Agroforestry for ruminants: a review of trees and shrubs as fodder in silvopastoral temperate and tropical production systems

Sophie Vandermeulen[A,B*], Carlos Alberto Ramírez-Restrepo[C], Yves Beckers[A], Hugues Claessens[D], Jérôme Bindelle[A,E]

[A]University of Liège, Gembloux Agro-Bio Tech, Precision Livestock and Nutrition Unit, 2 Passage des Déportés, 5030 Gembloux, Belgium. [*]Email: vandermeulen.sophie@gmail.com

[B]Research Foundation for Industry and Agriculture, National Scientific Research Foundation (FRIA-FNRS), 5 Rue d'Egmont, 1000 Bruxelles, Belgium

[C]CSIRO, Agriculture, Australian Tropical Sciences and Innovation Precinct, James Cook Drive, Townsville, QLD 4811, Australia

[D]University of Liège, Gembloux Agro-Bio Tech, Forest and Nature Management, 2 Passage des Déportés, 5030 Gembloux, Belgium.

[E]AgricultureisLife Platform, 2 Passage des Déportés, 5030 Gembloux, Belgium.

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Abstract.

Among the oldest agroforestry systems, silvopastoralism uses shrubs and trees to feed ruminants. The practice is common in extensive livestock production systems, while the intensification of grass-based systems in the past century has led to the removal of woody species from agricultural temperate landscapes. In Europe however, woody species are promoted again on grasslands through environment-friendly policies due to the ecosystem services they provide such as carbon sequestration, control of soil erosion, limitation of air-borne pollutants and biodiversity conservation. Positive effects of browse on rumen digestion and parasite control have also been documented across different plant species and regions. Under optimal conditions, feeding ruminants from woody fodder sustains animal production. Nonetheless, limitations can restrict the use of woody forage into animal diets, such as the presence of anti-nutritive and toxic compounds. The incorporation of this resource in ruminant feeding systems raises the question of the management of the interface between the plant and the animal. Various management systems are practiced. Temperate species such as *Salix* spp. and *Populus* spp. are fed to sheep and cattle in fodder blocks or by pruning trees in New Zealand, and *Fraxinus* spp. or *Corylus avellana* in hedgerows supply forage to livestock in Belgium, while *Leucaena leucocepahala* and *Desmanthus* spp. browsing is common in Australia. Nowadays, ensiling and pelleting techniques are being developed as a way to store browse forage. As the renewed interest in using shrubs and trees to feed ruminants is recent, especially in temperate regions, additional research about introducing optimally this resource within systems is needed.

Keyword: Silvopastoralism, livestock husbandry, browse species, feeding, nutritive value.

Introduction

Silvopastoralism, a multifunctional land-use system that associates animals with shrubs or trees and pasture, is one of the most ancient agroforestry systems (Etienne 1996). The integration of shrubs and trees as fodder resources into grazing systems is practiced in the tropics (Abdulrazak *et al.* 1996; Hove *et al.* 2001; Dalzell *et al.* 2006), the Mediterranean area (Papachristou and Papanastasis 1994; Mosquera-Losada *et al.* 2012) and in highlands around the globe (Vandenberghe *et al.* 2007; Buttler *et al.* 2009). However, in temperate Europe, particularly Germany, shrubs and trees have been progressively removed from agricultural landscapes due to the intensification of grass-based production systems (Nerlich *et al.* 2013). Unfortunately, although the interest for woody species as feed for livestock is rising again (Bestman *et al.* 2014; Smith *et al.* 2014; Vandermeulen *et al.* 2016), little is known about the use of fodder sources in more intensive ruminant production systems.

In silvopastoral systems, shrubs and trees can supply energy, protein and other nutrients to livestock (Papachristou and Papanastasis 1994; Kemp *et al.* 2001), while they may further become the only forage resource available during critical periods of grass shortages (Papachristou and Papanastasis 1994; Dalzell *et al.* 2006). They can also provide shelter against extreme environmental conditions (Hawkes and Wedderburn 1994; Liagre 2006; Van laer *et al.* 2015) and may improve reproductive performance (Pitta *et al.* 2005; Musonda *et al.* 2009), body growth (Abdulrazak *et al.* 1996; Gardiner and Parker 2012) and milk production (Maasdorp *et al.* 1999). Furthermore, depending on the browse species and their secondary compounds content (e.g. condensed tannins; CT), they may reduce internal parasite infestation (Mupeyo *et al.* 2011) and also methanogenesis (Ramírez-Restrepo *et al.* 2010). Nevertheless, besides all these beneficial effects, the incorporation of woody fodder in animal diets might be restricted due to low palatability (Kanani *et al.* 2006) or toxicity (Jones *et al.* 1976; Dalzell *et al.* 2006).

In modern silvopastoral systems, the interest in using trees as a supplementary fodder source for feeding animals is increasing although the woody plants may have originally been established for other purposes. For instance, willow (*Salix* spp.), planted for soil conservation in New Zealand

(Pitta *et al.* 2005) and to produce wood chips for energy in United Kingdom (Smith *et al.* 2014), is used to feed livestock at the same time. Shrubs and trees may then be established within grazing systems for environmental purposes as silvopastoral systems are considered to supply ecosystem services, at a range of spatial and temporal scales (Jose 2009; Sharrow *et al.* 2009). Planting shrubs and trees on farmlands has been shown to improve air and water quality. For example, hedgerows can mitigate undesirable livestock odors around the farm while wind and water erosion can be reduced by trees, leading to soil stabilization (Liagre 2006; Jose 2009). Shrubs and trees can play a significant role in carbon sequestration, above and below ground (Kaur *et al.* 2002) and improve the soil quality, e.g. through nutrient cycling. Shrub and tree legumes are particularly interesting for the fixation of atmospheric nitrogen used by the plant to produce protein while it can be cycled to the companion pasture plants (Dalzell *et al.* 2006; Cox and Gardiner 2013). Furthermore, feeding livestock with CT-containing woody fodder can enhance nitrogen recycling in the pasture by a shift from excretion in urine to faeces (Waghorn *et al.* 1987; Grainger *et al.* 2009), in which N is less volatile leading to lower risk of N_2O emissions and N losses (de Klein and Eckard 2008). Biodiversity conservation can also be promoted by shrubs and trees through a number of functions such as providing habitats for flora and fauna species (Liagre 2006; Pulido-Santacruz and Renjifo 2011) while the landscape aesthetics may be enhanced as well (Jose 2009).

Nowadays, the interest in such modern silvopastoral systems in which browse are used as an extra feed resource for ruminants from trees and shrubs primarily established for other purposes is growing (Pitta *et al.* 2005; Smith *et al.* 2014). However, more needs to be known about the different ways of sustainably introducing and managing woody forage in more intensive and sustainable temperate and tropical production systems. Therefore, this review aims to describe how trees and shrubs are currently integrated as fodder in ruminant diets. The potential outputs and limitations of using woody forage in the whole ruminant system are also discussed, as well as the contribution of shrub and tree species to temperate ruminant production systems, obstacles and requirements to their integration in these systems.

Silvopastoralism: Origin, practices and distribution throughout the world today

Agroforestry and silvopastoralism: concepts and definitions

Agroforestry is defined as a land-use system that combines on the same area woody perennials with crops and/or animal production (Nair 1991; Allen *et al.* 2011). Consequently, based on this combination, agroforestry is made up of silvoarable (i.e crops and trees), silvopastoral (i.e. animals and trees) and agrosilvopastoral (i.e. crops, animal and trees) systems.

Silvopastoral systems are encountered worldwide (Hove *et al.* 2001; Dalzell *et al.* 2006; Sharrow *et al.* 2009; Bestman *et al.* 2014) and reported as the most prevalent agroforestry system in developed countries (Sharrow 1999). They are diverse and complex: forest grazing or silvopastures (Sharrow *et al.* 2009), woodlands or wood-pastures (Rackham 2013), locally named as the *Dehesa* in Spain, *Montado* in Portugal (Dupraz and Liagre 2008) or *Streuobst* in some temperate European countries (Herzog 1998). In some systems, animals are set to graze the pasture growing under or beside the woody resource but are not fed with it, while in others, it is considered as feed, assuming that two types of fodder may be produced from shrubs and trees, the foliage (i.e. leaves and twigs) and the fruits (Liagre 2006). Usually foliage is the main fodder resource from which animals are fed, but sometimes, fruits can also be used in more specific cases. For example, chestnuts (*Castanea sativa*), honey locust pods (*Gleditsia triacanthos*) and acorns (*Quercus* spp.) may be fed to ruminants and sometimes monogastric animals (Liagre 2006). However, only shrub and tree foliage as a fodder resource will be discussed in this review.

Although a wide variety of systems exists according to objectives and management procedures, silvopastoral systems are commonly achieved in two ways, either by planting trees on an established pasture or by introducing livestock and/or forage production in a forestland (Peeters *et al.* 2014). In accordance with Etienne (1996) and Sharrow *et al.* (2009) at farm-scale level, three main silvopastoral structures can be considered in terms of plant composition:

- trees on pasture: woody perennials are planted widely-spaced on an already established sward in order to benefit from product diversification and/or from woody-herbaceous plants associations;

- grazed forest: an existing woodland or forest is thinned and sown to take advantage of the components interaction and/or diversification;
- forestry in a livestock farm or forested rangelands: trees and shrubs are planted at high density to diversify production at whole farm level.

Further distinction may include differences due to the animal species and breeds, the trees and shrubs species and cultivars, the pasture plants and other vegetation components, the soil, the climate, the land-use patterns and the planting arrangements (Calub 2003; Papanastasis *et al.* 2008). Considering ruminants, goats (Papachristou and Papanastasis 1994; Hove *et al.* 2001; Bestman *et al.* 2014), sheep (Pitta *et al.* 2005; Rangel and Gardiner 2009) and cattle (Moore *et al.* 2003; Vandermeulen *et al.* 2016) are reported as being managed with shrub and tree fodder.

Economic implications, benefits and limitations of woody plants in the whole farming system

Besides the environmental benefits of trees and shrubs mentioned previously, the livestock component integrated in a global agricultural system will provide income in the short term while multipurpose shrubs and trees can ensure long-term profits through timber for example (Sharrow *et al.* 2009). The timber sector can lead to various outcomes as the wood may be used as softwood lumber, firewood or ramial chipped wood used as litter for livestock (Liagre 2006). Besides economic outputs, shrubs and trees in grasslands can contribute to animal welfare by offering shelter against extreme weather conditions, e.g. shade and protection from rain and wind (Hawkes and Wedderburn 1994; Gregory 1995; Liagre 2006)

Regarding the animal component, shrubs and trees have demonstrated that they can support the production during challenging periods by reducing weight loss (McWilliam *et al.* 2005a; Dalzell *et al.* 2006; Moore *et al.* 2003) and further, they may improve the animal performances (e.g. Abdulrazak *et al.* 1996; Musonda *et al.* 2009; Rangel and Gardiner 2009). In temperate areas, the use of willow as fodder is common in the East Coast regions of New Zealand to secure forage supply during summer and autumn droughts (Charlton *et al.* 2003; Moore *et al.* 2003; Pitta *et al.* 2005). This temperate browse has been widely investigated for its impacts on animal performance. It has been reported to improve reproductive rate, e.g. by 20 % units in ewes, with more births of twin lambs (Pitta *et al.* 2005) or by 17 lambs/100 hoggets mated as a result of increased oestrus activity and conception rates (Musonda *et al.* 2009), and reduce post-natal lamb mortality from 17.1 to 8.4 % compared to a control group (McWilliam *et al.* 2005b). Full access to fodder blocks could lessen daily live weight (LW) loss by up to 60 % in sheep (McWilliam *et al.* 2005b; Pitta *et al.* 2005) and by 44 % when fresh willow prunings supplemented cattle grazing a summer dry pasture (Moore *et al.* 2003). Furthermore, willow is capable of reducing livestock parasitism e.g. by reducing nematode fecundity (Mupeyo *et al.* 2011). Most of these effects have been associated with condensed tannins (CT), bio-active secondary metabolites found in many woody species (Hove *et al.* 2001; Kemp *et al.* 2001). These molecules influence the rumen metabolism in many different ways, with beneficial or detrimental effects depending notably on the compound, the ingested amount and the animal species (Jones *et al.* 1976; Frutos *et al.* 2004; Bueno *et al.* 2015). The effects of CT on ruminant digestive metabolism have been extensively described (McLeod 1974; Makkar 2003; Frutos *et al.* 2004), and will not be detailed in this review.

In tropical ecosystems, the shrub legume leucaena (*Leucaena leucocephala*) is widely used to supply fodder to ruminants (Devendra 1989; Dalzell *et al.* 2006). In a study in the lowland semi-humid tropics of Kenya, this shrub fodder supplemented at 0, 4 and 8 kg level to *Pennisetum purpureum* lessened Ayrshire/Brown Swiss x Sahiwal crossbred cows LW loss (560, 235 and 175 g/day, respectively), increased daily milk production (7.3, 7.7 and 8.3 kg) and improved yield persistency (-370, -270 and -160 g loss per week) (Muinga *et al.* 1992). When consuming 4 kg DM of this legume per day (~35-40 % of the diet), 450 kg-steers could gain more than 1 kg of bodyweight per day, with LW gain reaching up to 1.6 kg/head.day for the best results obtained in Clermont (Queensland, Australia) for finishing steers with the legume (Dalzell *et al.* 2006). Steers fed *Pennisetum purpureum* diet increased the daily LW gain from 538 to 850 g when supplemented with leucaena and from 306 to 478 g/day with *Gliricidia sepium* (Abdulrazak *et al.* 1996). Among other legumes used as pasture supplementation, *Desmanthus* spp. appear promising since over a 3-month study during a dry winter in central Queensland, steers on a *Desmanthus*-buffel grass pasture gained an extra 40 kg of LW compared with steers grazing only buffel grass

(Gardiner and Parker 2012). This plant improved also the wool yield of supplemented Merino wethers with production reaching up to 0.18 mg wool/cm²/day higher than that of control animals (Rangel and Gardiner 2009), while potentially reducing CH_4 emissions (Vandermeulen *et al.* unpublished data).

Although woody plants can deliver benefits to animal production systems, limitations will restrict their implementation within production systems such as the presence of toxic compounds (Hegarty *et al.* 1964; Dalzell *et al.* 2006). Negative impacts of integrating trees into pasture in terms of reducing pasture productivity have been mentioned (Sharrow 1999; Devokta *et al.* 2009). Shrubs and trees and pasture plants compete for above- and below-ground resources. Major effects on pasture production are shade, and the competition for moisture and nutrients, and these effects are tree and pasture species dependent (Sharrow 1999; Devokta *et al.* 2009). Managing the appropriate species in the system is crucial; for example, in temperate systems, planting nitrogen-fixing trees as *Alnus* spp. are expected to enhance nutrient cycling and increase soil fertility which may be beneficial to pasture plants (Smith and Gerrard 2015). However the lack of knowledge about the technical itinerary is a significant barrier to the integration of shrubs and trees and their use of fodder for ruminants mainly in temperate systems.

Management of trees and shrubs as fodder in ruminant production systems

Irrespective of the feeding system (Table 1), woody perennials can be scattered or grouped, inside the land or on the edge (Peeters *et al.* 2014). However, the productivity and limitations of silvopastoral systems are variable due to species and cultivars, plant age and structure for feeding, growth status, harvesting period, environmental conditions and management (Table 2; Kemp *et al.* 2001; Douglas *et al.* 2003; Dalzell *et al.* 2006). Besides physical distribution, the use for ruminants can be undertaken in different ways: direct browsing or pruning, with or without preservation of the forage.

Direct browsing on plants.

Originally planted for soil conservation in New Zealand, the temperate species *Salix* and *Populus* spp. have been used to feed ruminants during summer and autumn droughts (Moore *et al.* 2003; McWilliam *et al.* 2005a; Pitta *et al.* 2005). Tree fodder from poplars (*Populus* spp.) and willows is obtained from cutting widely spaced trees that are used primarily for soil erosion management or from special purpose fodder blocks that may be coppiced or browsed (Charlton *et al*. 2003; Douglas *et al.* 2003; Table 1). These intensively planted browse blocks are less widely used and generally comprise willows. In the willow block systems, shrubs are established at a higher density (1500-30000 stems/ha) than the ones used for soil conservation (Douglas *et al.* 2003). The browse blocks can be designed e.g. by planting the shrubs at 1.2 m × 1.2 m and managing them through controlled browsing and trimming every year to maintain the branches within animals' reach (Table 2). Different species and cultivars have been developed for the fodder block systems in New Zealand, such as *Salix* spp., *Populus* spp. and *Dorycnium rectum* (Oppong *et al.* 2001; McWilliam *et al.* 2005a; Ramírez-Restrepo *et al.* 2010). In terms of yield (Table 2), *Salix matsudana* x *alba* can produce up to 7.2 t DM/ha.year of which 15-19 % is edible, compared to a perennial ryegrass (*Lolium perenne*) pasture yielding 9.8-10.9 t DM/ha in total during the season (Douglas *et al.* 1996). In an experiment with ewes accessing willow fodder blocks during late summer and autumn, the voluntary feed intake was estimated at 2.1 kg DM/ewe.day with 0.29 kg accounting for woody foliage, while the control pasture intake was in the range of 0.7-1.66 kg DM/ewe.day (Pitta *et al.* 2007). Kemp *et al.* (2001) observed that cattle browsed 0.7-2.4 kg DM of trees/animal at 1.6-2.2 m high.

In Europe, hedgerows and windbreaks (i.e. shelterbelts) aim primarily to enclose the fields and meadows (Baudry *et al.* 2000) and control erosion (Nerlich *et al.* 2013) respectively, while the shrubs and trees composing them may be browsed by animals (Vandermeulen *et al.* 2016; Table 1). The "*bocage"* in Brittany and Normandy in north-west of France is a typical example of hedgerow systems relying on lines of mid-stem e.g. *Carpinus betulus*, *Coryllus avellana*, *Acer campestre*, and high-stem trees species, such as *Castanea sativa*, *Fagus sylvatica* and *Quercus* spp. (Thenail *et al.* 2014). A large variety of other species can compose these hedgerow types e.g. *Fraxinus excelsior*, *Crataegus monogyna*, *Cornus sanguinea*, *Populus* spp. or *Salix* spp. (Baudry *et* *al.* 2000; Vandermeulen *et al.* 2016). The bocage landscapes are also found in northern Spain, Italy, Switzerland, Germany and Belgium (Baudry *et al.* 2000; Brootcorne 2011). However, this ancient agroforestry system has suffered from agricultural intensification during the second half of the 20th century with an important decrease in hedgerows numbers (Nerlich *et al.* 2013; Thenail *et al.* 2014; Vandermeulen *et al.* 2016); a situation that is trying to be reversed by the new establishment of hedgerows (Thenail *et al.* 2014).

In Belgium like in most European countries, woody perennials have been removed from farmland due to the intensification of production systems (Nerlich *et al.* 2013). However, due to new environmental policies [i.e. agri-environmental and climatic measures (AECM)], the integration of shrubs and trees is promoted again as farmers may receive annual subsidies for the establishment and maintenance of hedgerows and woody strips (25€/200 m) as well as individual shrubs, trees, bushes or groves (25€/20 units; Walloon Government 2015, 2016). Within this framework, several criteria must be met, such as the use of indigenous species e.g. *Fraxinus excelsior, Crataegus monogyna* or *Corylus avellana* (SPW 2010; Walloon Government 2016). In Wallonia in southern Belgium, it was reported that 13 m of hedgerow per ha of utilized agricultural area (UAA) and 1 tree per 6.4 ha have been newly planted into pasture (SPW 2010) while in 2010, it reached 16 m of hedge per ha of UAA and 1 tree for 5.8 ha (SPW 2012). Between 1999 and 2009, more than 100 km of hedgerows have been planted (SPW 2010). Among the AECM, hedges and woody strips are the most popular with 33% of total AECM newly implemented by farmers in 2012 (SPW 2014). The interest in the environment-friendly practices results in 12,370 km of hedgerows in total in Wallonia (SPW 2014). Overall, it is estimated that since the implementation of the program, farmers' participation has increased steadily. However, between 2013 and 2015, budget restrictions limited most AECM, while latest updates of policies related to aids granted for the plantation of live fences, linear coppices, orchards and tree alignments and for the maintenance of pollards, are promoting shrubs and trees on farmland e.g. 20 % grants increase if the project supports directly an ecosystem service (Walloon Government 2016).

As pointed out earlier, the interest in integrating shrubs and trees in agricultural landscapes in Belgium is driven by environmental concerns, but their use as an extra fodder resource might result from it. Recent studies (Vandermeulen *et al.* 2016) found that grazing cattle may browse shrub and tree fodder integrated as hedgerows during the grazing season, from spring (i.e. April) to autumn (i.e. October). It is also interesting to see that current research projects in Europe are aiming to integrate woody forage in ruminant systems (Bestman *et al.* 2014; Smith *et al.* 2014; Van laer *et al.* 2015). Nevertheless, it should be stated that additional research is needed to better understand the sustainable productivity from introduced browsing plant species.

In the Tropics, continuous, rotational or seasonal grazing systems facilitate browsing practices using leucaena to support beef cattle industry in the north-east region of Australia (Dalzell *et al.* 2006; Cox and Gardiner 2013), where the plant is also aligned along hedgerows (i.e. live fences; Table 1). Leucaena productivity was reported to vary between 13.7 and 32.0 tons of dry matter (DM)/ha depending on the harvest interval and row spacing (Ferraris 1979; Table 2). Thus, to ensure plant survival and optimal productivity, plant height (i.e. 1.5 to 2.0 m) and age (i.e. 6 to 12 months after seeding) should be considered at the time of browsing (Dalzell *et al.* 2006). It is also reported that the stocking rate on leucaena-grass pastures in Queensland can range between 0.6 head/ha in leucaena-buffel grass (*Pennisetum ciliare*) pastures to 2.5 steers/ha in irrigated systems assuming that 450 kg steers would ingest 35 % of leucaena in their diet (Dalzell *et al.* 2006). Although leucaena is known to be palatable, nutritious, productive and widely established in Australia (Dalzell *et al.* 2006; Shelton and Dalzell 2007), its toxicity limits its introduction in ruminant systems (Table 2). Furthermore, this plant is considered as an environmental weed that can threaten the whole grassland ecosystem (Dalzell *et al.* 2006). Nevertheless, actions may be taken to deal with adverse outcomes e.g. inoculating the ruminal bacterium *Synergistes jonesii* (Allison *et al.* 1992) which is able to degrade mimosine to non-toxic end products or the implementation of preventive procedures to minimize the spread of unwanted plants (Dalzell *et al.* 2006).

Calliandra calothyrsus is another tropical shrub legume used in direct browsing or in cut-and-carry systems (Palmer and Schlink 1992; Maasdorp *et al.* 1999; Franzel *et al.* 2014). In the highlands of Eastern Africa, including Kenya, Uganda or Rwanda, this species is one of the most commonly planted trees for feeding livestock and those plants are grown mainly in hedges (Franzel *et al.* 2014). *Calliandra calothyrsus* contains CT (> 50 g/kg DM; Table 3) which eaten in large quantities may reduce DM intake (DMI) and disrupt animal performance (Barry and Duncan 1984; Frutos *et al.* 2004). However, studies conducted by Hove *et al.* (2001) indicated that goats fed with a native pasture hay supplemented with *C. calothyrsus* (196 g CT/kg DM) had similar DMI of goats fed *Acacia augustissima* (33 g CT/kg DM) or *L. leucocepahala* (134 g CT/kg DM).

Beside *L. leucocepahala* and *C. calothyrsus*, *Stylosanthes* spp., *Sesbania sesban*, and *Gliciridia sepium* are among perennial woody legumes promoted in the north-east semi-arid region of Australia (Palmer and Schlink 1992; Cox and Gardiner 2013). Characterized by a seasonally dry period extending from April to October, grasslands of this region have been mixed with shrub or tree legumes to supply quality feed and to improve the total nutrient availability to grazing cattle during grass shortages (Cox and Gardiner 2013). In contrast with temperate areas, many genera and species used as pasture plants for cattle have been selected. *Leucaena leucocephala* previously mentioned is one example of a native shrub from America largely introduced in northern Australian grasslands, with about 150,000 ha reported in Queensland in 2007. In the specific context of semi-arid clay soils of northern Australia, the genus *Desmanthus* has also been selected for its persistence in this environment while other sown species did not survive (Gardiner and Swan 2008). *Desmanthus* spp. are palatable, non-toxic, non-thorny and protein rich trees (Gardiner *et al.* 2013). They are also well adapted to heavy grazing systems (Pengelly and Conway 2000). In this context, *D. bicornutus*, *D. leptophyllus* and *D. virgatus* have been particularly targeted (Gardiner *et al.* 2013) to improve paddock performance and sustain livestock production in dry tropics systems. Natural grazing lands with trees browsed by ruminants are commonly found in arid, semi-arid and sub-humid zones of Africa (Le Houérou 1980; Franzel *et al.* 2014; Toth *et al.* 2017). However, the emergence of new agroforestry practices for feeding ruminants has resulted in planting shrubs and trees, in particular in East African highlands (Franzel *et al.* 2014). Native or introduced species such as *Acacia* spp., *Prosopis Africana*, *Leucaena* spp., *S. sesban* or *C. calothyrsus* are found (Le Houérou 1980; Franzel *et al.* 2014; Toth *et al.* 2017).

Although livestock are considered as a product, animals can be used as a tool to manage the woody plants by grazing the grass stratum and browsing shrubs and trees (Sharrow *et al.* 2009). Livestock, mainly goats, also have a role in reducing fire risk in Mediterranean systems by grazing and browsing the understorey vegetation (Papanastasis *et al*. 2008, 2009), and in weed control (Sharrow 2009). In plantation systems associating several browse species, it is preferable to include plants of similar palatability to avoid overbrowsing of the preferred ones (Papachristou and Papanastasis 1994). To insure optimal productivity, the browse height needs to be regulated and varies with the livestock species. In Australian beef cattle grazing systems, leucaena should be managed to remain between 2 to 3 m tall based on appropriate browsing pressure and cuttings (Dalzell *et al.* 2006). In contrast, willow fodder blocks may be cut at 0.4 m above ground to be browsed by sheep (Douglas *et al.* 2003). The complementarity between different animal species might be exploited as it is the case in New Zealand with willow block systems browsed by sheep first and then by cattle to overcome excessive plant development (Pitta *et al.* 2007). However, care must be exercised to avoid irreversible damage from large animals (Eason *et al.* 1996; Vandenberghe *et al.* 2007). Although very little data were found in the literature, the sensitivity to browsing varies between species. For example, Eason *et al.* (1996) observed that *F. excelsior* suffered more from browsing by sheep than *Acer pseudoplatanus* which could be due to the difference in palatability and/or tree height. Greater browsing height of cattle (~ 1.8 m) can be destructive to some tree species.

Pruned shrubs and trees (fresh fodder).

Instead of direct browsing, woody forage can be cut and distributed to the animals at the stalls or eaten on-site (Charlton *et al.* 2003; Bestman *et al.* 2014) as practiced for example by French shepherds in the Pyrenees and the Massif Central with *Fraxinus excelsior* branches (Liagre 2006). The cut-and-carry practice has a long tradition in tropical silvopastoral systems (Calub 2003) and in temperate feeding systems (Baudry *et al.* 2000; Liagre 2006). Traditional cut-and-carry systems (Table 1) are widely used in many countries of Asia as in Indonesia with leucaena or in Nepal with *Ficus* spp., or in tropical Africa (Devendra 1989; Calub 2003).

Different pruning methods may be used to harvest the shrub and tree fodder e.g. shredding, pollarding and coppicing (Table 1). Shredding is achieved by cutting lower lateral branches resulting in a 5 to 7 m-trunk with branches longwise while pollarding produces multiple branches on the top of a short trunk of 1.5 to 2.5 m (Baudry *et al.* 2000; Charlton *et al.* 2003; Papanastasis *et al.* 2009), protecting trees from browsing. Both techniques in Greece are typically used in traditional silvopastoral systems with *Quercus* spp. and *Fagus* spp., but these management practices have been progressively abandoned (Papanastasis *et al.* 2009).

Coppicing consists of producing a basal stump with growing branches (Baudry *et al.* 2000) by cutting trees to near ground level, for example at 0.3-0.5 m high (Charlton *et al.* 2003). The fodder is carried afterwards to the stall or left on-site for eating. This technique is commonly found in New Zealand with willows and poplars that are used originally for soil conservation (Charlton *et al.* 2003; Douglas *et al.* 2003). In this kind of system, Hereford-Friesian crossbred cows grazing a sparse pasture supplemented with unchopped pruned *Salix* spp. could ingest between 0.5 to more than 3 kg DM/cow.day (Moore *et al.* 2003). In browse fodder blocks also performed in New Zealand, coppicing may be performed as post-browsing shrub management (Douglas *et al.* 2003).

Plant material is usually harvested mechanically as carried out by dairy farmers in cut-and-carry systems in the Netherlands with willows, ash (*F. excelsior*) or hazels (*C. avellana*) (Bestman *et al.* 2014) and with tagasaste (*Chamaecytisus prolifer* var. *palmensis*) in Western Australia (Cook *et al.* 2005; Wiley 2009). Some operations can be manual such as topping *Salix* spp. trees to stumps in fodder blocks in New Zealand (Douglas *et al.* 2003; Pitta *et al.* 2007). The way of feeding can also vary between systems as the fodder can be distributed as whole plants (i.e. branches and leaves) or by separating leaves from branches while the forage can be kept intact (i.e. not fragmented) or shredded (Bestman *et al.* 2014). Once the fodder is harvested, it may be provided fresh to the animals. Alternatively a preservation method can extend the use of the harvested forage.

Preservation of shrub and tree forage.

Preserving browse hay is notably practiced in Greece (Papanastasis *et al.* 2009), Norway and France (Baudry *et al.* 2000; Thiébault 2005) for winter. Nevertheless, browse preservation methods are time-consuming which explains why some have progressively disappeared (Liagre 2006).

Chemical composition and nutritive value of shrubs and trees fodder depend on the species and cultivars, composition of the plant material, growth status, harvesting period, environment and management (Papachristou and Papanastasis 1994; Kemp *et al.* 2001; Dalzell *et al.* 2006), but the processing of the forage, e.g. fresh, dried, silage or pellets, is a determinant as well (Palmer and Schlink 1992; Smith *et al.* 2014; Table 3). For example, it is suggested to distribute *C. calothyrsus* fresh in a minimum time after harvesting, instead of dried (Palmer and Schlink 1992; Maasdorp *et al.* 1999) as drying decreases DM digestibility of this species.

The fodder can be dried naturally in the sun (Hove *et al.* 2001) or force-dried in an oven (Palmer and Schlink 1992). Ash has been traditionally used as fresh fodder during summer drought or dried for winter in France, to feed ruminants (Liagre 2006). With a high concentration in Ca, this forage is particularly recommended for suckler and lactating cows. Nowadays, techniques that are commonly used to preserve herbaceous forage are being applied to browse. The ensilability of *Salix* spp. foliage was recently investigated in The Netherlands (Bestman *et al.* 2014) and the United Kingdom (Smith *et al.* 2014). However, the effects of the conservation method on the plants palatability (Bestman *et al.* 2014) and nutritive value are still unknown (Smith *et al.* 2014). Since tannins can prevent feed protein degradation in silages of some legumes (Albrecht and Muck 1991), woody legumes containing these bio-active compounds could yield high quality silage by preventing proteolysis.

In the tropics, pelleting leaves of e.g. *L. leucocephala* (Hung *et al.* 2013) or mulberry (*Morus alba*; Huyen *et al.* 2012) has been used to supplement ruminants. The pellets are prepared by mixing, in different proportions, the tree leaf meal with urea, molasses, cassava starch, salt, sulfur and a mineral mixture (Huyen *et al.* 2012; Hung *et al.* 2013).

Integrating shrubs and trees into temperate ruminant production systems: contributions, obstacles and prospects

Shrubs and trees have the potential to contribute to temperate ruminant production systems. They can secure forage supply to ruminants by supplementing pasture during summer and autumn droughts (Liagre 2006; Douglas 2003). Because shrubs and trees are usually considered as a forage security rather than a definite production, it is difficult to have a good overview of both the nutritive value of the different woody species and their productivity over the year (Liagre 2006).

In browsing systems where pasture biomass production might be sufficient to cover livestock requirements as in Belgium, other reasons than fodder supply might encourage herbivores to choose woody plants over grass. When mixing trees with grass, the animals have the opportunity to diversify their diet. This can satisfy the individual nutritional requirements and preferences but it also offers alternatives to better cope with toxins and parasites (Provenza *et al.* 2003; Manteca *et al.* 2008). Parasitized animals offered plant secondary compounds-containing feed are able to self-medicate, as it has been reported that lambs with parasitic burdens ingested more of the tannin-containing feed than unparasitized animals (Lisonbee *et al.* 2009; Villalba *et al.* 2010). Feeding willow fodder to young sheep in New Zealand reduced nematodes burden and fecundity which has been associated to willow CT content (Mupeyo *et al.* 2011). Hence, taking care of animals according to the therapeutic or nutritive properties of some species is a frequent argument (Thiébault 2005). Fodder trees can also improve low-quality pasture or diet by delivering N and mineral supplement to animals (Leng 1992), and the plant feeding value can influence the choice between plants to ingest (Decruyenaere *et al.* 2009; Meier *et al.* 2014). Unfortunately, the selection of woody species to implement within a production system relies sometimes on local traditional knowledge or beliefs rather than proper scientific evaluation (Thiébault 2005).

Although trees and shrubs might contribute to ruminant livestock production systems, obstacles to their introduction within systems and their use as fodder have been reported. Farmers mentioned the additional labour, regulatory requirements and administrative constraints, cost of planting shrubs and trees, lack of training, interference with agriculture mechanization or pasture problems such as locally lower pasture production due to tree shade (Brootcorne 2011; Luske 2014). Regarding weed and disease control, some declared that hedges play a significant role in the transmission of beef cattle scabies (Brootcorne 2011). These constraints differ according to the systems; the management of tree regeneration seems more complex with goats than dairy cows (Luske 2014). This highlights the lack of knowledge about the technical itinerary in temperate production systems. Recent research evaluated how woody species can fit within the systems (Bestman *et al.* 2014; Luske 2014; Smith *et al.* 2014; Vandermeulen *et al.* 2016). However, there is still a need to deeper investigate the potential productivity of fodder woody species and the management of the access by animals to this forage resource (Luske 2014; Vandermeulen *et al.* 2016). It will also be determinant to measure the economic balance between investments, labour and profits (Bestman *et al.* 2014) to ensure that this fodder resource provides positive economic outcomes for farmers.

Conclusion

Feeding ruminants with browse species has been practiced in many regions while it has progressively declined in intensive production systems. Nevertheless, environment-friendly policies are promoting silvopastoral systems as multipurpose shrubs and trees are known to be able to deliver ecosystem services. Furthermore, woody fodder has been reported to improve ruminal protein digestion, reduce parasitic infestation or lessen methane emissions but limitations such as toxins can restrict their use. Integrating this overlooked forage resource in ruminant husbandry can be achieved by direct browsing, cut-and-carry systems or conserving fodder. Several programs are studying the pelleting or ensiling of browse fodder. In optimal conditions, shrubs and trees sustain and further enhance animal production. As the renewed interest in using this fodder resource more intensively is rather young, further research is needed to more deeply investigate a wider range of systems and promising species, especially in temperate regions.

Conflicts of Interest

The authors declare no conflicts of interest.

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745 Table 1. Main feeding methods, animals and woody species in silvopastoral systems.

Feeding system	Type/Description	Animal	Trees/shrubs species	Examples of regions/countries where it is used	References
Browsing	Hedgerows	Cattle	*Leucaena leucocepahala*	Northern Australia	Dalzell *et al.* (2006)
			Various native species: e.g. *Fraxinus excelsior*, *Quercus* spp., *Corylus avellana, Acer* spp.	Europe e.g. France, Belgium	Baudry *et al.* (2000), Liagre (2006); Vandermeulen *et al.* (2016)
		Cattle, goats, sheep	Indigenous and introduced species, e.g. *Calliandra calothyrsus* *Sesbania sesban,* etc.	Africa e.g. Kenya, Rwanda, Tanzania, Malawi	Franzel *et al.* (2014); Toth *et al.* (2017)
	Browse blocks	Sheep, cattle, goats	*Salix* spp., *Populus* spp.	New Zealand	Charlton *et al.* (2003), Douglas *et al.* (2003), Pitta *et*

					al. (2007)
			Quercus spp., *Corylus avellana*, *Robinia pseudoacacia*, etc.	Greece	Papachristou and Papanastasis (1994)
	Scattered trees and shrubs	Cattle	*Desmanthus* spp. + other woody legumes	Australia	Rangel and Gardiner (2009), Gardiner *et al.*(2013)
Pruned fodder	Traditional cut-and-carry systems	Cattle, sheep, goats	Various species e.g. *L. leucocepahala*, *Ficus* spp., *Populus* spp., *Chamaecytisus prolifer* var. *palmensis*	Asia e.g. Indonesia, Nepal, China; Africa	Devendra (1989), Calub (2003), Cook *et al*. (2005)
	Shredding	Cattle Sheep, goats	*Fraxinus excelsior* *Quercus* spp., *Fagus*	Mediterranean region e.g. Greece	Papanastasis *et al*. (2009)

			spp.		
	Pollarding	Sheep, goats, cattle	*Morus alba*, *Fraxinus excelsior*, *Salix* spp., *Populus* spp., *Quercus* spp., *Fagus* spp.	Mediterranean region e.g. South of France, Greece; New Zealand	Charlton *et al.* (2003), Liagre (2006), Papanastasis *et al.* (2009)
	Coppicing	Sheep, cattle	*Salix* spp., *Populus* spp.	New Zealand	Charlton *et al.* (2003), Douglas *et al.* (2003)
Preserved forage	Dried	Sheep, cattle	*Fraxinus excelsior*	France	Liagre (2006)
	Silage	Goats, cattle	*Salix* spp.	Europe e.g. United Kingdom, The Netherlands	Bestman *et al.* (2014), Smith *et al.* (2014)
	Pellets	Cattle, goats, buffalo	*Morus alba*, *Leucaena leucocepahala*,	India, Thailand	Anbarasu *et al.* (2004), Huyen *et al.* (2012), Hung *et al.*

	Tectona grandis	(2013)

Table 2. Examples of management and production characteristics of silvopastoral woody species and limitations of their use to feed ruminants.

Species	Ecological area	Utilization practices/management	Potential yield	Limitations	References
Calliandra calothyrsus	Humid to sub-humid tropics Mean T° between 18-28°C 700-4000 mm 0-1850 m altitude	Hedgerows: Seedlings planted 0.5-1.0 m apart in hedgerows spaced 3-4 m apart, Fodder banks spaced 0.5-1.0 m apart in a grid pattern Cut-and-carry	3-14 t of DM/ha.year^{1}	Possibly due to high CT content (> 50 g kg DM ; see Table 3)	Cook *et al.* (2005)
Corylus avellana	Eurasia (subatlantic-submediterranean trend) Up to 1700 m	Hedgerows	ND	ND	Rameau *et al.* (1989); Vandermeulen *et al.* (2016); Thenail *et al.* (2014)
Desmanthus virgatus	From continuously wet to lengthened	Pure legume in cut-and-carry systems	Up to 7.6 t	ND	Cook *et al.* (2005); Jones and Brandon (1998)

	dry season environments Up to 1800 m	Used in legume-grass pasture in Queensland, Australia	DM/ha[1]		
Fraxinus excelsior	Europe (subatlantic trend) Up to 1400 m	Hedgerows Pollarding or shredding (fresh or dried)	40-60 kg of leaves/tree.year[2]	ND	Rameau *et al.* (1989); Liagre (2006)
Leucaena leucocephala	Sub-tropics Annual rainfall > 600 mm Optimum T°: 25-30°C	Hedgerows: sown 5-10 m apart	0.6-25.9 kg DM/tree[1] over a 2-year period	Mimosine content Considered as environmental weed	Cook *et al.* (2005); Dalzell *et al.* (2006); Mullen and Gutteridge (2002)
Populus deltoides x *nigra*	New Zealand notably	Coppicing or browsing of fodder blocks	1.6-18 kg DM/tree[2]	ND	Kemp *et al.* (2001)

Salix matsudana x *alba*	New Zealand notably	Coppicing or browsing of fodder blocks	<1-22 kg DM/tree[2]	ND	Douglas *et al.* (2003); Kemp *et al.* (2001); Oppong *et al.* (2001)
Salix viminalis	Eurasia Up to 400 m	Coppicing or browsing of fodder blocks	ND	ND	Rameau *et al.* (1989)

ND: Not documented

[1]Total biomass including branches and leaves

[2]Edible biomass or leaves

Table 3. Chemical composition and nutritive value of browse species.

Species	Plant part	Processing	CP (% DM)	NDF (% DM)	IVOMD	CT (%DM)	References
Calliandra calothyrsus	Leaves	Sun-dried	11.9[A]	53.4		19.6	Hove *et al.* (2001)
		Dried	25.3	39.6	0.409	0.4 – 12.7	Salawu *et al.* (1997)
Corylus avellana	Leaves (+ twigs)		9.1 – 18.1	43.2 – 53.5	0.384 – 0.535		Papachristou and Papanastasis (1994)
Leucaena leucocephala	Leaves	Sun-dried	20[A] 17[A]	34.9 27.8		13.4 3.8	Hove *et al.* (2001) McSweeney *et al.* (1999)
	Leaves + petioles	Oven-dried (65°C)			0.420 – 0.510		Edwards *et al.* (2012)
Populus deltoides x *nigra*	Leaves + edible stems (< 5mm diameter)		12.8 – 17.9			0.6 – 2.6	Kemp *et al.* (2001)

Robinia pseudoacacia	Leaves (+ twigs)		11.6 – 29.3	33.1 – 56.7	0.483 – 0.632		Papachristou and Papanastasis (1994)
Salix matsudana x *alba*	Leaves + edible stems (< 5 mm diameter)		11.7 – 15.5			1.8 – 4.2	Kemp *et al.* (2001)
Salix viminalis	Leaves + stems (< 8 mm diameter)	Dried	16.7	57.3	0.405		Smith *et al.* (2014)
		Silage	18.2	44.0	0.421	4.7	
	Leaves	Silage	21.9	28.7	0.511	10.3	

CP: Crude protein; CT: Condensed tannins; DM: Dry matter; IVOMD: *In vitro* organic matter digestibility; NDF: neutral detergent fiber.

[A]CP = N × 6.25