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


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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 leucocephala* 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; Vande Meerden *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 N₂O 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
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 CH₄ 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
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
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; Vanlaer 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. leucocephala* (134 g CT/kg DM).

Beside *L. leucocephala* 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; Vandenbergehe 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.

**References**


doi:10.1016/j.beproc.2009.06.009


Musonda K, Barry TN, McWilliam EL, López-Villalobos N, Pomroy WE (2009) Grazing willow (Salix spp.) fodder blocks for increased reproductive rates and internal parasite control in


<table>
<thead>
<tr>
<th>Feeding system</th>
<th>Type/Description</th>
<th>Animal</th>
<th>Trees/shrubs species</th>
<th>Examples of regions/countries where it is used</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Browsing</td>
<td>Hedgerows</td>
<td>Cattle</td>
<td><em>Leucaena</em> leucocephala</td>
<td>Northern Australia</td>
<td>Dalzell <em>et al.</em> (2006)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Various native species:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Europe e.g. France, Belgium</td>
<td>Baudry <em>et al.</em> (2000), Liagre</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>e.g. <em>Fraxinus excelsior,</em> <em>Quercus</em> spp., <em>Corylus</em></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td><em>avellana, Acer</em> spp.</td>
<td>Vandermeulen <em>et al.</em> (2016)</td>
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<tr>
<td></td>
<td></td>
<td>Cattle, goats,</td>
<td></td>
<td>Africa e.g. Kenya, Rwanda, Tanzania, Malawi</td>
<td>Franzel <em>et al.</em> (2014); Toth <em>et al.</em></td>
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<td></td>
<td></td>
<td>sheep</td>
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<td></td>
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<td>Indigenous and</td>
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<td></td>
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<td>introduced</td>
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<tr>
<td></td>
<td></td>
<td>species, e.g.</td>
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<td></td>
<td></td>
<td><em>Calliandra</em></td>
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<td></td>
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<td><em>calothyrsus</em></td>
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<td></td>
<td></td>
<td><em>Sesbania</em> sesban, etc.</td>
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<tr>
<td></td>
<td>goats</td>
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<tr>
<td>Pruned fodder</td>
<td>Traditional cut-and-carry systems</td>
<td>Shredding</td>
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<tr>
<td>Scattered trees and shrubs</td>
<td>Cattle</td>
<td>Desmanthus spp. + other woody legumes</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cattle, sheep, goats</td>
<td>Various species e.g. L. leucocephaala, Ficus spp., Populus spp., Chamaecytisus prolifer var. palmensis</td>
<td>Fraxinus excelsior</td>
<td></td>
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<tr>
<td>Asia e.g. Indonesia, Nepal, Devendra (1989), Calub (2003), Cook et al. (2005)</td>
<td>Mediterranean region e.g. Greece</td>
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<tr>
<td>cattle, sheep, goats</td>
<td>Mediterranean region e.g. Greece</td>
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</tbody>
</table>

Quercus spp., Corylus avellana, Robinia pseudoacacia, etc. in Greece by Papachristou and Papanastasis (1994).
<table>
<thead>
<tr>
<th>Method</th>
<th>Animals</th>
<th>Species</th>
<th>Regions/Other Information</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cattle</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Preserved forage</td>
<td>Dried</td>
<td>Sheep, cattle</td>
<td><em>Fraxinus excelsior</em></td>
<td>Liagre (2006)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>France</td>
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<tr>
<td>Silage</td>
<td>Goats, cattle</td>
<td><em>Salix</em> spp.</td>
<td>Europe e.g. United Kingdom, The Netherlands</td>
<td>Bestman <em>et al.</em> (2014), Smith <em>et al.</em> (2014)</td>
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</tbody>
</table>
Tectona grandis (2013)

746
Table 2. Examples of management and production characteristics of silvopastoral woody species and limitations of their use to feed ruminants.

<table>
<thead>
<tr>
<th>Species</th>
<th>Ecological area</th>
<th>Utilization practices/management</th>
<th>Potential yield</th>
<th>Limitations</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Calliandra</em> calothyrsus</td>
<td>Humid to sub-humid tropics</td>
<td>Hedgerows: Seedlings planted 0.5-1.0 m apart in hedgerows; Mean T° between 18-28°C; Fodder banks spaced 0.5-1.0 m apart in a grid pattern</td>
<td>3-14 t of DM/ha.year¹</td>
<td>Possibly due to high CT content (&gt; 50 g kg DM)</td>
<td>Cook <em>et al.</em> (2005)</td>
</tr>
<tr>
<td><em>Corylus avellana</em></td>
<td>Eurasia (subatlantic- submediterranean trend)</td>
<td>Hedgerows</td>
<td>ND</td>
<td>ND</td>
<td>Rameau <em>et al.</em> (1989); Vandermeulen <em>et al.</em> (2016); Thenail <em>et al.</em> (2014)</td>
</tr>
<tr>
<td><em>Desmanthus virgatus</em></td>
<td>From continuously wet to lengthened systems</td>
<td>Pure legume in cut-and-carry systems</td>
<td>Up to 7.6 t</td>
<td>ND</td>
<td>Cook <em>et al.</em> (2005); Jones and Brandon (1998)</td>
</tr>
<tr>
<td>Species</td>
<td>Origin/Environment</td>
<td>Management Method</td>
<td>DM/ha/DM/tree/ND</td>
<td>Reference(s)</td>
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<tr>
<td><strong>Fraxinus excelsior</strong></td>
<td>Europe (subatlantic trend)</td>
<td>Hedgerows</td>
<td>40-60 kg</td>
<td>Rameau et al. (1989); Liagre (2006)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pollarding or shredding (fresh or dried)</td>
<td>ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leucaena leucocephala</strong></td>
<td>Sub-tropics</td>
<td>Hedgerows: sown 5-10 m apart</td>
<td>0.6-25.9 kg</td>
<td>Cook et al. (2005); Dalzell et al. (2006); Mullen and Gutteridge (2002)</td>
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<tr>
<td></td>
<td>Annual rainfall &gt; 600 mm</td>
<td></td>
<td>Mimosine content</td>
<td></td>
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<tr>
<td></td>
<td>Optimum T°C: 25-30°C</td>
<td></td>
<td>2-year period</td>
<td></td>
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</tr>
<tr>
<td><strong>Populus deltoides x nigra</strong></td>
<td>New Zealand</td>
<td>Coppicing or browsing of fodder</td>
<td>1.6-18 kg</td>
<td>Kemp et al. (2001)</td>
<td></td>
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<tr>
<td></td>
<td>notably</td>
<td>blocks</td>
<td>ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>Origin</td>
<td>Region</td>
<td>Management Method</td>
<td>Biomass</td>
<td>Units</td>
</tr>
<tr>
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</tr>
<tr>
<td><em>Salix matsudana</em> x <em>alba</em></td>
<td>New Zealand</td>
<td>Coppicing or browsing of fodder blocks</td>
<td>&lt;1-22 kg DM/tree²</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td><em>Salix viminalis</em></td>
<td>Eurasia</td>
<td>Up to 400 m</td>
<td>Coppicing or browsing of fodder blocks</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND: Not documented

¹Total biomass including branches and leaves

²Edible biomass or leaves
Table 3. Chemical composition and nutritive value of browse species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Plant part</th>
<th>Processing</th>
<th>CP (% DM)</th>
<th>NDF (% DM)</th>
<th>IVOMD</th>
<th>CT (% DM)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Calliandra calothyrsus</em></td>
<td>Leaves</td>
<td>Sun-dried</td>
<td>11.9^A</td>
<td>53.4</td>
<td>19.6</td>
<td></td>
<td>Hove <em>et al.</em> (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dried</td>
<td>25.3</td>
<td>39.6</td>
<td>0.409</td>
<td>0.4 – 12.7</td>
<td>Salawu <em>et al.</em> (1997)</td>
</tr>
<tr>
<td><em>Corylus avellana</em></td>
<td>Leaves (+ twigs)</td>
<td></td>
<td>9.1 – 18.1</td>
<td>43.2 – 53.5</td>
<td>0.384</td>
<td>0.535</td>
<td>Papachristou and Papanastasis (1994)</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>Leaves + petioles (65°C)</td>
<td>Oven-dried</td>
<td>20^A</td>
<td>34.9</td>
<td>13.4</td>
<td></td>
<td>Hove <em>et al.</em> (2001) McSweeney <em>et al.</em> (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17^A</td>
<td>27.8</td>
<td>3.8</td>
<td></td>
<td>Edwards <em>et al.</em> (2012)</td>
</tr>
<tr>
<td><em>Populus deltoides</em></td>
<td>Leaves + edible stems (&lt; 5mm diameter)</td>
<td></td>
<td>12.8 – 17.9</td>
<td></td>
<td>0.6 – 2.6</td>
<td></td>
<td>Kemp <em>et al.</em> (2001)</td>
</tr>
<tr>
<td>Species</td>
<td>Material Description</td>
<td>CP</td>
<td>CT</td>
<td>NDF</td>
<td>Source</td>
<td></td>
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<td>---------------------</td>
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</tr>
<tr>
<td><em>Robinia pseudoacacia</em></td>
<td>Leaves (+ twigs)</td>
<td>11.6 – 29.3</td>
<td>33.1 – 56.7</td>
<td>0.483 – 0.632</td>
<td>Papachristou and Papanastasis (1994)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Salix matsudana</em> x <em>alba</em></td>
<td>Leaves + edible stems (&lt; 5 mm diameter)</td>
<td>11.7 – 15.5</td>
<td>1.8 – 4.2</td>
<td>1.8 – 4.2</td>
<td>Kemp <em>et al.</em> (2001)</td>
<td></td>
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</tr>
<tr>
<td><em>Salix viminalis</em></td>
<td>Leaves + stems Dried (&lt; 8 mm diameter)</td>
<td>16.7</td>
<td>57.3</td>
<td>0.405</td>
<td>Smith <em>et al.</em> (2014)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Silage</td>
<td>18.2</td>
<td>44.0</td>
<td>0.421</td>
<td>4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leaves Silage</td>
<td>21.9</td>
<td>28.7</td>
<td>0.511</td>
<td>10.3</td>
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</tr>
</tbody>
</table>

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

\[ \text{CP} = \text{N} \times 6.25 \]