistribution of water and minerals from the deep soil layers, normally inaccessible to the roots of herbaceous plants. In addition, certain species of trees and shrubs fix atmospheric nitrogen, enriching the soil through a symbiotic relationship with specific bacteria, which could promote the growth of neighbouring plants. These include species in the legume family (*Fabaceae*) such as honey locust (*Gleditsia triacanthos*), but also alders (*Alnus* spp) and sea buckthorn (*Hippophae rhamnoides*).

Figure 2. ***Consumption of tree fodder (Lutèce elm) by a Holstein x Jersey x Scandinavian Red crossbred cow (© Photo credit: G. Mesbahi – INRAE).***

Agroforestry positively impacts soil biodiversity, more so in silvoarable systems (Marsden *et al.*, 2020; Beule *et al.*, 2022) than in silvopastoral systems (Cubillos *et al.*, 2016; Poudel *et al.*, 2022).

The presence of animals in treed areas (woodlands, perennial crops) results in the deposition of mineral-rich droppings (urine, faeces) beneficial to tree growth. For example, the biological activity of soils and the availability of nitrogen and phosphorus are improved in vineyards and olive groves grazed by sheep (Ferreira *et al.*, 2013; Brewer *et al.*, 2022). However, the effects can be reversed beyond a certain threshold: for example, while poultry can enrich wooded soils with nitrogen (Hilimire *et al.*, 2013), prolonged presence at high stocking densities can result in nutrient overload, which is detrimental to fruit trees (Timmermans & Bestman, 2016).

■ 1.2. Mitigating the negative effects of agriculture on the environment

a. Ecosystem services and biodiversity

Beyond improving soil fertility, the balanced integration of animals and trees can also help mitigate the environmental and climatic impacts of agricultural practices.

Deforestation to create pastureland results in the loss of the water regulation services provided by trees (Jose, 2009; Zhu *et al.*, 2020; Smith *et al.*, 2022). In silvopastoralism, the trees act as a "safety net" that limits the flow of water and nutrients not absorbed or recycled by the herbaceous layer, which could potentially lead to environmental pollution or reduced system efficiency (Udawatta *et al.*, 2011; Zhu *et al.*, 2020). This aspect is particularly important in pig farming, which generates high concentrations of nitrogen in localised hotspots ("latrines"), efficiently captured by tree roots (Jakobsen *et al.*, 2019).

Agroforestry creates spatial heterogeneity, leading to diverse potential habitats, which generally has a positive effect on biodiversity. This effect is clear in silvoarable systems (Beillouin *et al.*, 2021), but is more nuanced in silvopastoral systems: while some studies suggest that wooded pastures attract both forest species and those adapted to open habitats (Mcadam *et al.*, 2007), others conclude that silvopastoralism does not support greater biodiversity than pastoral or forest environments (Mupepele *et al.*, 2021). This result could be due to the observed decline in grassland-specific and threatened plant species when trees develop on permanent grasslands (Boch *et al.,* 2019). The climatic zone also seems to be important: in Europe, the ecosystem services provided by silvopastoral systems are generally positive in Mediterranean environments, but neutral in temperate, continental and alpine environments (Torralba, 2016). The design of rangelands (choice of species, type of landscaping) and their connectivity to a diverse landscape mosaic are therefore crucial to maximising the effectiveness of silvopastoralism in terms of biodiversity (Béral *et al.*, 2014).

Mechanical mowing in vineyards, orchards, and woodland is destructive towards poorly mobile arthropod species, which can therefore benefit from ground cover management by animal grazing. In addition, the presence of animal dung can attract coprophagous beetles specialised in decomposition, initially absent from cultivated areas, which in turn provide numerous ecosystem services (Nichols *et al.*, 2008).

b. Carbon sequestration

The transition from conventional agricultural practices to agroforestry generally increases the carbon stock of the plot (De Stefano & Jacobson, 2018; Mayer *et al.*, 2022), resulting from tree biomass production both above and below ground, and modification of carbon and nitrogen cycles due to tree-induced microclimates (Marsden *et al.*, 2020). This effect is mostly observed in surface horizons, even though trees are also capable of storing carbon in deeper soil layers. Deciduous trees are associated with greater carbon sequestration, probably due to their deeper roots and the quantity and ease of degradation of their litter (Mayer *et al.*, 2022).

However, the disturbance generated by the establishment of a silvopastoral system from a forest or grassland environment seems to potentially cause temporary or long-term soil carbon losses (De Stefano & Jacobson, 2018; Contosta *et al.*, 2022; Mayer *et al.*, 2022). Indeed, temperate permanent grasslands are nearing the saturation point of their organic carbon stock, and the establishment of trees can disrupt established herbaceous communities (Mayer *et al.*, 2022). Nevertheless, the long-term carbon storage potential of silvopastoralism appears to be higher than that of open pastures (Contosta *et al.*, 2022).

Conversely, converting temperate temporary crop plots to agroforestry can greatly increase carbon stocks, as these stocks are often initially low (De Stefano & Jacobson, 2018; Mayer *et al.*, 2022).

In vineyards or wild cherry tree plantations, it has been shown that grazing leads to increased carbon storage, whatever depth is observed, provided that it is carried out correctly (Ferreiro-Domínguez *et al.*, 2016; Brewer *et al.*, 2022). Animal manure enriches the soil in carbon directly and indirectly *via* the activation of the microbial community (Brewer & Gaudin, 2020). However, it could also increase emissions of the powerful greenhouse gases N_2O and CH_4 (Lazcano *et al.*, 2022).

In summary, agroforestry could contribute to limiting climate change, especially in *alley-cropping* systems. Indeed, the carbon stock has a greater potential for improvement in rotational plots than in permanent grasslands. Silvopastoral systems are also particularly effective at storing carbon in tropical environments, while in temperate climates their value lies mainly in decreasing water and wind erosion and improving microclimates (Mayer *et al.*, 2022).

c. Methane emissions

In addition to their role in carbon sequestration, fodder trees can help reduce greenhouse gas emissions from ruminants. For example, tree browsing or the consumption of leaf plugs can reduce methane emissions, often to a small extent (Ramírez-Restrepo *et al.*, 2010; Terranova *et al.*, 2021). In addition, a reduction in urinary nitrogen emissions is sometimes observed, leading to a reduction in N_2O emissions, which is also a greenhouse gas (Terranova *et al.*, 2021).

This reduction is often linked to the condensed tannin content of forages (Terranova *et al.*, 2021), but other secondary compounds, such as saponins and phenols, could also play a role, although this is still poorly understood. The temperate-climate woody species with high tannin contents (> 50 g/kg DM) are, in ascending order: beech, kiwi, grapevine, hazelnut, willow and black locust (Novak *et al.*, 2020a) – the last two species even having higher contents than sainfoin. However, these levels vary depending on the individual and the soil and climatic conditions. Hazelnut, willow and black locust are of particular interest, as numerous observations have shown that they are appreciated by ruminants.

2. Coexistence of trees and animals: potential synergies and technical challenges of agroforestry

■ 2.1. Animal welfare and health

a. Microclimate and shade

Agroforestry creates microclimatic heterogeneities at plot level, allowing animals to choose the environment best suited for their well-being. Trees provide protection from the sun, buffer temperature variations, and limit wind speed (Karki & Goodman, 2015): temperatures can thus be reduced by 3 to 6 °C during summer, compared with a grassland without trees (Béral *et al.*, 2018). Under cold, rainy or windy conditions, trees also provide climatic protection: sheep actively seek out their cover, and cattle benefit from wintering in wooded areas if the soils allow it. A regularly wooded plot provides easy-to-reach shelter, which could limit the energy expenditure of livestock (Béral *et al.*, 2018).

Overall, the protection and diversity of microclimates offered by trees improve the well-being of ruminants, pigs, poultry and rabbits by providing shelter from adverse conditions and allowing them to express their natural behaviours (Dal Bosco *et al.*, 2014; Jakobsen, 2018; Savietto, 2023) (Figure 3).

b. Impact of the presence of trees on animal health

The introduction of trees into grazing areas or animal feed could be an opportunity to reduce the medicinal inputs used on farms, particularly by helping to control internal parasitism. However, the therapeutic or harmful effects of tree elements on farm animals, under operating conditions, are still uncertain and require more in-depth research to provide farmers with better support.

Wooded rangelands encourage animals to explore a larger environment (Germain, 2014), which may help to limit their concentration and hence their parasitic reinfestation. In addition, certain chemical compounds present in tree leaves could help limit intestinal parasite populations in grasslands before they are ingested by livestock. On the other hand, the cooler, wetter microclimate generated by the trees (and by irrigation in the case of orchards) may benefit these parasites; data is still lacking on this subject.

Animals are likely to spontaneously consume certain plants as a form of self-medication, although this behaviour is highly dependent on their breed and history, and is still debated by the scientific community (Villalba *et al.*, 2014). For example, heavily parasitised goat kids start to eat *Pistachio lentisca*, which reduces infestation (Landau *et al.*, 2010). Furthermore, lambs infested with parasites increase their consumption of tannin-rich forage (Lisonbee *et al.*, 2009).

Indeed, the leaves, fruit, green wood and bark of trees can contain high levels of tannins (Novak *et al.*, 2020a), which are recognised for their anti-parasitic effect. Ingestion of tannin-rich fresh willow reduces infestation in lambs (Musonda *et al.*, 2009; Mupeyo *et al.*, 2011). Consumption by pigs of fruits rich in tannins and sesquiterpene lactones (chestnuts, walnuts, hazelnuts, acorns, etc.) improves their tolerance to nematodes and pathogenic bacteria (Hassan *et al.*, 2020).

However, the diversity of tannins, the molecules with which they associate and the environment in which the animals live make it impossible at this stage to draw any conclusion about the actual properties of the different tannins on health under rearing conditions. Some studies, for example, show the importance of combining tannins with low-protein rations, since tannins associated with proteins lose their effectiveness (Butter *et al.*, 2000) and inhibit protein assimilation. Conversely, a protein-rich ration could enable the animal to expel more parasites, reduce weight loss and limit reinfestation (Butter *et al.*, 2000).

Woody fodder can also play a role in the mineral nutrition of livestock. For example, leaves from fig, mulberry and lime trees contain 15 times more calcium than maize (Novak *et al.*, 2020a). To optimise the utilisation of these minerals, it is therefore possible to plant "medicinal hedges" at the edges of pastured areas or along the paths used by herds.

However, some trees may contain toxic molecules. The risks are low for ruminants, but seem significant for monogastric animals. These risks are still very poorly understood, as they depend on the ingested quantities, proportion in the ration, phenological stage of the leaves or fruits consumed, animal species, herd's habits, interactions between molecules and possible "cocktail" effects, etc.

Figure 3. ***Shropshire ewes enjoying the shade of a peach orchard during the scorching summer of 2022 (© Photo credit: L. Marie – FiBL France).***

c. Predation

Small farm animals (poultry, rabbits) are particularly prone to predation in the open, either from the air (birds of prey) or from the ground (foxes, martens, etc.) (Stahl *et al.*, 2002).

Hens can protect themselves from ground predation by perching in trees, although this behaviour depends on the breed and individual, as well as on how they are reared (amputation of wing feathers). The protection provided by trees against aerial predation is also of interest, even though some raptor species, such as the goshawk, are capable of hunting in the undergrowth (Bestman & Bikker-Ouwejan, 2020).

The presence of trees provides a feeling of security for poultry and rabbits, but is not sufficient on its own to guarantee protection against predation and animal theft, which remain major challenges for agroforestry systems (García de Jalón *et al.*, 2018a). Other protection systems, such as closed shelters for the night, electrified fencing and scaring systems, are therefore of essential importance (Knierim, 2006).

The layout of the tree cover could lead to changes in vigilance behaviour in relation to the risk of attack. Cattle would not lie down near a hedge, where wolves could hide, whereas they would allow themselves to rest in an isolated grove with good visibility (Kluever *et al.*, 2008) – a behaviour that sheep do not seem to adopt (Monier S., personal communication).

■ 2.2. Damage to trees

The association of animals with trees has a high potential for reciprocal benefits, but also comes with risks regarding the sustainability of the plantations. These depend on the animal species, stocking rate, duration of the animal presence, type of herd management, etc. The available literature on this topic mainly regards damage caused by wild ungulates or rodents, and cannot always be transposed to situations involving livestock.

Figure 4. ***Apple trees (Kermerrien/M7 variety) debarked by sheep (Merino x Mourérous) in the autumn of 2022 (© Photo credit: M. Trouillard – FiBL France).***

a. Browsing

The first type of damage that animals can cause to trees concerns browsing, i.e., the consumption of leaves and twigs. This action is not necessarily harmful, and may even be desirable when grazing fodder trees, in moorland, scrubland or woodland (pruning of low branches), provided that the terminal bud is inaccessible (Gill, 1992b).

In intensive fruit-growing areas, however, this leads to a loss of yield in the area accessible to animals, which is also the most easily accessible for harvesting. In winter, the damage caused by sheep grazing is generally acceptable (a few buds consumed), but after bud break, vegetation can be consumed up to a height of 1.60 m (SSBA, 2017; Conrad *et al.*, 2022), which is often considered prohibitive by farmers (AREFE, 2018). Some sheep breeds, such as Shropshire (Danish lineage) and Southdown, appear to be unable to stand on their hind legs, which could reduce the height at which damage occurs (Conrad *et al.*, 2022). Trees can be protected from browsing by electric wire or barbed wire, while the application of repellents appears to be effective in the short term against browsing by sheep (Guittonneau *et al.*, 2023a) but not so much against browsing by cattle (Novak *et al.*, 2020b).

Obviously, larger animals (cattle, horses) are likely to cause browsing damage up to greater heights, not to mention the risk of branches being torn due to rubbing. In such situations, only relatively old woodland and high-stem orchards will be suitable.

In viticulture, although the same type of problem arises, it is interesting to note that some farmers (mainly in New Zealand and Australia) use sheep to carry out targeted leaf removal in the cluster area, with no damage to the grapes if the timing is controlled (Emms, 2010). Shoot thinning (removal of non-fruiting shoots) by sheep may also be possible (Conrad *et al.*, 2022).

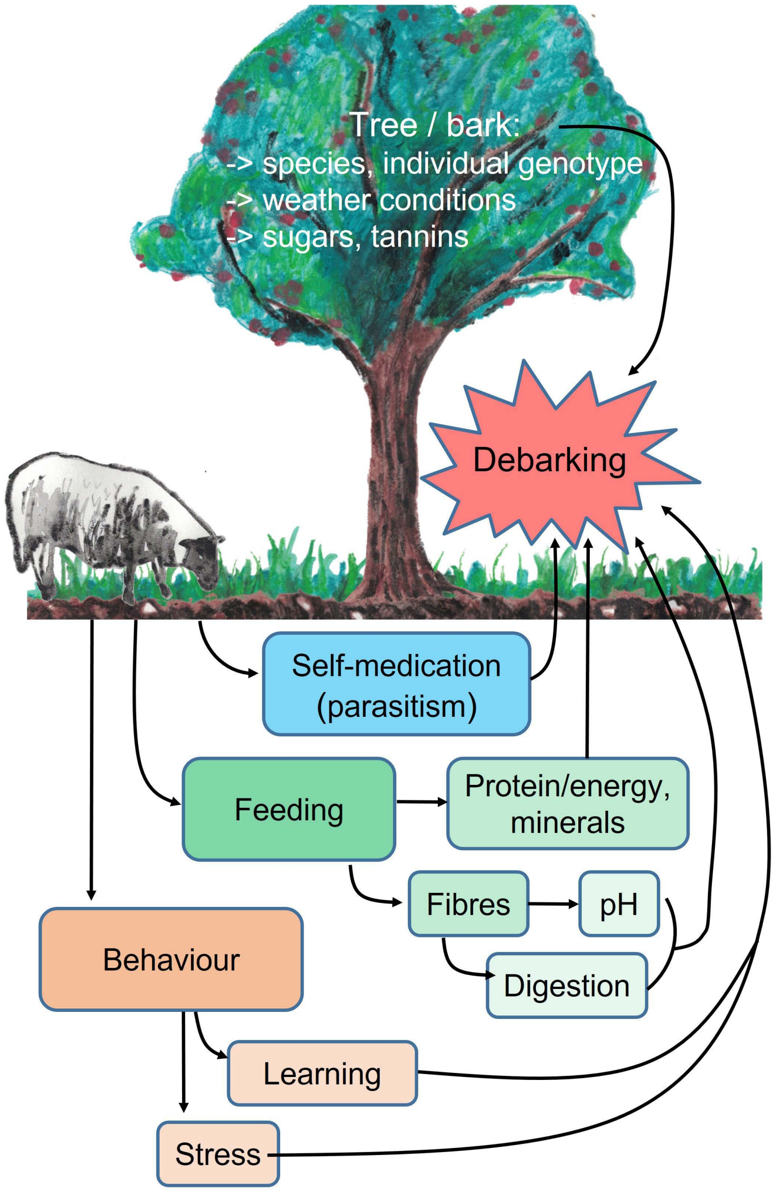
b. Debarking

Many animals are likely to consume or damage the bark of trees in their grazing paddocks, which can be prohibitive if the trees represent significant added value (orchards, valuable timber).

Sheep can debark apple trees massively and suddenly while grazing in orchards without previous incident (Figure 4). However, over several years of grazing, they appear to cause less cumulative damage than cattle or horses (López-Sánchez *et al.*, 2020). Rabbits, on the other hand, are generalists, capable of debarking young trees on a massive scale, particularly in winter, but with a preference for fruit trees (Gill, 1992a). Adequate tree protection using sleeves is an effective way of mitigating this risk (Savietto, 2023). Preliminary observations by FiBL France indicate that fattening pigs can cause significant damage by eating bark and roots, with a greater predilection for certain species (apple, apricot, cherry, plum, whitebeam), while others seem to be spared (maple, narrow-leaf ash, wayfaring tree, common spindle). Even among trees of the same species, the genotype of certain individuals has an impact on the probability of debarking (Guerreiro *et al.*, 2015).

For example, it has been observed that deer prefer to consume the bark of beech trees with the highest sugar content (Kurek *et al.*, 2019). Ruminants seem to increase their propensity to debark trees when their diet is deficient in fibre, minerals or protein (SSBA, 2017; Nicodemo & Porfírio-da-Silva, 2019). Furthermore, Keenan (1986) observed that the debarking of eucalyptus by horses seemed to be linked to the presence of irrigation on their pasture. Farmers' testimonies also point in the same direction, linking abundant rainfall and low fibre content in herbaceous forage to sheep debarking behaviour.

Figure 5. ***Multifactorial aspect of herbivore debarking behaviour (adapted from-Nicodemo & Porfírio-da-Silva, 2019).***



However, this factor was seen to be insufficient to provoke debarking behaviour among small groups of sheep grazing in apple orchards (Guittonneau *et al.*, 2023b).

Many other factors seem to have an influence on the triggering of this behaviour: tree and stocking density, herd management, social learning and collective dynamics within the herd, self-medication (see § 2.1.b), stress, boredom, etc. (Figure 5). The debarking behaviour should therefore probably be considered as the result of a set of concordant factors – the relative importance of which remains to be understood. These uncertainties make grazing in agroforestry potentially insecure for herd and plot managers.

However, cases of mass mortality in plantations following the introduction of livestock are still relatively rare, especially when compared with the damage caused by wild animals such as voles, rabbits and deer. Herd monitoring and management are crucial factors in limiting debarking to light or moderate damage, but these can nevertheless lead to a loss of tree performance if frequently repeated (López-Sánchez *et al.*, 2020). Studies are needed to document more precisely the impact of occasional debarking on tree physiology and productivity.

2.3 Specific features of grazing vines and orchards

a. Risks associated with plant protection products used in organic farming

When the tree component of the silvopastoral system is a high-added-value crop (e.g., vineyards, orchards), plant protection products are generally applied to the foliage. A wide variety of substances are used, and their effects on the health of humans, and *a fortiori* animals, are not always well known. Animals are thus potentially highly exposed to toxicity risks, particularly when they consume understory vegetation and/or soil components, or even tree leaves. Studies that assess pesticide toxicity are generally carried out on model animals (rats, dogs, etc.) and wild animals (fish, insect pollinators, etc.), but there is very little data on farm animals, and toxicity thresholds vary significantly from one species to another.

Organic farming makes extensive use of copper-based fungicides/bactericides, especially in viticulture and arboriculture (Andrivon *et al.*, 2019; Lamichhane *et al.*, 2018). Copper is well tolerated by many animals, even promoting growth in pigs, poultry and rabbits. However, even a relatively small amount of copper ingested over several months can be lethal to cattle and sheep (National Research Council, 2005; Suttle, 2010). In sheep, copper is mainly accumulated in the liver, from where it can be released suddenly into the bloodstream following a stressful event (change of diet or plot, parturition, etc.), causing the animal to die within a few days.

Winter grazing of vines and orchards by sheep can nevertheless be carried out without risk of intoxication if it occurs sufficiently late after the last copper spraying. Copper is then diluted by plant growth and washed away by rain, reducing its concentration to non-toxic levels within a few weeks (Trouillard *et al.*, 2021; Dufils *et al.*, 2022). The situations requiring particular monitoring are therefore those where grazing takes place quickly after the application of copper-based products: spring/summer for apple or walnut trees (Trouillard *et al.*, 2023), winter/spring for peach trees, winter in apple orchards that have undergone early defoliation with copper chelates – or when the consumption of vine leaves by sheep is deliberate (Emms, 2010). If necessary, the risk of intoxication can be estimated based on copper, molybdenum and sulphur levels (antagonists of copper absorption) in the plant cover (Trouillard *et al.*, 2021).

Phytopharmaceutical applications could occasionally produce beneficial "collateral effects" in veterinary medicine: for example, azadirachtin, used to treat infestations of various insects in organic orchards, might have an anti-parasitic effect on sheep gastro-intestinal strongyles (Iqbal *et al.*, 2010) and on swine mange (Pasipanodya *et al.*, 2021). It remains to be determined whether the doses ingested by the animals offer them any real health benefits.

The issue of pesticide residues in animal products intended for human consumption is complex, due to the diversity of substances used (Dasenaki *et al.*, 2023). Copper, on the other hand, accumulates very little in animal muscles, and humans are generally not affected by it at the encountered doses (Anses, 2012).

b. Orchard prophylaxis linked to grazing

While the main goal of integrating animals into arboriculture is weed management, it can also be a means of controlling pests and diseases (Paut *et al.*, 2021), particularly in the case of poultry. However, the integration of animals should be used as a preventive measure, not as a curative solution (Laget *et al.*, 2015). Animals can provide direct prophylaxis by predating pests, and indirect prophylaxis by making the environment unfavourable to their presence and development.

Direct prophylaxis mainly involves the ingestion of pests by animals: hens can predate on certain fruit crop pests such as the Japanese beetle (*Popillia japonica*) and the tarnished plant bug (*Lygus lineolaris*) (Clark & Gage, 1996). Animals can also consume pests or pathogens in or on fruits that have fallen to the ground (Lavigne *et al.*, 2012). Following the introduction of pigs into apple or pear orchards, almost all of the fallen fruits were consumed, thereby helping to control apple maggot (*Rhagoletis pomonella*) or reduce the inoculum of codling moth (*Cydia pomonella*) and oriental fruit moth (*Grapholita molesta*) (Nunn *et al.*, 2007; Buehrer & Grieshop, 2014).

In terms of indirect control, the presence of chickens in an orchard reduces the populations of aphid mutualist ants, which could limit the impact of aphids (Hilaire & Mathieu, 2000). The consumption of the herbaceous layer by herbivores exposes rodents (Wilson & Hardestry, 2006) and insects (Witt *et al.*, 1995; Clark & Gage, 1996) to their natural predators and to an unfavourable climate. Sheep trampling also appears to destroy the galleries and mounds of voles that consume fruit tree roots (Pype & Venineau-Delvalle, 2016), and could reduce the inoculum of apple scab (*Venturia inaequalis*) by degrading the litter, although this remains difficult to confirm (Dufils, 2017).

To characterise the prophylactic potential of the animal species to be introduced, it is essential to consider its feeding preferences, foraging behaviour (scratching the ground, browsing, grazing, etc.) and morphology. A balance must be found between the desired prophylactic effect and the risk of damaging the orchard, such as animals passing under low branches or causing soil compaction. Adaptations of the silvopastoralism management may be necessary (relocation of shelters, rotating pens) to synchronise the animal presence with the vulnerability stage of the targeted pest, in order to optimise prophylactic effectiveness.

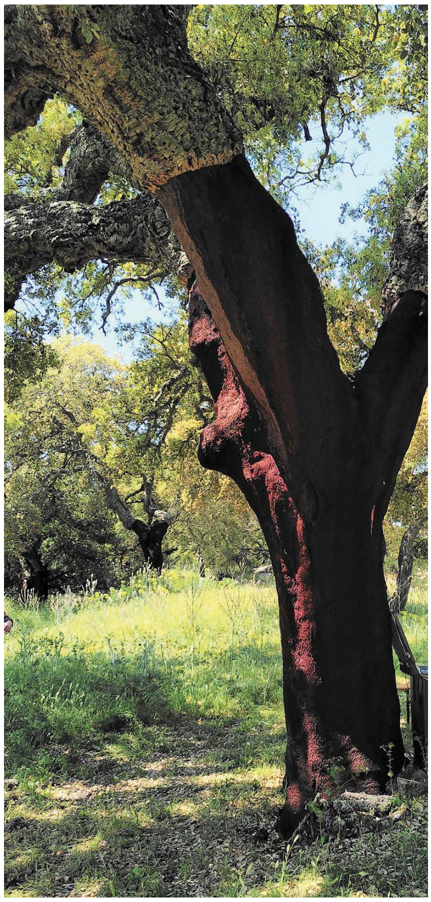
3. Agroforestry as a way of facing the economic and organisational challenges of livestock farming

3.1 Income diversification, but additional costs

In addition to providing ecosystem and agronomic services, the integration of a new production system on a farm offers new opportunities for income and savings. Tree cultivation can provide timber, wood fuel, fruit and other commodities (Figure 6), and livestock farming generates marketable animal products: eggs, meat and other co-products such as wool (Moreno *et al.*, 2018). Animal waste provides nutrients for crops (see § 1.1. e), which can make a significant contribution in a context of high volatility in the price of fertilisers. In addition, animals in vineyards and orchards are often used for branding purposes, potentially enhancing the economic value of products (Mohamed, 2015).

The diversification generated by the association of trees and animals becomes a source of economic resilience, since separate production types are impacted in different ways by climatic (late frost, drought) or economic hazards (variation in buying and selling

Figure 6. ***Economic utilisation of cork from* Quercus suber *in the silvopastoral landscapes of Sardinia, also contributing to their high cultural and heritage value (© Photo credit: M. Trouillard – FiBL France).***



prices) (Cubbage *et al.*, 2012). This effect is reinforced by the timing differences between productions (Smith *et al.*, 2022). Short-term valuation of livestock products can provide income while awaiting longer-term valuation of fruit or timber trees (Dupraz & Liagre, 2008; Smith *et al.*, 2022). Similarly, the seasonal income from the sale of fruit can, for example, complement the more regular income generated by egg production.

Complementarities between productions can express themselves in time but also in space: savings can be made thanks to the coexistence and synergies between simultaneous productions in a limited space, particularly in terms of cycle completion (Rocchi *et al.*, 2019). A third area of complementarity lies in the methods of economic valorisation in long or short distribution channels and/or self-consumption, etc. – potentially contributing to stabilising farm economics by enhancing their potential for subsistence production (Moreno *et al.*, 2018; Guittonneau & Pellissier, 2023).

However, setting up an additional production system is also costly (Paut *et al.*, 2021). Investments are needed to develop a livestock farm: fencing, buildings, treatment facilities, and possibly processing and packaging facilities for animal products. The tasks specific to livestock farming (monitoring, care, watering, feeding, etc.) and their cost are added to the expenses already incurred for vineyards or orchards, which can be difficult to manage for some farmers (Moreno *et al.*, 2018; Guittonneau & Pellissier, 2023).

Introducing trees in a livestock farm also involves some investment and regular costs to ensure their proper development: plant material, protective devices, fertilisation, irrigation, mulching, etc. (Béral *et al.*, 2014). The costs associated with harvesting operations (felling, cutting, transport) must also be factored into the planned economic model (Solagro, 2016).

In all cases, new knowledge and skills need to be acquired, and mistakes made through inexperience can affect the success of the farm and/or the economic value of the trees. A silvopastoral system, therefore, requires careful management, which may be resource-consuming, but has the potential to generate additional income if managed properly (Jose *et al.*, 2017; Pent, 2020).

3.2 Organisation and workload, regulations

Developing a silvopastoral system from a livestock farm does not fundamentally alter how the farm is organised. The presence of trees provides a certain amount of flexibility: mobilisation of tree fodder resources in the event of a shortage, and/or rapid cash flow from harvesting mature trees (Dupraz & Liagre, 2008). On the other hand, mechanisation (hay production, shredding of feed refusals) can become more tedious. Young trees need regular care (irrigation, weeding, etc.), which can be burdensome. From a regulatory point of view, the planting of vines can require administrative procedures for monitoring, and trees of the *Prunus* genus may be subject to control visits to check for the absence of plum pox virus. Obviously, the trees must be managed organically in order to enable the organic certification of the animals that graze therein.

When a livestock unit is developed on a fruit, wine or forestry farm, some aspects of work organisation can be facilitated: the timing of the introduction of animals into the plots is flexible, which is important for controlling bio-aggressors (see § 2.3.b), carry out a cultivation operation at a lower cost (e.g. de-budding and leaf removal by sheep, see § 2.2.a), or limit the height of the grass in anticipation of a spring frost. Animal waste provides manure and compost, which improves organic matter self-sufficiency (see § 1.1.e).

Farmers who practise this combination nevertheless mention additional organisational constraints: increased workload and complexity, and administrative management (García de Jalón *et al.*, 2018a). Peak workloads for fruit crops are difficult to reconcile with the time constraints inherent in livestock farming, and the presence of animals can be incompatible with work on perennial crops (phytosanitary treatments, presence of employees, farm machinery, etc.), leading to livestock movements and/or the use of fallback plots (Moraine *et al.*, 2012). These may also be justified in terms of forage resource management (Dufils, 2017) or preservation of the herbaceous layer from soil-disturbing animals such as hens (Bosshardt *et al.*, 2022) or pigs.

The establishment of local partnerships between livestock farmers and tree growers (see § 3.3) makes it possible to retain some of the services provided by the animals in the plots (Moraine *et al.*, 2012), without requiring a radical reorganisation of the way the farm operates. The success of such an association depends on the willingness of the parties involved to work together and to make the necessary mutual adjustments, especially in terms of timing.

Silvopastoralism has several specific regulatory aspects, which are often not addressed in current legislation: common agricultural policy (CAP) declaration in the event of mixed land use, required waiting period after the application of a plant protection products, animal exclusion time before harvesting, biosafety rules requiring the creation of a specific fence in a grazed vineyard or orchard, etc. (Riffard & Liagre, 2023). Regulatory loopholes can sometimes give farmers flexibility, but they can also represent bottlenecks or areas of concern if a problem arises. The French example shows that a text such as the "Guidelines for good hygiene practice [...] in fresh fruit productions", mentioning that "as far as possible, [animals] should be kept away from crops", may potentially be legally enforceable since it has been published in the *Journal officiel* (official journal) (CTIFL, 2012).

According to the EU regulations, organic farming allows non-organic animals to graze on labelled land for up to four months a year. The reciprocal (grazing of organically labelled animals on non-organic plots) is not possible, even if the grazed plot has trees. Forest and agroforestry trees are exempt from organic certification as long as they "do not produce marketable agricultural products" (INAO, 2023), which raises questions if their aim is to be primarily used as fodder.

■ 3.3. Integration into the local environment and heritage

At the beginning of the 20th century, farming was still based on a close, synergistic relationship between plants and animals (Mazoyer & Roudart, 2017), but the movement towards agricultural "modernisation" (mechanisation and "chemicalisation") has led to a dissociation between these two worlds. This division between animal and plant productions now structures both space, which is divided into specialised production "basins", and sectors.

The territorial scale seems both relevant and promising for reconnecting these two worlds (Moraine *et al.*, 2016; Napoleone *et al.*, 2022). Several recent or ongoing research-action projects, in France and elsewhere, bear witness to this renewed interest in practices that are often traditional but threatened with decline: for example, the complementarity between olive trees, vines and sheep in Mediterranean areas (Mohamed, 2015) or grazing in walnut groves bordering mountainous summer pasture areas.

In these cases, a form of temporary association between a livestock farmer and one or more tree growers is developed to generate territorial synergies. Although this type of association requires a great deal of coordination between the parties involved, it is generally formalised by a simple oral agreement. A number of recent projects have proposed workshops and/or documents for reaching an agreement, promoting understanding between livestock farmers and growers and anticipating possible conflicts, while maintaining the spontaneous nature of their collaboration (Lyazid *et al.*, 2021). From an operational point of view, online tools have recently been developed in France to connect local stakeholders.[2]

2 For example, the "Who wants my grass?" https://gard.chambre-agriculture.fr/productions-techniques/elevage/repertoire-pastoral-des-costieres/ or https://www.echange-cerealier-eleveur.fr/

Livestock farming creates and maintains social and agronomic links on a regional scale. Herd movements generate organic matter in areas where livestock farming is scarce, reducing their dependence on external fertilisers and their ecological footprint. Exchanges between lowland and upland areas can help to make livestock farms more self-sufficient in forage (Napoleone *et al.,* 2022), and (re-) use land that has been abandoned. In some cases, the grazing of wooded areas has enabled "landless" or "herbage-only" sheep farmers to set up in business, thereby contributing to the establishment of farmers with no family farming history. Fruit, wine and cereal producers in a given region may agree to offer a grazing area large enough to justify the relocation of a livestock farmer.

Reintroducing animals into an area of a specialised crop changes the visual, acoustic and olfactory environment of farming. The presence of farm machinery is reduced, but new potential nuisances may arise: noise from animals, smell of droppings, risk of animals escaping, etc. The introduction of trees into landscapes that are more or less devoid of them (intensive agricultural plains, but also mountain pastures and extensive pastures without hedgerows) has a generally positive impact on the quality of life of residents (García de Jalón *et al.*, 2018a; Elbakidze *et al.*, 2021). Tree planting patterns can break up the monotony of landscapes by adopting circular layouts or following contour lines (Dupraz & Liagre, 2008; Giambastiani *et al.*, 2023), especially if the main agricultural activity is livestock rearing with little or no mechanisation.

Areas with an agroforestry tradition (*bocage*, meadow orchard, *dehesa*, *montado*, *streuobst*, etc.) tend to claim this aspect of their landscape as a valuable cultural feature, and to promote it as part of their heritage and tourism (Moreno *et al.*, 2018), as well as a brand image for agricultural products (see § 3.1). The multifunctionality of agroforestry (Veldkamp *et al.*, 2023) is thus fully revealed at this scale of the territory, producing positive economic spin-offs for farmers, but also an ecological and landscape network which can lead to the definition of a local cultural identity (Jeanneret *et al.*, 2021).

Conclusion and challenges for research

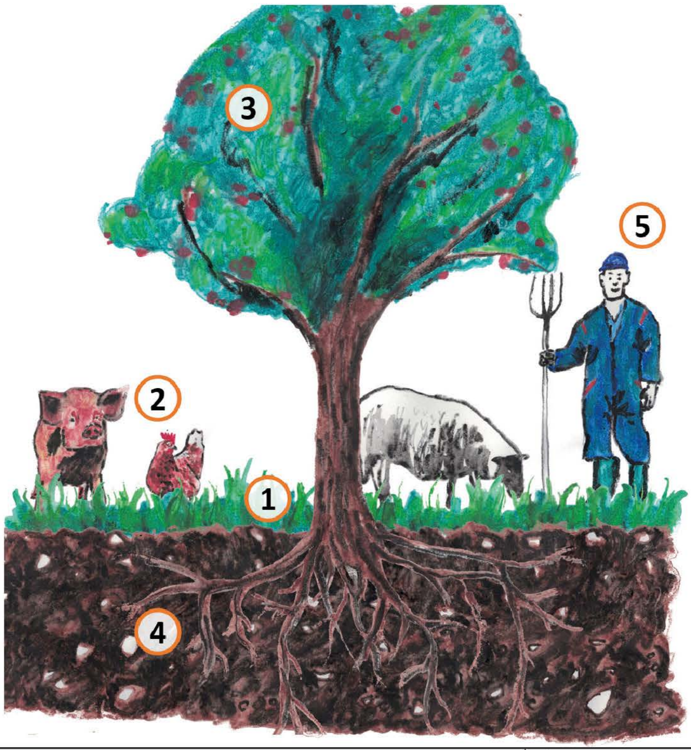
Organic livestock farming still faces many challenges, and agroforestry has the potential to meet a number of them. Silvopastoral systems can make farms more resilient by providing fodder resources that are less affected by climatic hazards, and by diversifying the sources of income. Herbivores can consume the plant cover in specialised orchards and fertilise their soil. Trees can provide shelter and a medicinal resource for the animals, which in turn can help to control pests and diseases of perennial crops. All these potential synergies between animals and trees mean that agroforestry strongly aligns with the principles of organic farming: health, ecology, equity and precaution.

There are, however, some limitations to these benefits, which pose new challenges: for instance, animals can damage high-value trees or be poisoned by plant protection products; the carbon storage potential of agroforestry applied to permanent grassland is low; agroforestry livestock farming can be difficult to manage, as well as time- and money-consuming.

These different aspects of agroforestry in livestock farming, discussed throughout this article, are summarised in Figure 7.

Like organic farming, agroforestry is about balancing agronomic performance with biodiversity preservation or enhancement, farmers' income, social connections, etc. It requires fine-tuning of a complex system to position the agroecosystem on a series of productive and environmental optimums. This involves intensive management of the interactions between the elements of the system, a potential mental workload increase, as well as a time and financial

Figure 7. *Elements of silvopastoral systems involving interactions between animals, trees, vegetation cover, soil, and humans (Adapted from Smith* et al.*, 2022); synergies and limitations of the association of livestock with trees.*



no.	Element	Benefits/advantages	Constraints/disadvantages
1	Ground cover	Extension of the productive season Conservation of forage quality and quantity	Reduction in legume plants Alteration of the herbaceous layer (chickens, pigs)
2	Animals	Protection against heat stress, rain, wind, etc. Forage from fodder trees, valorisation of fallen fruits Decrease in predation Extension of the explored grazing area, facilitation of natural behaviour expression Prophylaxis against parasitic and bacterial infestations, self-medication	Risks associated with plant protection products applied to the trees Increased survival of gastrointestinal parasites (protection by the shade of trees and irrigation)?
3	Trees	Fertilisation with animal manure Prophylaxis against vole, scab, codling moth, etc.	Potential over-fertilisation (poultry, pigs) Debarking, browsing
4	Soil and ecosystem	Improvement of nutrient cycling Better water infiltration when trees are present, reduced nutrient leaching Increased biodiversity through habitat diversification Carbon storage (especially in silvoarable systems)	Risk of compaction (reversible) Possible decline in biodiversity in the event of overgrazing or environment closure Little additional carbon storage compared with natural grasslands
5	Humans	Economic diversification and income stabilisation Improved fodder and organic matter autonomy; organisational flexibility Social links between farmers, livestock breeders, consumers, brand image enhancement Aesthetic and cultural value Feeling of comfort, meaningfulness and motivation at work	Need for training and investment Regular presence and supervision, specific needs for each workshop Nuisance caused by the presence of animals (smell, noise…) Mechanization impaired by the presence of trees

investment in the design of the system and in the acquisition of equipment and skills. Specific constraints linked to legislation and social acceptance also need to be taken into account.

Scientific research has a role to play in generating new knowledge in this field, contributing to the development of tools that support the design of silvopastoral systems, helping to inform the decision-making, and facilitating the training of farmers and agroforestry advisers. We believe that the priority tracks for research are:

i) understanding mechanisms and identifying threshold effects, beyond which synergies are effective or, on the contrary, disservices appear;

ii) economic profitability of agroforestry, a major driving force behind its development;

iii) relationships between agroforestry stakeholders, in the territories and within society as a whole.

Organic agriculture is guided by strong principles and backed by a very positive brand image, but it has so far only partially succeeded in abolishing the separation between animal and plant production that has prevailed since the second half of the 20th century. Agroforestry can be a part of this reconnection, since it is highly relevant from an agronomic point of view but also bears an emotional, "philosophical" or even spiritual dimension for farmers (Foyer *et al.*, 2020). Until recently, livestock farming was always envisioned and practised in landscapes that included trees, and organic farming cannot afford to ignore such precious allies.

Authors' contributions

Co-ordination, M.T.; Conceptualisation, M.T., F.D.; Fund acquisition, M.T., A.D., B.D., F.D., G.M. and S.B.; Writing – original version, M.T., G.M., M.T., G.M., A.D., B.D., F.D. and S.B.; Writing – revision and editing, M.T., S.B., A.D., F.D. and G.M.; Design, layout and adaptation of figures: M.T. Revision and editing of the English version: M.T., G.M. All authors have read and approved the published version of the manuscript.

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Références

Andrivon, D., Bardin, M., Bertrand, C., Brun, L., Daire, X., Fabre, F., Gary, C., Montarry, J., Nicot, P.- C., Reignault, P., Tamm, L., & Savini, I. (2019). *Peut-on se passer du cuivre en protection des cultures biologiques ?* Éditions Quæ. https://hal.inrae.fr/hal-02791366

Anses (2012). *Avis de l'Anses relatif à « la contamination d'agneaux par du cuivre : éventuelles répercussions sur la qualité sanitaire des viandes et abats qui en sont issus »*, Saisine n° 2012-SA-0270. https://www.anses.fr/fr/system/files/ERCA2012sa0270.pdf

AREFE (2018). *Arbre et élevage : La pratique du pré-verger en Lorraine*. https://arbele.projet-agroforesterie.net/documents/presentations/ARBELEArbreetelevagelapartiquedupre-vergerenLorraine.pdf

Beillouin, D., Ben-Ari, T., Malezieux, E., Seufert, V., & Makowski, D. (2021). Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Global Change Biology, 27*(19), 4697-4710. https://doi.org/10.1111/gcb.15747

Béral, C., Andueza, D., Ginane, C., Bernard, M., Liagre, F., Girardin, N., … Rocher, A. (2018). PARASOL : Agroforesterie en système d'élevage ovin – étude de son potentiel dans le cadre de l'adaptation au changement climatique. http://www.parasol.projet-agroforesterie.net

Béral, C., Guillet, P., & Brun, V. (2014). *Aménagements arborés des parcours de volailles - Guide technique.* https://www.itavi.asso.fr/publications/guide-technique-amenagement-arbores-des-parcours-de-volailles

Béral, C., & Moreau, J. C. (2020). La présence d'arbres intraparcellaires affecte-elle la productivité des prairies permanentes en climat tempéré ? *Fourrages*, *242*, 9-18. https://afpf-asso.fr/revue/fourrages-et-agroforesteries?a=2248

Bernard, M., Ginane, C., Deiss, V., Emile, J. C., & Novak, S. (2020). Ingestion volontaire et digestibilité in vivo de feuilles de deux essences d'arbres, le frêne commun (*Fraxinus excelsior*) et le mûrier blanc (*Morus alba*). *Fourrages*, *242*, 55-59. https://afpf-asso.fr/revue/fourrages-et-agroforesteries?a=2254

Bestman, M., & Bikker-Ouwejan, J. (2020). Predation in organic and free-range egg production. *Animals*, *10*(2), 177. https://doi.org/10.3390/ani10020177

Beule, L., Vaupel, A., & Moran-Rodas, V. E. (2022). Abundance, diversity, and function of soil microorganisms in temperate alley-cropping agroforestry systems: A review. *Microorganisms*, *10*(3), 616. https://doi.org/10.3390/microorganisms10030616

Boch, S., Bedolla, A., Ecker, K. T., Ginzler, C., Graf, U., Küchler, H., … Bergamini, A. (2019). Threatened and specialist species suffer from increased wood cover and productivity in Swiss steppes. *Flora*, *258*, 151444. https://doi.org/10.1016/j.flora.2019.151444

Bosshardt, S., Sabatier, R., Dufils, A., & Navarrete, M. (2022). Changing perspectives on chicken-pastured orchards for action: A review based on a heuristic model. *Agricultural Systems*, *196*, 103335. https://doi.org/10.1016/j.agsy.2021.103335

Boyer, C. (2022). *Résultats d'essai sur le pâturage de mûriers blancs au Pradel.* JPO, Le Pradel. https://idele.fr/cappradel/?eID=cmis_download&oID=workspace://SpacesStore/18876ed8-1cea-489c-a190-78ae28f0ebc4&cHash=1263981ee4bca9b6295dc17d5408be21

Brewer, K., & Gaudin, A. (2020). Potential of crop-livestock integration to enhance carbon sequestration and agroecosystem functioning in semi-arid croplands. *Soil Biology and Biochemistry, 149*, *107936*. https://doi.org/10.1016/j.soilbio.2020.107936

Brewer, K., Muñoz-Araya, M., Martinez, I., Marshall, K., Tiffany, S., & Gaudin, A. (2022). *Carbon sequestration and soil health outcomes in California integrated sheep-vineyard systems*. Davies: UC. https://fibershed.org/wp-content/uploads/2022/06/ISVS-survey_findings_2022.pdf

Buehrer, K. A., & Grieshop, M. J. (2014). Postharvest grazing of hogs in organic fruit orchards for weed, fruit, and insect pest management. *Organic Agriculture, 4*(3), 223-232. https://doi.org/10.1007/s13165-014-0076-0

Butter, N., Dawson, J., Wakelin, D., & Buttery, P. (2000). Effect of dietary tannin and protein concentration on nematode infection (*Trichostrongylus colubriformis*) in lambs. *The Journal of Agricultural Science, 134*(1), 89-99. https://doi.org/10.1017/S0021859699007315

Clark, M. S., & Gage, S. H. (1996). Effects of free-range chickens and geese on insect pests and weeds in an agroecosystem. *American Journal of Alternative Agriculture*, *11*(1), 39 – 47. https://doi.org/10.1017/S0889189300006718

Conrad, L., Hörl, J., Henke, M., Luick, R., & Schoof, N. (2022). Sheep in the vineyard: suitability of different breeds and potential breeding objectives. *Animals, 12*(19), 2575. https://doi.org/10.3390/ani12192575

Contosta, A. R., Asbjornsen, H., Orefice, J., Perry, A., & Smith, R. G. (2022). Climate consequences of temperate forest conversion to open pasture or silvopasture.

Agriculture *Ecosystems & Environment, 333*, 107972. https://doi.org/10.1016/j.agee.2022.107972

CTIFL (2012). *Guide des bonnes pratiques d'hygiène HACCP pour les fruits et légumes frais non transformés*. https://www.ctifl.fr/gbph-fruits-et-legumes-frais-non-transformes

Cubbage, F., Balmelli, G., Bussoni, A., Noellemeyer, E., Pachas, A. N., Fassola, H., Colcombet, L., Rossner, B., Frey, G., Dube, F., de Silva M.- L., Stevenson, H., Hamilton J., & Hubbard, W. (2012). Comparing silvopastoral systems and prospects in eight regions of the world. *Agroforestry Systems, 86*, 303-314. https://doi.org/10.1007/s10457-012-9482-z

Cubillos, A. M., Vallejo, V. E., Arbeli, Z., Terán, W., Dick, R. P., Molina, C. H., Molina, E., Roldan, F. (2016). Effect of the conversion of conventional pasture to intensive silvopastoral systems on edaphic bacterial and ammonia oxidizer communities in Colombia. *European Journal of Soil Biology, 72*, 42-50. https://doi.org/10.1016/j.ejsobi.2015.12.003

Dal Bosco, A., Rosati, A., Paoletti, A., Caporali, S., & Castellini, C. (2014). Effect of range enrichment on performance, behavior, and forage intake of free-range chickens. *Journal of Applied Poultry Research, 23*(2), 137-145. https://doi.org/10.3382/japr.2013-00814

Dasenaki, M. E., Kritikou, A. S., & Thomaidis, N. S. (2023). Meat safety: II Residues and contaminants. *Lawrie's Meat Science*, 2023, 591-626. https://doi.org/10.1016/B978-0-323-85408-5.00007-8

De Stefano, A., & Jacobson, M. G. (2018). Soil carbon sequestration in agroforestry systems: a meta-analysis. *Agroforestry Systems, 92*, 285-299. https://doi.org/10.1007/s10457-017-0147-9

DeBruyne, S. A., Feldhake, C. M., Burger, J. A., & Fike, J. H. (2011). Tree effects on forage growth and soil water in an Appalachian silvopasture. *Agroforestry Systems, 83*(2), 189-200. https://doi.org/10.1007/s10457-011-9376-5

Dufils, A. (2017). Associer arbres fruitiers et élevage ovin, une pratique ouverte au plus grand nombre. *Arboriculture Fruitière, 715*, 17-20. https://hal.inrae.fr/hal-02618739

Dufils, A., Trouillard, M., & Bérud, M. (2022). *Le pâturage ovin en verger et le risque cuivre : Expérimentations et recommandations* – Fiche technique du projet DéPASSE n° 2. https://hal.inrae.fr/hal-03986703

Dupraz, C., & Liagre, F. (2008). *Agroforesterie : des arbres et des cultures*. Paris : France Agricole Editions.

Elbakidze, M., Surová, D., Muñoz-Rojas, J., Persson, J.-O., Dawson, L., Plieninger, T., & Pinto-Correia, T. (2021). Perceived benefits from agroforestry landscapes across North-Eastern Europe : What matters and for whom? *Landscape and Urban Planning, 209*, 104044. https://doi.org/10.1016/j.landurbplan.2021.104044

Emms, C. (2010). A guide to using sheep for leaf-plucking in the vineyard. https://www.premier1supplies.com/img/newsletter/09-05-13-sheep/sheep-for-leaf-plucking-booklet.pdf

Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., … Yadav, D. K. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability, 14*(22), 14877. https://doi.org/10.3390/su142214877

Ferreira, I. Q., Arrobas, M., Claro, A. M., & Rodrigues, M. (2013). Soil management in rainfed olive orchards may result in conflicting effects on olive production and soil fertility. *Spanish Journal of Agricultural Research, 11*(2), 472-480. https://doi.org/10.5424/sjar/2013112-3501

Ferreiro-Domínguez, N., Rigueiro-Rodríguez, A., Rial-Lovera, K., Romero-Franco, R., & Mosquera-Losada, M. (2016). Effect of grazing on carbon sequestration and tree growth that is developed in a silvopastoral system under wild cherry (Prunus avium L.). *Catena, 142*, 11-20. https://doi.org/10.1016/j.catena.2016.02.002

Foyer, J., Hermesse, J., & Hecquet, C. (2020). Quand les actes agricoles sont au care et au compagnonnage : L'exemple de la biodynamie. *Anthropologica, 62*(1), 93-104. https://doi.org/10.3138/anth.2018-0103.r1

García de Jalón, S., Burgess, P. J., Graves, A., Moreno, G., McAdam, J., Pottier, E., … Vityi, A. (2018a). How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. *Agroforestry Systems, 92*(4), 829-848. https://doi.org/10.1007/s10457-017-0116-3

García de Jalón, S., Graves, A., Moreno, G., Palma, J. H., Crous-Durán, J., Kay, S., & Burgess, P. J. (2018b). Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability. *Ecological Modelling, 372*, 24-32. https://doi.org/10.1016/j.ecolmodel.2018.01.017

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., … Tempio, G. (2013). *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities.* Food and Agriculture Organization of the United Nations (FAO), https://openknowledge.fao.org/server/api/core/bitstreams/e1afd815-5a76-4b88-beac-fb9bc0e92001/content

Germain, K. (2014). Conduite de productions animales dans des couverts complexes. Production de volailles biologiques en parcours prairiaux et arborés. *Innovations Agronomiques, 40*, 125-132. https://doi.org/10.17180/sb3y-sd91

Giambastiani, Y., Biancofiore, G., Mancini, M., Di Giorgio, A., Giusti, R., Cecchi, S., … Errico, A. (2023). Modelling the effect of keyline practice on soil erosion control. *Land, 12*(1), 100. https://doi.org/10.3390/land12010100

Gill, R. (1992a). A review of damage by mammals in north temperate forests. 2. Small mammals. *Forestry: An International Journal of Forest Research, 65*(3), 281-308. https://doi.org/10.1093/forestry/65.3.281

Gill, R. (1992b). A review of damage by mammals in north temperate forests: 1. Deer. *Forestry: An International Journal of Forest Research, 65*(2), 145-169. https://doi.org/10.1093/forestry/65.2.145

Guerreiro, M. F., Nicodemo, M. L. F., & Porfírio-da-Silva, V. (2015). Vulnerability of ten eucalyptus varieties to predation by cattle in a silvopastoral system. *Agroforestry Systems, 89*, 743-749. https://doi.org/10.1007/s10457-015-9797-7

Guittonneau, M., & Pellissier, P. (2023). Pâturage ovin en vergers : Cahier technico-économique. Fiche technique ECORCE n° 1, FiBL France. https://doi.org/10.5281/zenodo.10364819

Guittonneau, M., Marie, L., Rivoire, C., & Trouillard, M. (2023a). Pâturage ovin en vergers : Abroutissement des arbres fruitiers. Fiche technique ECORCE n° 3, FiBL France. https://doi.org/10.5281/zenodo.10364183

Guittonneau, M., Rivoire, C., & Trouillard, M. (2023b). Pâturage ovin en vergers : Écorçage des arbres fruitiers. Fiche technique ECORCE n° 2, FiBL France. https://doi.org/10.5281/zenodo.10301158

Hassan, Z. M., Manyelo, T. G., Selaledi, L., & Mabelebele, M. (2020). The effects of tannins in monogastric animals with special reference to alternative feed ingredients. *Molecules, 25*(20), 4680. https://doi.org/10.3390/molecules25204680

Hilaire, C., & Mathieu, V. (2000). Le poulet label, un auxiliaire sélectif. *Infos-CTIFL, 170.*

Hilimire, K., Gliessman, S. R., & Muramoto, J. (2013). Soil fertility and crop growth under poultry/crop integration. *Renewable Agriculture and Food Systems, 28*(2), 173-182. https://doi.org/10.1017/S174217051200021X

IFOAM (2005). Principles of Organic Agriculture. https://www.ifoam.bio/sites/default/files/2020-03/poa_english_web.pdf.

INAO (2023). Note de lecture : Matériel de Reproduction Végétal en AB (novembre 2023). https://extranet.inao.gouv.fr/fichier/Note-GL-2023-MRV.pdf

Iqbal, Z., Lateef, M., Jabbar, A., & Gilani, A. (2010). In vivo anthelmintic activity of Azadirachta indica A. Juss seeds against gastrointestinal nematodes of sheep. *Veterinary parasitology, 168*(3-4), 342-345. https://doi.org/10.1016/j.vetpar.2009.11.005

Jakobsen, M. (2018). Integrating foraging and agroforestry into organic pig production-environmental and animal benefits [PhD Thesis, Aarhus University]. Retrieved from https://orgprints.org/id/eprint/33776/7/Endelig%20afhandling_tryk_Malene_Jakobsen_20111406%20(002)X.pdf

Jakobsen, M., Hermansen, J. E., Andersen, H. M.-L., Jørgensen, U., Labouriau, R., Rasmussen, J., & Kongsted, A. G. (2019). Elimination behavior and soil mineral nitrogen load in an organic system with lactating sows–comparing pasture-based systems with and without access to poplar (Populus sp.) trees. *Agroecology and Sustainable Food Systems, 43*(6), 639-661. https://doi.org/10.1080/21683565.2018.1541039

Jeanneret, P., Aviron, S., Alignier, A., Lavigne, C., Helfenstein, J., Herzog, F., …Petit, S. (2021).

Agroecology landscapes. *Landscape Ecology, 36*(8), 2235-2257. https://doi.org/10.1007/s10980-021-01248-0

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems, 76*, 1-10. https://doi.org/10.1007/s10457-009-9229-7

Jose, S., & Dollinger, J. (2019). Silvopasture: a sustainable livestock production system. *Agroforestry Systems, 93*, 1-9. https://doi.org/10.1007/s10457-019-00366-8

Jose, S., Walter, D., & Mohan Kumar, B. (2017). Ecological considerations in sustainable silvopasture design and management. *Agroforestry Systems, 93*, 317-331. https://doi.org/10.1007/s10457-016-0065-2

Jurjanz, S., Germain, K., Juin, H., & Jondreville, C. (2015). Plant and soil intake by organic broilers reared in tree-or grass-covered plots as determined by means of n-alkanes and of acid-insoluble ash. *Animal, 9*(5), 888-898. https://doi.org/10.1017/S1751731114002870

Kallenbach, R. L., Kerley, M. S., & Bishop-Hurley, G. J. (2006). Cumulative Forage Production, Forage Quality and Livestock Performance from an Annual Ryegrass and Cereal Rye Mixture in a Pine Walnut Silvopasture. *Agroforestry Systems, 66*(1), 43-53. https://doi.org/10.1007/s10457-005-6640-6

Karki, U., & Goodman, M. S. (2015). Microclimatic differences between mature loblolly-pine silvopasture and open-pasture. *Agroforestry Systems, 89*, 319-325. https://doi.org/10.1007/s10457-014-9768-4

Keenan, D. (1986). Bark chewing by horses grazed on irrigated pasture. *Australian Veterinary Journal, 63*(7), 234-235. https://doi.org/10.1111/j.1751-0813.1986.tb03008.x

Kluever, B. M., Breck, S. W., Howery, L. D., Krausman, P. R., & Bergman, D. L. (2008). Vigilance in cattle: the influence of predation, social interactions, and environmental factors. *Rangeland Ecology & Management, 61*(3), 321-328. https://doi.org/10.2111/07-087.1

Knierim, U. (2006). Animal welfare aspects of outdoor runs for laying hens: a review. *NJAS – Wageningen Journal of Life Sciences, 54*(2), 133-145. https://doi.org/10.1016/S1573-5214(06)80017-5

Kongsted, A. G. (Director). (2022). Animal welfare, environmental and climate impact of organic pig-willow silvopastoral [mixed webinar]. Denmark: Aarhus University. Retrieved from https://www.youtube.com/watch?app=desktop&v=03_Wr6RraLE

Kurek, T., Todys, J., Pazdrowski, W., Szymański, M., & Łukowski, A. (2019). Intensity of stripping and sugar content in the bark and the bast of European beech *(Fagus sylvatica)*. *Open life sciences, 14*(1), 19-28. https://doi.org/10.1515/biol-2019-0003

Laget, E., Guadagnini, M., Plénet, D., Simon, S., Assie, G., Billotte, B., … Zavagli, F. (2015). *Guide Ecophyto Fruits - Guide pour la conception de systèmes de production fruitière économes en produits phytopharmaceutiques*. GIS Fruits et ministère de l'Agriculture, https://www.gis-fruits.org/media/files/guide-ecophyto-fruits/guide-ecophyto-fruits-guide-methodologique-ld

Lamichhane, J. R., Osdaghi, E., Behlau, F., Köhl, J., Jones, J. B., & Aubertot, J.-N. (2018). Thirteen decades of antimicrobial copper compounds applied in agriculture. A review. *Agronomy for Sustainable Development, 38*(3), 28. https://doi.org/10.1007/s13593-018-0503-9

Landau, S., Azaizeh, H., Muklada, H., Glasser, T., Ungar, E., Baram, H., … Markovics, A. (2010). Anthelmintic activity of Pistacia lentiscus foliage in two Middle Eastern breeds of goats differing in their propensity to consume tannin-rich browse. *Veterinary parasitology, 173*(3-4), 280-286. https://doi.org/10.1016/j.vetpar.2010.07.006

Lavigne, A., Dumbardon-Martial, E., & Lavigne, C. (2012). Les volailles pour un contrôle biologique des adventices dans les vergers. *Fruits, 67*(5), 341-351. https://doi.org/10.1051/fruits/2012029

Lazcano, C., Gonzalez-Maldonado, N., Yao, E. H., Wong, C. T., Merrilees, J. J., Falcone, M., … Decock, C. (2022). Sheep grazing as a strategy to manage cover crops in Mediterranean vineyards: Short-term effects on soil C, N and greenhouse gas (N_2O, CH_4, CO2) emissions. *Agriculture ecosystems & environment, 327*, 107825. https://doi.org/10.1016/j.agee.2021.107825

Lebret, B. (2008). Effects of feeding and rearing systems on growth, carcass composition and meat quality in pigs. *Animal, 2*(10), 1548-1558. https://doi.org/10.1017/S1751731108002796

Lisonbee, L. D., Villalba, J. J., Provenza, F. D., & Hall, J. O. (2009). Tannins and self-medication: Implications for sustainable parasite control in herbivores. *Behavioural Processes, 82*(2), 184-189. https://doi.org/10.1016/j.beproc.2009.06.009

López-Sánchez, A., Perea, R., Roig, S., Isselstein, J., & Schmitz, A. (2020). Challenges on the conservation of traditional orchards: Tree damage as an indicator of sustainable grazing. *Journal of environmental management, 257*, 110010. https://doi.org/10.1016/j.jenvman.2019.110010

Lyazid, N., Boisvert, B., Ducourtieux, C., Jousseins, C., & Tyssandier, P. (2021). *Un équilibre gagnant/gagnant autour du pâturage ovin en vergers, vignes, céréales*. Chambre d'agriculture de Dordogne, https://www.inn-ovin.fr/wp-content/uploads/2021/06/Guide_Partenariat_eleveurs_exploitants_2021.pdf

Marsden, C., Martin-Chave, A., Cortet, J., Hedde, M., & Capowiez, Y. (2020). How agroforestry systems influence soil fauna and their functions-a review. *Plant and Soil, 453*, 29-44. https://doi.org/10.1007/s11104-019-04322-4

Maupertuis, F., & Desaint, B. (2023). Valorisation parcours et fourrages (SECALIBIO, ECOFEED, VALORAGE) en élevage porcin. https://www.pays-de-la-loire.chambres-agriculture.fr/fileadmin/user_upload/Pays_de_la_Loire/022_Inst-Pays-de-la-loire/RUBR-RD-innovation/Agriculture-biologique/Evenements/2023/2023_JR_7_ans_recherche_AB_Atelier_Monogastriques_Presentation_1_valorisation_parcours_porcs.pdf

Mayer, S., Wiesmeier, M., Sakamoto, E., Hübner, R., Cardinael, R., Kühnel, A., & Kögel-Knabner, I. (2022). Soil organic carbon sequestration in temperate agroforestry systems – A meta-analysis. *Agriculture Ecosystems & Environment, 323*, 107689. https://doi.org/10.1016/j.agee.2021.107689

Mazoyer, M., & Roudart, L. (2017). *Histoire des agricultures du monde. Du néolithique à la crise contemporaine*. Paris : Éditions du Seuil. https://hal.inrae.fr/hal-02826757

Mcadam, J., Sibbald, A., Teklehaimanot, Z., & Eason, W. R. (2007). Developing silvopastoral systems and their effects on diversity of fauna. *Agroforestry Systems, 70*, 81-89. https://doi.org/10.1007/s10457-007-9047-8

Mesbahi, G., & Novak, S. (2022). Rendement, valeur nutritive et appétence des fourrages ligneux. https://rmt-agroforesteries.fr/wp-content/uploads/documents/fiche_patura3d-1.pdf

Mesbahi, G., Barre, P., Delagarde, R., Bourgoin, F., Perceau, R., & Novak, S. (2022a). Dynamic of 16 fodder trees' nutritive values from June to October. In: *Agroforestry for the Green Deal transition. Research and innovation towards the sustainable development of agriculture and forestry: 6th European Agroforestry Conference* (pp. 340-342). Nuoro: EURAF. https://hal.inrae.fr/hal-03683783

Mesbahi, G., Jawahir, A., Berthet, M., Ginane, C., Delagarde, R., Chargelègue, F., & Novak, S. (2022b). *Rethinking grasslands in 3D: feeding preferences of dairy cows between temperate fodder trees*. 29th Meeting of the European Grassland Federation, Caen. https://hal.inrae.fr/hal-03744539

Mohamed, M. (2015). L'intégration agriculture-élevage entre exploitations spécialisées pour alimenter les troupeaux méditerranéens ovins en France. [Mémoire de fin d'études, ISTOM]. https://climed.cirad.fr/content/download/4531/32834/version/2/file/MFE_madiha_mohamed_novembre2015.pdf.

Moraine, M., Therond, O., Leterme, P., & Duru, M. (2012). Un cadre conceptuel pour l'intégration agroécologique de systèmes combinant culture et élevage. *Innovations Agronomiques, 22*, 101-115. https://doi.org/10.17180/7thh-f276

Moraine, M., Grimaldi, J., Murgue, C., Duru, M., & Therond, O. (2016). Co-design and assessment of cropping systems for developing crop-livestock integration at the territory level. *Agricultural Systems, 147*, 87-97. https://doi.org/10.1016/j.agsy.2016.06.002

Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., de Jalón, S. G., … Palma, J. H. (2018). Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. *Agroforestry systems, 92*, 877-891. https://doi.org/10.1007/s10457-017-0126-1

Mupepele, A.-C., Keller, M., & Dormann, C. F. (2021). European agroforestry has no unequivocal effect on biodiversity: a time-cumulative meta-analysis.

BMC Ecology and Evolution, 21(1), 193. https://doi.org/10.1186/s12862-021-01911-9

Mupeyo, B., Barry, T. N., Pomroy, W. E., Ramírez-Restrepo, C. A., López-Villalobos, N., & Pernthaner, A. (2011). Effects of feeding willow (Salix spp.) upon death of established parasites and parasite fecundity. *Animal Feed Science and Technology, 164*(1), 8-20. https://doi.org/10.1016/j.anifeedsci.2010.11.015

Musonda, K., Barry, T. N., McWilliam, E. L., Lopez-Villalobos, N., & Pomroy, W. E. (2009). Grazing willow (*Salix* spp.) fodder blocks for increased reproductive rates and internal parasite control in mated hoggets. *Animal Feed Science and Technology, 150*(1), 46-61. https://doi.org/10.1016/j.anifeedsci.2008.08.003

Napoleone, M., Gravas, O., Rouquette, A., Cittadini, R., & Campoy, E. (2022). L'intégration culture-élevage à l'échelle régionale : Le projet Fricato en Pyrénées Orientales. In M. Barbier, C. Lamine & N. Couix (Coord.), *Pratiques et savoirs agricoles dans la transition agroécologique* (pp. 225-242). Paris : Éditions des archives contemporaines. https://doi.org/10.17184/eac.3048

National Research Council (2005). *Mineral Tolerance of Animals*. Washington:The National Academies Press. https://doi.org/10.17226/11309

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M., & Network, T. S. R. (2008). Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological Conservation, 141*(6), 1461-1474. https://doi.org/10.1016/j.biocon.2008.04.011

Nicodemo, M. L. F., & Porfírio-da-Silva, V. (2019). Bark stripping by cattle in silvopastoral systems. *Agroforestry Systems, 93*, 305-315. https://doi.org/10.1007/s10457-018-0185-y

Novak, S., Barre, P., Delagarde, R., Mahieu, S., Niderkorn, V., & Emile, J. C. (2020a). Composition chimique et digestibilité *in vitro* des feuilles d'arbre, d'arbuste et de liane des milieux tempérés en été. *Fourrages, 242*, 35-47. https://hal.inrae.fr/hal-02913155

Novak, S., Chargelègue, F., Chargelègue, J., Audebert, G., Liagre, F., & Fichet, S. (2020b). Premiers retours d'expérience sur les dispositifs agroforestiers intégrés dans le système laitier expérimental OasYs. *Fourrages, 242*, 71-78. https://hal.inrae.fr/hal-03147342

Nunn, L., Embree, C. G., Hebb, D., Bishop, S. D., & Nichols, D. (2007). *Rotationally grazing hogs for orchard floor management in organic apple orchards*. International Symposium on Organic Apple and Pear, Wolfville. https://doi.org/10.17660/ActaHortic.2007.737.9

Pasipanodya, C. N., Tekedza, T. T., Chatiza, F. P., & Gororo, E. (2021). Efficacy of neem (*Azadirachta indica*) aqueous fruit extracts against *Sarcoptes scabiei* var. *suis* in grower pigs. *Tropical Animal Health and Production, 53*, 135. https://link.springer.com/article/10.1007/s11250-020-02545-7

Paut, R., Dufils, A., Derbez, F., Dossin, A.-L., & Penvern, S. (2021). Orchard grazing in France: multiple forms of fruit tree–livestock integration in line with farmers' objectives and constraints. *Forests, 12*(10), 1339. https://doi.org/10.3390/f12101339

Pent, G. J. (2020). Over-yielding in temperate silvopastures: a meta-analysis. *Agroforestry Systems, 94*(5), 1741-1758. https://doi.org/10.1007/s10457-020-00494-6

Poudel, S., Bansal, S., Podder, S., Paneru, B., Karki, S., Fike, J., & Kumar, S. (2022). Conversion of open pasture to hardwood silvopasture enhanced soil health of an ultisol. *Agroforestry Systems, 96*(8), 1237-1247. https://doi.org/10.1007/s10457-022-00783-2

Pype, S., & Venineau-Delvalle, C. (2016). *Introduction d'un troupeau de brebis Shropshire dans les vergers basses tiges*. Portrait d'éleveur innovant INOSYS Réseaux d'élevage, Idele. https://rd-agri.fr/detail/DOCUMENT/idele_970

Ramírez-Restrepo, C., Barry, T., Marriner, A., López-Villalobos, N., McWilliam, E., Lassey, K., & Clark, H. (2010). Effects of grazing willow fodder blocks upon methane production and blood composition in young sheep. *Animal Feed Science and Technology, 155*(1), 33-43. https://doi.org/10.1016/j.anifeedsci.2009.10.003

Rasmussen, P. (1989). Leaf-foddering of Livestock in the Neolithic: Archaeobotanical Evidence from Weier, Switzerland. *Journal of Danish Archaeology, 8*(1), 51-71. https://doi.org/10.1080/0108464X.1989.10590019

Reidsma, P., Tekelenburg, T., Van den Berg, M., & Alkemade, R. (2006). Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. *Agriculture Ecosystems & Environment, 114*(1), 86-102. https://doi.org/10.1016/j.agee.2005.11.026

Riffard, L., & Liagre, F. (2023). *Pâturage ovin en vergers : État des lieux réglementaire et juridique. Fiche technique ECORCE n°5*, FiBL France. https://doi.org/10.5281/zenodo.10364922

Rocchi, L., Paolotti, L., Rosati, A., Boggia, A., & Castellini, C. (2019). Assessing the sustainability of different poultry production systems: A multicriteria approach. *Journal of cleaner production, 211*, 103-114. https://doi.org/10.1016/j.jclepro.2018.11.013

Rosati, A., Borek, R., & Canali, S. (2021). Agroforestry and organic agriculture. *Agroforestry Systems, 95*, 805-821. https://doi.org/10.1007/s10457-020-00559-6

Savietto, D. (2023). Projet LAPOESIE: Le lapin, le pommier et les bénéfices écosystémiques interspécifiques. https://metabio.hub.inrae.fr/thematiques/conception-de-systemes-multi-performants/lapoesie-projet-exploratoire-2020-2022

Schlink, A., Nguyen, M., & Viljoen, G. (2010). Water requirements for livestock production: a global perspective. *Revue Scientifique et Technique, 29*(3), 603-619. https://doi.org/10.20506/rst.29.3.1999

Shakesby, R., Coelho, C., Schnabel, S., Keizer, J., Clarke, M., Lavado Contador, J., . . . Doerr, S. (2002). A ranking methodology for assessing relative erosion risk and its application to dehesas and montados in Spain and Portugal. *Land Degradation & Development, 13*(2), 129-140. https://doi.org/10.1002/ldr.488

Sharrow, S. H. (2007). Soil compaction by grazing livestock in silvopastures as evidenced by changes in soil physical properties. *Agroforestry Systems, 71*, 215-223. https://doi.org/10.1007/s10457-007-9083-4

Smith, M. M., Bentrup, G., Kellerman, T., MacFarland, K., Straight, R., Ameyaw, L., & Stein, S. (2022). Silvopasture in the USA: A systematic review of natural resource professional and producer-reported benefits, challenges, and management activities. *Agriculture Ecosystems & Environment, 326*, 107818. https://doi.org/10.1016/j.agee.2021.107818

Solagro (2016). *Réintroduire le pâturage dans les cultures pérennes enherbées.* Osaé. Retrieved from https://osez-agroecologie.org/reintroduire-le-paturage-dans-les-cultures-perennes-enherbees

SSBA (2017). Two Crops from One Acre - A comprehensive guide to using Shopshire Sheep for grazing tree plantations. The Shropshire Sheep Breeders' Association, https://www.shropshire-sheep.co.uk/wp-content/uploads/2021/12/Two_Crops_from_One_Acre_Third-edition.pdf

Stahl, P., Ruette, S., & Gros, L. (2002). Predation on free-ranging poultry by mammalian and avian predators: field loss estimates in a French rural area. *Mammal review, 32*(3), 227-234. https://doi.org/10.1046/j.1365-2907.2002.00110.x

Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., Rosales, M., Rosales, M., & de Haan, C. (2006). *Livestock's long shadow: environmental issues and options*, FAO, https://openknowledge.fao.org/handle/20.500.14283/a0701e

Suttle, N. (2010). Copper. In: N. Suttle (Ed), *Mineral nutrition of livestock* (pp. 255-305). Wallingford: CABI. https://doi.org/10.1079/9781845934729.0000

Terranova, M., Eggerschwiler, L., Ortmann, S., Clauss, M., Kreuzer, M., & Schwarm, A. (2021). Increasing the proportion of hazel leaves in the diet of dairy cows reduced methane yield and excretion of nitrogen in volatile form, but not milk yield. *Animal Feed Science and Technology, 276*, 114790. https://doi.org/10.1016/j.anifeedsci.2020.114790

Timmermans, B., & Bestman, M. (2016). *Quality of apple trees and apples in poultry free range areas*. 3rd European Agroforestry Conference, Montpellier. https://www.louis-bolk.nl/sites/default/files/publication/pdf/3147.pdf

Torralba, M. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture Ecosystems & Environment, 230*, 150-161. https://doi.org/10.1016/j.agee.2016.06.002

Trouillard, M., Lèbre, A., & Heckendorn, F. (2021). Grazing sheep in organic vineyards: an on-farm study about risk of chronic copper poisoning. *Sustainability, 13*(22), 12860. https://doi.org/10.3390/su132212860

Trouillard, M., Bouy, M., Constancis, C., & Heckendorn, F. (2023). *Pâturage ovin en vergers : Risque d'intoxication au cuivre*. Fiche technique ECORCE nº4, FiBL France. https://doi.org/10.5281/zenodo.10346056

Udawatta, R. P., Garrett, H. E., & Kallenbach, R. (2011). Agroforestry buffers for nonpoint source pollution reductions from agricultural watersheds. *Journal of Environmental Quality, 40*(3), 800-806. https://doi.org/10.2134/jeq2010.0168

Vandermeulen, S., Ramírez-Restrepo, C. A., Marche, C., Decruyenaere, V., Beckers, Y., & Bindelle, J. (2018). Behaviour and browse species selectivity of heifers grazing in a temperate silvopastoral system. *Agroforestry Systems, 92*(3), 705-716. https://doi.org/10.1007/s10457-016-0041-x

Veldkamp, E., Schmidt, M., Markwitz, C., Beule, L., Beuschel, R., Biertümpfel, A., … Göbel, L. (2023). Multifunctionality of temperate alley-cropping agroforestry outperforms open cropland and grassland. *Nature Communications Earth & Environment, 4*(1), 20. https://doi.org/10.1038/s43247-023-00680-1

Villalba, J. J., Miller, J., Ungar, E. D., Landau, S. Y., & Glendinning, J. (2014). Ruminant self-medication against gastrointestinal nematodes: evidence, mechanism, and origins. *Parasite, 21*, 31. https://doi.org/10.1051/parasite/2014032

Wilson, L. M., & Hardestry, L. H. (2006). Targeted grazing with sheep and goats in orchard settings. In K. Launchbaugh (Ed.), *Targeted grazing: A natural approach to vegetation management and landscape enhancement* (pp. 99-106). Englewood: American Sheep Industry Association. https://www.webpages.uidaho.edu/rx-grazing/handbook/asitargetgrazingbook2006.pdf

Witt, A. R., Little, R. M., & Crowe, T. M. (1995). The effectiveness of helmeted guineafowl *Numida meleagris* (Linnaeus 1766) in controlling the banded fruit weevil *Phlyctinus callosus* (Schönherr 1826), and their impact on other invertebrates in apple orchards in the Western Cape Province, South Africa. *Agriculture Ecosystems & Environment, 55*(3), 169-179. https://doi.org/10.1016/0167-8809(95)00626-4

Zhu, X., Liu, W., Chen, J., Bruijnzeel, L. A., Mao, Z., Yang, X., … Seitz, S. (2020). Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. *Plant and Soil, 453*, 45-86. https://doi.org/10.1007/s11104-019-04377-3

Abstract

In organic agriculture, farmers' practices are inspired by natural mechanisms that allow life to thrive. In contrast, the modernization process undergone by agriculture in developed countries since the mid-20th century disconnected animal and vegetal productions, impeding the realization of many ecosystem services, and weakening the sustainability of many farms.
Agroforestry, an agroecological practice that consists in integrating trees to one or more agricultural production, shows a potential for limiting those drawbacks in animal husbandry. Indeed, the association of trees with animals generates heterogeneities at farm and landscape scales, which creates habitats for biodiversity, stimulates soil functions, and favors animal welfare and health. It also helps achieve farm economic sustainability, and improves the citizens' and consumers' view of animal production.
Agroforestry makes the farming systems more complex, meaning that its elements become more numerous and intricate. To achieve maximal performance, these systems therefore require suitable design as well as fine tuning and management, raising the need for additional competencies and novel knowledge production.
This article reviews the available scientific literature about the benefits and drawbacks of agroforestry for animal husbandry ("silvopastoralism") in temperate areas, for both animal farming under trees, and perennial crops (fruit and forest trees, wines) welcoming grazing animals.

Résumé

L'agroforesterie : atouts et points de vigilance pour répondre aux défis de l'élevage bio

La philosophie de l'agriculture biologique implique que les pratiques agricoles s'inspirent des mécanismes naturels de développement du vivant. À ce titre, la déconnexion des productions animales et végétales opérée depuis la deuxième moitié du XXe siècle entrave la fourniture de nombreux services écosystémiques, et fragilise les exploitations qui prennent la décision de renoncer à certains aspects de la « modernisation » agricole.
Dans cette optique, l'agroforesterie présente un fort potentiel pour accompagner le développement de l'élevage biologique. Cette pratique agroécologique consiste à faire coexister des arbres avec une ou plusieurs autres productions agricoles : en créant des hétérogénéités à l'échelle de la parcelle et du territoire, l'association arbres/animaux augmente la diversité des plantes fourragères, génère des habitats pour la biodiversité, stimule le fonctionnement des sols, et favorise le bien-être et la santé des animaux. Elle permet aussi de stabiliser les exploitations sur le plan économique, et d'améliorer l'image de l'élevage auprès des citoyens et consommateurs.
L'agroforesterie implique une complexification du système productif, multipliant ainsi les éléments qui le constituent et leurs interactions. De ce fait, elle se heurte à certaines difficultés potentielles de conception, pilotage et gestion, nécessitant l'acquisition de connaissances et de compétences, et la production de nouveaux référentiels.
À partir d'une synthèse bibliographique, cet article explore les bénéfices et limites de l'agroforesterie dans les systèmes d'élevage en régions tempérées, en adoptant le double point de vue du pâturage en zones arborées, et des cultures pérennes (arbres fruitiers, vignes) ou sylvicoles accueillant des animaux.

TROUILLARD, M., BOSSHARDT, S., DERBEZ, F., DESAINT, B., DUFILS, A., & MESBAHI, G. (2024). Agroforestry: benefits and considerations to meet the challenges of organic livestock production. *INRAE Productions Animales*, *37*(2), 7468.
https://doi.org/10.20870/productions-animales.2024.37.2.7468