Nutritional and fermentation quality of ensiled willow from an integrated feed and bioenergy agroforestry system in UK

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Abstract

Agroforestry, the integration of trees and agriculture, is valued as a multifunctional land use approach that balances the production of commodities (food, feed, fuel, fibre etc.) with non-commodity outputs such as environmental protection and cultural and landscape amenities.

In this study, the possibilities for fodder production from a short rotation coppice of willow (*Salix viminalis*) used for wood chips to produce energy were investigated. The nutritional value and ensilability were assessed from first year regrowth of willow harvested on 29 June 2011 at Wakelyns Agroforestry, Suffolk, UK. The willow branches with a stem diameter less than 8 mm were manually harvested from 4 plots in two replicates. From 2 plots, another sample was prepared including leaves only. Both dried raw material and silage samples ensiled in evacuated polyethylene bags were analyzed.

The crude protein concentration was relatively high in leaf + stem silage (182 g/kg dry matter (DM)) and even higher in leaf only silage (219 g/kg DM) and the fibre concentration was relatively low. However, the organic matter digestibility determined by *in vitro* pepsin-cellulase method was low (0.421 for leaf + stem silage and 0.511 for leaf only silage) and it cannot be considered as a suitable feed for lactating dairy cows. However, it might be suitable for other animal groups with lower energy requirements.

The appearance and smell of the silage samples at opening of the vacuum plastic bags was rather pleasant with minor deteriorations (probably yeasts) visible. The extent of fermentation was low and pH high (5.79) for a rather low DM material (DM concentration 276 g/kg). The water soluble carbohydrates of the raw material (35 g/kg DM) and the residual water soluble carbohydrate concentration in silages was relatively low, which at least partly explains the restricted production of fermentation acids. The fermentation profile was heterofermentative (acetic acid dominated instead of lactic acid). The concentrations of total condensed tannins fractions were almost twice as high in the leaf only silage compared to leaf + stem silage.

Although the feed values of willow were low, it may have a role in multifunctional systems, where it can provide additional values in grazing situations such as self-medication and microclimate benefits. For easy and efficient use in animal production, controlled browsing might be used; otherwise methods for harvesting and preservation need to be developed. There seems to be some scope for ensiling willow material.

This work is part of an EU FP7 funded project “Sustainable organic and low input dairying” (SOLID, KBBE.2010.1.2-02). For more information on the project, see www.solidairy.eu.

Key words: Condensed tannins, digestibility, feed value, fermentation quality, *Salix viminalis*, silage

Introduction

Agroforestry, the integration of trees and agriculture, is valued as a multifunctional land use approach that balances the production of commodities (food, feed, fuel, fibre etc.) with non-commodity outputs such as environmental protection and cultural and landscape amenities (IAASTD, 2008). Silvopastoral systems that combine livestock and trees offer two main advantages for the animals. First, trees modify microclimatic conditions including temperature, water vapour content or partial pressure, and wind speed, which can have beneficial effects on pasture growth and animal welfare (Bird, 1998; Jose et al., 2004). Second, trees also provide alternative feed resources during periods of low forage availability, particularly in climates with seasonal droughts such as the Mediterranean (Papanastasis et al., 2008). Further, trees and shrubs may contain certain substances such as tannins that may affect nutrient availability or anthelmentic effects acting as self-medication (Mupeyo et al., 2011).

Traditionally, tree fodders have been important for ruminant nutrition, and still remain significant in some European farming systems, for example, deciduous oak leaves are shredded and dried for sheep fodder in Greece, while in Crete and Sicily, carob pods are stored for fodder (Eichhorn et al., 2006). The most extensive silvopastoral system in Europe is the dehesa (scattered cork oaks) which covers 3.5 million hectares in the south-west of the Iberian peninsula (Olea et al., 2005; Casals et al., 2008). Pollarding (cutting branches from trees two to three metres above ground level) for fodder was particularly common in northern Europe and mountainous areas such as the Pyrenees, Alps and high pasture areas of the Basque country.

Since the introduction of agroforestry as a concept in the late 1970's (Bene et al., 1977), the emphasis has been on the development of new systems designed to fulfil the potential benefits of increased productivity balanced with resource and environmental conservation. Silvopastoral systems that cultivate trees specifically for fodder include fodder bank systems, where trees and shrubs are planted at high densities and pruned regularly to maximize productivity, and alley pasture systems which further integrate livestock and tree production with rows of trees and shrubs separated by alleys of pasture, with perceived benefits to enhanced nutrient cycling and improved animal welfare (Ibrahim et al., 2005).

In modern silvopastoral systems that seek to maximize resource efficiency, however, there is growing interest in exploiting browse as an extra resource from trees planted for other purposes. For example, farmers in New Zealand have recently been exploring the value of willows and poplars planted for soil conservation to provide emergency feed during severe summer droughts (Anon., 1996). The value of tree fodder as a feed resource to buffer forage shortages is also increasingly appreciated in areas of seasonal droughts (Lefroy et al., 1992; Andrews, 1998; Moore et al., 2003; Papanastasis et al., 2008).

Traditionally, many species of deciduous trees have been used for fodder, in particular Wych or Scots Elm (*Ulmus glabra*), ash (*Fraxinus excelsior*), silver birch (*Betula pendula*), downy birch (*Betula pubescens*) and goat willow (*Salix caprea*) (Austad and Hauge, 2006). In Norway, cattle and pigs were primarily fed leaves of *Ulmus glabra* and *Fraxinus excelsior* while leaves of *Betula* sp. and *Alnus* sp. were given to sheep and goats (Austad and Hauge, 2006). Important fodder resources in Mediterranean systems include natural woody plant communities such as the maquis, garrigues and dehesa, and cultivated species including leguminous shrubs such as bladder senna (*Colutea arborescens*) and tree medic (*Medicago arborea*), as well as the C4 perennial saltbushes (*Atriplex halimus* and *A. nummularia*) (Papanastasis et al., 2008). More recently, the productivity and nutritional value of novel species such as black locust (*Robinia pseudoacacia*), tagasaste or tree lucerne (*Chamaecytisus palmensis*), and thornless honeylocust (*Gleditsia triacanthos*) have been the subject of investigation, particularly in silvopastoral systems of North America and the Mediterranean (Barrett et al., 1990; Burner et al., 2005; Burner et al., 2008; Papanastasis et al., 2008).

Browse from trees and shrubs plays an important role in feeding ruminants in many parts of the world, particularly in the tropics, and there has been considerable research into the nutritional potential and limitations of many tropical fodder species (Devendra, 1992). However, comparatively little is known about the potential of temperate browse species. The increasing need for food and bioenergy requires new solutions to be found. Agroforestry can be one way to combine these goals.

The possibilities for fodder production in UK from a short rotation coppice of willow used for wood chips to produce energy were investigated by Smith et al. (2012). In this study, the same material was used to evaluate the possibilities of ensiling the willow for subsequent use for livestock as one additional benefit from the system. This work is part of an EU FP7 funded project "Sustainable organic and low input dairying" (SOLID, KBBE.2010.1.2-02), which aims to support developments and innovations in organic and low input dairy systems to optimize competitiveness while maximizing the potential of these systems to deliver environmental goods and biodiversity. For more information on the project, see www.solidairy.eu.

Materials and Methods

The nutritional value and ensilability was assessed from first year regrowth of short rotation coppiced willow (*Salix viminalis*) harvested on 29 June 2011 at Wakelyns Agroforestry, Suffolk, UK (Figure 1). The integrated system is based on an alley-cropping design, with twin rows of SRC willow separated by 12 m wide alleys of pasture. The tree rows are orientated north/south to minimise shading effects in the alleys. The willow is harvested on a 2-3 year rotation, dried and chipped for use in wood chip boilers. For more details on the experiment, see Smith et al. (2012).

To evaluate the potential for ensiling, the willow branches with a stem diameter less than 8 mm were manually harvested from 4 plots in two replicates. From 2 plots, another sample was prepared including leaves only. Subsamples were chopped to a length of approximately 1 cm and ensiled in evacuated polythene bags (approximately 200 grammes per bag).

Both dried raw material and silage samples were analyzed. Analysis of the silage took place after an approximately six month ensiling period. The feed values and fermentation quality of the samples were analyzed at MTT Agrifood Research Finland using standard laboratory methods as reported by Seppälä et al. (2012). The organic matter digestibility (OMD) of the samples was determined using a pepsin-cellulase method, and the solubility values were converted to represent *in vivo* digestibility values using the general equation presented by Huhtanen et al. (2006).

The concentration of free (FreeT), protein-bound (PT) and fibre-bound (FT) condensed tannins were determined in feed samples using the procedure proposed by Pérez Maldonado and Norton (1996). Condensed tannins from quebracho powder (Roy Wilson Dickson Ltd., Mold, U.K.) were used as the standard.

Figure 1. Harvesting willow in UK on 29 June 2011 (photo: K. Leach) and subsequent willow leaf silage after a storage of half a year (photo: M. Rinne).

Results and Discussion

Chemical composition and digestibility of the willow material

The chemical composition and *in vitro* digestibility of leaf + stem raw material and silage, and the leaf only silage is presented in Table 1. The CP concentration was relatively high in leaf + stem silage (182 g/kg DM) and even higher in leaf only silage (219 g/kg DM) and the fibre concentration was relatively low. However, the OMD determined by *in vitro* pepsin-cellulase method was low (0.421 for leaf + stem silage and 0.511 for leaf only silage) and it cannot be considered a suitable feed for lactating dairy cows, for which the D-value recommendation of forage is typically 0.65-0.70. However, it might be suitable for other animal groups with lower energy requirements.

The *in vitro* method we used has not been validated to be used on woody materials and there are some uncertainties related to the use of it. In literature, the reported OMD values for woody materials average around 0.5, which is comparable to our values, but the range is wide. However, it must be remembered that predicting nutritive value of tree material reliably from chemical analysis is difficult, because of the interference of CT’s and other phenolic compounds with the digestibility of the fibre fraction (Tolera et al., 1997). McWilliam et al. (2005) validated a reasonably reliable calibration curve for prediction of *in vivo* digestibility of willow by sheep, from the results of *in vitro* analysis based on the enzymatic method of Rougham and Holland (1977), across a limited range of composition. This gave slightly different predictions from those derived using a calibration curve for grass-clover herbage and was therefore deemed preferable.

Measuring digestibility *in vivo* would be the best method to determine digestibility. Organic matter digestibility measured in cryptorchid lambs in New Zealand fed fresh tree fodder twice daily, ranged from 0.64 to 0.70 for willow and from 0.62 to 0.67 for poplar over one growing season (McWilliam et al., 2005). Intake of these lambs was between 0.75 and 1.12 kg DM/day for poplar and 0.91 and 1.01 kg DM/day for willow (McWilliam et al., 2005).

Digestibility generally decreases over the growing season; for example, Papachristou and Papanastasis (1994) measured *in vitro* organic matter digestibility of a range of Mediterranean species over the growing season. This ranged from 0.54 for *Corylus avellana* to 0.67 for *Carpinus orientalis* for fresh growth in spring (average 0.61 for 7 species), and declined over the season to an average of 0.47 as the leaves senesced in September.

In vitro organic matter digestibility of poplar and willow in New Zealand was recorded by Kemp et al. (2003) as 0.70 and 0.69 respectively, with significantly higher levels in spring than summer. A decline over the season of approximately 0.10 was attributed mainly to maturing of the thin stems as the digestibility of the leaves decreased by only 0.03 units over the growing season. Willow leaves have a higher OMD than the edible stems (<5mm diameter); the difference varies depending on species, but OMD of leaves can be twice that of the edible stems (Oppong et al., 2001).

McWilliam et al. (2005) found that while the digestibility of willow and poplar tree fodders declined from late spring to autumn, the decline in OMD was much smaller than the decline in digestibility of grass-based pastures in New Zealand over the same period, thus making these tree fodders effective supplements to livestock grazing drought pastures.

Experiments have shown that the diameter of stems selected by livestock increases with time; after 10 weeks, willow selected by lambs increased in diameter from 3 to 4.2 mm diameter (Diaz Lira et al., 2008), while cattle selected willow increasing in diameter from 4 mm initially up to 8 mm in diameter after 81 days (Moore et al., 2003). In this last trial the amount eaten also increased over time, from approximately 1.5 kg/cow/day at the start to 3.5 kg/cow/day after 81 days (Moore et al., 2003). These increases may have been influenced by familiarity and the availability of alternative forage.

Tree management also influences chemical composition of fodder; for example, management by short rotation coppicing produces fresh growth with a high leaf-to-stem ratio, low in lignin and high potential feeding value compared to mature trees (Baertsche et al., 1986).

Table 1. Chemical composition and *in vitro* digestibility of willow silages.

	Leaf + stem				Leaf only silage	
	Raw material		Silage			
	Mean	S.D.[1)]	Mean	S.D.	Mean	S.D.
n	4		8		4	
Dry matter (DM; g/kg)	265	22.3	276	20.2	282	3.8
In DM (g/kg DM)						
Ash	71	2.5	73	3.7	94	5.4
Crude protein	167	17.3	182	12.8	219	13.1
Water soluble carbohydrates	35.3	2.36	7.9	1.66	15.4	5.03
Neutral detergent fibre	573	12.9	440	18.4	287	7.3
Acid detergent fibre	410	13.3	317	14.3	199	8.2
Lignin	184	12.8	85	6.7	52	5.6
Based on *in vitro* pepsin cellulase solubility						
Organic matter digestibility (g/kg)	0.405	0.0267	0.421	0.0257	0.511	0.0106
D-value[2)] (g/kg DM)	376	25.8	390	24.6	463	11.7

[1)]S.D. = Standard deviation [2)]Digestible organic matter

Ensilability

During ensiling, concentrations of water soluble carbohydrates (WSC) and the fibre fractions decreased clearly (Table 1). During the fermentation process, WSC are converted to fermentation acids, which explains the decrease. A decrease in fibre fractions is also often seen in e.g. grass silages, and it can be explained as a result of acid hydrolysis. The large extent of fibre degradation in this material with relatively high pH is however surprising.

The appearance and smell of the silage samples at opening of the vacuum plastic bags was rather pleasant with minor deteriorations (probably yeasts) visible. The fermentation quality of the willow silages is reported in Table 2. The extent of fermentation was low and pH high (5.79) for a rather low DM material (DM concentration 276 g/kg). The WSC of the raw material (35 g/kg DM) and the residual WSC concentration in silages was low, which at least partly explains the restricted production of fermentation acids. Possibly the CT present in the material also play a role. The fermentation profile was heterofermentative (acetic acid dominated instead of lactic acid).

The results show that willow material has some potential for ensiling, but it should be verified in larger scale experiments. Questions related to harvesting, storage and feeding technology are obviously key points that need to addressed in order to effectively use agroforestry in a larger scale. Manual cutting and transporting is laborious and time consuming, while direct browsing requires careful management that balances keeping tree height accessible to livestock with minimizing damage to the tree. Innovative dairy farmers in the Netherlands have been investigating silage making as a means of preserving willow coppice for feeding to dairy goats (see www.voederbomen.nl/oogst for a film of the process). Fodder blocks of trees can be established on unproductive land (e.g. willow does well in wet areas), and regular coppicing or direct browsing maintains the blocks at a manageable height. Alternatively, pollarding promotes tree growth above livestock grazing height and reduces canopy effects on pasture productivity (Benavides et al*.*, 2009).

One of the limitations of using tree fodder as a feed is that the nutritive value and digestibility peaks in spring and decreases through to autumn. Baertsche et al. (1986) carried out ensiling trials of several short rotation coppiced hardwood species. They found that all species apart from elm and willow ensiled adequately after 24 days. Willow and elm samples developed a mould growth and deteriorated rapidly, which was attributed to their high levels of dry matter (over 40% after wilting) and lower leaf-to-stem ratios compared to other species. This meant that insufficient moisture and WSC were available for rapid fermentation to take place, and it was difficult to pack silos tightly so preventing completely anaerobic conditions. The chemical composition of the other species changed little with ensiling, although crude protein decreased slightly. In temperate Bhutan, willow leaves were mixed with other forages to produce silage, with "good animal performance" reported (although no details are given) (Roder, 1992). However, hay made from small willow branches was not acceptable to cattle.

Table 2. Fermentation quality of willow silages.

	Leaf + stem silage		Leaf only silage	
	Mean	S.D.[1)]	Mean	S.D.
pH	5.80	0.225	5.78	0.064
In dry matter (g/kg)				
Lactic acid	3.9	3.09	2.5	0.50
Acetic acid	6.3	1.36	4.7	1.27
Propionic acid	0.4	0.58	0.1	0.02
Butyric acid	0.4	0.47	0.2	0.02
Isobutyric acid	0.0	0.01	0.0	0.00
Isovaleric acid	0.1	0.02	0.1	0.02
Valeric acid	0		0	
Capronic acid	0		0	
Ethanol	0		0	
Ammonium N (g/kg total N)	45	12.5	19	3.0

[1)]S.D. = Standard deviation

Condensed tannins

The concentrations of free, protein-bound, fibre-bound and total condensed tannins in the silages are presented in Table 3. The concentrations of all tannin fractions were almost twice as high in the leaf only silage compared to leaf + stem silage. Although tree fodder is generally higher in protein and minerals than dry season pasture, the presence of tannins and other phenolic compounds may reduce digestibility and availability of protein, and palatability and intake (Tolera et al., 1997). The concentration of the anti-nutritional factots crucially affects the productive outcome of this effect. At low concentrations, some condensed tannins (CT) can in fact have a beneficial influence, by reducing protein degradation in the rumen and increasing the flow of protein and essential amino acids to the intestine (Rogosic et al., 2006). The acceptable limit for condensed tannin concentrations is <5 g CT/100 g DM, but sheep have been observed browsing readily on leaves with higher CT concentrations than this (Oppong et al., 2001). Nevertheless, the effects depend not only on the concentration of CT in feeds, but also on their reactivity, associated with their chemical nature (Kraus et al., 2003). The influence of anti-nutritional factors introduces variability to *in vitro* evaluation of tree fodders, and some uncertainty into the prediction of animal performance based on *in vitro* analyses (Papachristou and Papanastasis, 1994; McWilliam et al., 2005).

Levels of CT vary considerably between species. Secondary compound concentrations can vary also between different species of the same genus (e.g. CT concentration of *Salix kinuyanagi* was four times higher than *Salix matsudana x alba* (Oppong et al., 2001)) and even between cultivars of the same species (Kemp et al., 2003). Environmental conditions can influence the level of secondary compounds; total CT concentrations from willow leaves in a New Zealand silvopasture varied between 45 and 303 g/kg DM with the higher concentrations recorded from willow grown in more hostile sites (low soil fertility, low temperatures and strong winds) (Oppong et al., 2001). Given the levels of CT reported here an *in vitro* evaluation of the effect of feeding willow with or without a tannin binding agent would provide more insight on the potential biological effect of such secondary compounds (Makkar et al., 1995).

Other secondary compounds have importance in particular tree species. For example, although the phenolic glucoside salicin is well known to be a component of willow and to have anti-inflammatory properties, it has not been widely evaluated in terms of its content within tree fodders or consequent effects on animal performance. Salicin content is known to influence selection of willow and poplar by herbivores including sheep (McKinnon et al, 2000, in Kemp et al., 2003). However, the balance between rejection of plant species or varieties on the basis of palatability (Boeckler et al., 2011), and the intermittent positive selection by animals of certain species (presumed to be for self medication or meeting particular metabolic needs), which is anecdotally reported, is not well explained in the scientific literature.

Table 3. Concentrations of different condensed tannin fractions in willow silages.

	Leaf + stem silage		Leaf only silage	
	Mean	S.D.[1)]	Mean	S.D.
Condensed tannins (g/100 g dry matter)				
Free	4.7	3.40	10.3	3.19
Protein-bound	1.8	0.88	2.7	0.33
Fibre-bound	0.8	0.50	1.5	1.01
Total	7.3	3.64	14.6	3.87

[1)]S.D. = Standard deviation

Conclusions

Although the feed values were low, willow may have a role in multifunctional systems, where it can provide additional values in grazing situations such as self-medication and microclimate benefits. For easy and efficient use in animal production, controlled browsing might be used, otherwise methods for harvesting and preservation need to be developed. There seems to be some scope for ensiling willow material.

The unpredictability and variability in feed supply from agro-forestry systems seems to be one of the biggest challenges to their use at present as there are so many different species available and the seasonal variation is so great. However, fast growing trees provide the potential for a large quantity of material. Another challenge is the lack of structured preparation and distribution, and mechanisation for harvesting/handling - both for preparation and feeding. Using a silvopastoral approach needs a change in the mindset of the farmer and several practical issues in production system need to be solved. Much of the work to date has been done with tropical trees and information from temperate climates in Central and Northern Europe is limited.

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