Agroforest Syst
DOI 10.1007/s10457-016-0041-x

Behaviour and browse species selectivity of heifers grazing in a temperate silvopastoral system

Sophie Vandermeulen · Carlos Alberto Ramírez-Restrepo · Christian Marche · Virginie Decruyenaere · Yves Beckers · Jérôme Bindelle

Received: 30 June 2015 / Accepted: 11 November 2016

Abstract In Belgium silvopastoral grazing systems associating trees and pasture are instrumental in enhancing dynamic trade-offs between ruminant farming and habitat improvement. A 130-day study was conducted in Belgium from April to September 2013 to evaluate the effects of browsing a combination of shrubs and trees (i.e. hedge) on the selective behaviour of cattle and to relate these observations to changes in forage nutritive value. Twelve Holstein dairy heifers (*Bos taurus*; 487 kg) were allocated to either a control ryegrass pasture (i.e. control pasture group; CPG) or a pasture plus unrestricted browsing (i.e. browsing group; BG) of a hedge composed of shrubs and trees. Behaviour and selectivity towards the woody species were recorded for 14 h on a daily basis during three consecutive days over spring, early summer and late summer. Leaves and stems of woody species and faecal samples were collected during each season to analyse their nutritive value and predict the dry matter intake by means of near infrared reflectance spectroscopy. Integrating shrubs and trees along a pasture influenced the heifers' behaviour and BG heifers spent 19.3, 5.9 and 5.4% of their time browsing during spring, and early and late summer, respectively ($P < 0.001$). This behaviour was correlated to the pre-grazing pasture biomass ($r = 0.50$; $P < 0.001$). Compared with the summer seasons, the greater browsing activity in spring was associated with higher plant feeding value. Overall, the most ingested species were *Carpinus betulus, Cornus sanguinea, Corylus avellana* and *Crataegus monogyna.* It was concluded that cattle use a significant time budget for browsing on temperate ryegrass pasture but further research is required to investigate potential benefits of silvopastoral systems in Belgium.

Keywords Agroforestry · Ruminant · Woody fodder · Dietary preference · Feeding value · NIRS

S. Vandermeulen (✉) · Y. Beckers · J. Bindelle
Precision Livestock and Nutrition Unit, Gembloux Agro-Bio Tech, University of Liège, 2 Passage des Déportés, 5030 Gembloux, Belgium
e-mail: vandermeulen.sophie@gmail.com

S. Vandermeulen
Research Foundation for Industry and Agriculture, National Scientific Research Foundation (FRIA-FNRS), 5 Rue d'Egmont, 1000 Brussels, Belgium

C. A. Ramírez-Restrepo
CSIRO Agriculture, ATSIP, James Cook University, 145 James Cook Drive, Townsville, QLD 4811, Australia

C. Marche
Centre des Technologies Agronomiques, 16 Rue de la Charmille, 4577 Strée, Belgium

V. Decruyenaere
Production and Sectors Department, Walloon Agricultural Research Centre, 8 Rue de Liroux, 5030 Gembloux, Belgium

Introduction

Browsing woody forage by ruminants is a common practice during the dry season in the tropics (Lefroy

Published online: 19 November 2016

et al. 1992; Liagre 2006), in high mountains (Vandenberghe et al. 2007), and in the Mediterranean region (Le Houérou 2006; Papanastasis et al. 2008). Various reasons motivate ruminants to browse shrub and tree forage (STF), including strong seasonal shortages of herbaceous forage biomass (Liagre 2006; Lefroy et al. 1992) or low quality grass supplementation (Hirata et al. 2008; Leng 1992). Trees and shrubs with grasses growing underneath (i.e. silvopastoral system) supply energy, protein and other nutrients (Lefroy et al. 1992). They also provide shelter (Liagre 2006), improve livestock productivity (Murgueitio et al. 2011; Paciullo et al. 2011), offspring survival (Liagre 2006; Pollard 2006) and they can reduce internal parasite infestation (Nguyen et al. 2005; Ramírez-Restrepo et al. 2010a). Condensed tannins (CT)-forage legumes (i.e. herbaceous and trees) have been demonstrated to induce in sheep increased reproductive efficiency (Ramírez-Restrepo et al. 2005a), reproductive rate (Pitta et al. 2005), lamb growth and wool production (Ramírez-Restrepo et al. 2004, 2005a). They can lead to the expansion of immune cells subsets (Ramírez-Restrepo et al. 2010a), while lowering nematode parasite fecundity (Mupeyo et al. 2011), parasite counts, anthelmintic drenching (Ramírez-Restrepo et al. 2005b), and methanogenesis (Ramírez-Restrepo et al. 2010b).

In Belgium, trees and shrubs have been withdrawn from production systems during agricultural intensification (Nerlich et al. 2013). However, they are promoted again through the establishment of hedges and woody strips into pasture owing to new European agri-environmental policies (Walloon Government 2014). Unfortunately, little is known about cattle browsing behaviour under these conditions and its effects on nutrition and productivity. Consequently, farmers do not take advantage of the potential benefits of this forage resource. The first objective of this study was to measure the grazing behaviour of Holstein heifers in presence of a hedge composed of 11 temperate browse species planted along a mixed *Lolium perenne* (ryegrass)/*Poa trivialis* (rough meadow grass) pasture and to determine which woody species are consumed. The second objective was to determine if the behaviour and browsing selectivity of woody species are associated with the changes in nutritive value of the silvopastoral forage components throughout the seasonal periods.

Materials and methods

Location and experimental treatments

A grazing experiment was conducted at the Centre des Technologies Agronomiques (CTA), Strée, Belgium (50°30′N, 18°6′E) between 29 April and 5 September (130 days) of 2013. The experiment was designed and conducted following animal ethics guidelines issued by the Belgian Government. Twelve Holstein dairy heifers (*Bos taurus*) were weighed, balanced and randomly allocated to control pasture group (CPG; 1 ha grazing pasture; n = 6, 489 ± 41 kg live weight (LW), mean ± SD) and browsing group (BG; 1 ha grazing pasture and browsing, n = 6, 485 ± 67 kg). Heifers had access to water ad libitum throughout the study. Pasture in both treatments was dominated by perennial ryegrass (*Lolium perenne*), rough meadow grass (*Poa trivialis*), dandelion (*Taraxacum* spp.) and white clover (*Trifolium repens*). Previously during the spring of 2005 the hedge was planted with 11 three-shrub species (i.e. woody forage). They were: *Acer campestre*, *A. pseudoplatanus*, *Carpinus betulus*, *Cornus sanguinea*, *Corylus avellana*, *Crataegus monogyna*, *Fraxinus excelsior*, *Populus nigra*, *Quercus robur*, *Robinia pseudoacacia* and *Sambucus nigra.* Shrubs and trees were pruned each year at 2.5 m high as a period maintenance.

The experiment was conducted in late spring (May), early summer (July) and late summer (September) and behaviour was monitored during three to four consecutive measurement days in each time block. An adaptation period of 14 days was implemented preceding measurement periods, and the heifers were allocated into a pasture with similar characteristics. At the initiation of the experimental periods, animals were weighed and moved to the experimental paddocks and behaviour measurements started 3–4 days later for 3–4 days (3 days per group). Once observations were finished, animals were weighed and maintained as a single grazing herd between measurement periods. The same groups of heifers allocated respectively to treatments BG and CPG in spring were kept in early and late summer. In total, for each season, animals were kept 20–22 days in separate experimental groups (i.e. BG and CPG treatments) and they were kept together 27–35 days between measurement periods. The experimental paddocks were the same during the whole experiment. Paddock rotation was

Table 1 Description of the recorded behavioural activities

Behaviour category	Description
Grazing	Eating herbaceous species on the pasture
Browsing	Eating ligneous species in the hedge
Search for food	Searching for food with the head downwards (grazing) or upwards (browsing) without ingestion
Rumination (standing/lying)	Chewing with the specific regular pattern for rumination, either lying or standing
Resting (standing/lying)	The heifer is still with open or closed eyes (standing or lying) or with the head backwards (lying)
Social activity	Playing, fighting or mounting another animal
Grooming	Licking oneself or another heifer
Walking	Walking or running (without eating/searching for food)
Drinking	Drinking at the common trough
Other activity	Any other activity not described before

performed to allow a resting period of 20–30 days according to the season. Lower paddock biomass results from low rainfall in July and September and subsequent shorter resting period compared to that in May. At the end of the first season, the maximum height at which heifers browsed was measured at 15 sites along the hedge.

Weather data were collected daily by CTA. The monthly average temperature was 10.8, 19.6 and 14.2 °C, and average rainfall was 36.3, 17.7 and 19.4 mm in spring, early and late summer, respectively.

Plant measurements

Pre- and post-grazing pasture biomass was determined with a rising plate meter ($30 \times 30 \times 1.5$ cm^3 aluminium plate 4.05 kg m^{-2}) deployed in a zigzag pattern with minimum 33 measurements in each paddock using an in-house calibration curve (Sanderson et al. 2001).

The pasture botanical composition was determined in spring before starting the measurement period, using 132 quadrats (0.090 m^2) set every 10 m along four transects (32–34 quadrats each) following the dry-weight rank method of Nijland (2000). The three most abundant species in each quadrat were classified as highest to lowest biomass by ranking from 1 to 3 according to their biomass contribution on a dry-weight basis. For each species, the sum for rank 1, 2 and 3 were multiplied by 3, 2 and 1, respectively to obtain the dominance percentage. The proportion of STF species in the hedge was measured by dividing the number of individuals by the total number of shrubs and trees present.

Before each measurement period, samples of mixed pasture forage (n = 6; 3 in each paddock), perennial ryegrass (n = 3) and white clover (n = 3) were collected. Leaves and petioles of three individuals per woody species (n = 3) were also sampled separately in the hedge. Pasture and woody forage samples were stored at −18 °C until laboratory analyses. *Robinia pseudoacacia* was not collected because of its invasiveness (i.e. non-endemic species in Belgium; Halford et al. 2011).

Animal measurements

The heifers' behaviours in each group and season were recorded by two observers from 0600 to 2000 h over three consecutive days. In the first morning, each observer was assigned to either CPG or BG and they shifted groups on a daily basis to avoid bias. Each heifer was observed during 1 min every 20 min and her activity recorded classified (Table 1). Each behaviour activity was expressed as the proportion of the time spent displaying the behaviour relative to the total time. This was calculated per animal and per day for each measurement period. The woody species consumed were recorded to estimate the proportion of the species and selectivity of the browsed diet. Selectivity was defined as the proportion of a given woody species in the browsed diet relative to its proportion in the hedge.

The selectivity index of Jacobs (1974) was determined as follows:

$$S_i = \frac{(D_i - H_i)}{(D_i + H_i - 2D_iH_i)}$$

where D_i is the proportion of the woody species in the browsed diet (between 0 and 1); H_i is the proportion of the species in the hedge (between 0 and 1) and the selectivity (S_i) can vary between −1 and 1. H_i proportion represents the STF availability for heifers; it is based on the number of STF in the hedge but not its actual biomass.

The total time for forage intake corresponded to grazing for the CPG and to summing up grazing and browsing behaviours for the BG (Table 1). For rumination and resting behaviours, the position (s-tanding or lying) was recorded while total rumination and total rest were obtained by summing up the time spent in standing and lying position.

Faeces samples from fresh spontaneous emissions were collected from all heifers at the end of each measurement period and stored at −18 °C until laboratory analysis.

Laboratory analyses

Forage and faeces samples were freeze-dried (min pressure 0.630 mbar; Delta 1–24 LSC, Martin Christ, Osterode, Germany) and ground to pass a 1 mm mesh sieve (Cyclotec 1093 Sample Mill, FOSS Electric, Hillerød, Denmark) before being analysed by means of near infrared reflectance spectroscopy (NIRS) using a XDS monochromator spectrometer system (FOSS Electric, Hillerød, Denmark). The absorption data was recorded as log 1/R from 1100 to 2498 nm, every 2 nm (WINISI 1.5, FOSS Tecator Infrasoft International LCC, Hillerød, Denmark). The NIRS system used the equations of Meuret et al. (1993), Decruyenaere et al. (2009) and Decruyenaere et al. (2015) for the forage chemical composition (Organic matter (OM), crude protein (CP), crude fiber (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL)) and the in vitro organic matter digestibility (IVOMD; i.e. based on a pepsin-cellulase method); the chemical composition of the faeces (OM, CP, NDF, ADF and ADL) and DM intake (DMI; g kg^{-1} $LW^{0.75}$ d^{-1}) and in vivo OMD, respectively.

Statistical analysis

Data were analysed using fixed linear models in the MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

Pre-grazing herbage mass on pasture, faeces chemical composition, predicted DMI and OMD were compared between experimental groups (i.e. CPG or BG), seasons (i.e. late spring, early and late summer) and their interaction. Forage chemical composition and IVOMD considered the effects of forage type or species (i.e. herbaceous pasture, woody shrubs and trees), seasons and their interaction.

Differences in LW and behaviours were assessed considering the effects of seasons, groups and their interaction. For rumination and resting, the position (i.e. standing or lying) effect was also considered. Browsing was only compared across seasons. The proportion of woody species composing the browsed diet was compared using the effects of shrub and tree species, the seasons and their interaction. To explore inter-individual difference, the proportion of each species in the browsed diet considered the effects of heifers (i.e. 1 to 6), woody species and their interactions, while FNIRS predictions (i.e. faeces chemical composition, DMI and OMD) considered the effect of heifers. Correlation coefficients were obtained using the CORR procedure in SAS. Least square means were declared significantly different at $P \leq 0.05$ and tending to differ when $P \leq 0.10$.

Results

Pasture botanical composition and biomass

The CPG paddock was composed (%) of *Lolium perenne* (41.7), *Poa trivialis* (26.4), *Taraxacum* spp. (20.2), *Trifolium repens* (4.7) and other species (7.0), whilst following the same botanical order, the BG paddock comprised 46.2, 22.5, 23.2, 5.1 and 3.0%, respectively.

Irrespective of the treatment, pre-grazing herbage mass decreased from spring to summer ($P < 0.001$). In late spring, early and late summer 2025, 1863 and 1398 kg DM ha^{-1}, respectively, were recorded. However, the biomass tended ($P = 0.06$) to be marginally more abundant in the CPG paddock than in the BG paddock.

Chemical composition and in vitro organic matter digestibility of pasture and hedge fodder

Chemical composition and IVOMD of pasture and hedge forage varied between forage plants and seasons

(Table 2; $P < 0.01$). Across woody plants, averaged CP decreased ($P < 0.001$) from spring to early and late summer (178, 142 and 133 g kg^{-1} DM, respectively) but was similar for pasture forage ($P > 0.05$). Averaged NDF (280, 320 and 317 g kg^{-1} DM), ADF (122, 165 and 165 g kg^{-1} DM) and ADL (56, 84 and 89 g kg^{-1} DM) concentrations in woody foliage increased between spring and late summer ($P < 0.001$), while the pasture ADF concentration was higher in spring (219 g kg^{-1} DM; $P < 0.01$) than in early (206 g kg^{-1} DM) and late summer (209 g kg^{-1} DM). The pasture NDF concentration was lower in early summer (399 g kg^{-1} DM; $P < 0.01$) than in spring and late summer (419 vs. 427 g kg^{-1} DM).

The ADL concentration of STF was higher than that of pasture plants (77 vs. 27 g kg^{-1} DM; $P < 0.001$), whilst NDF concentration in pasture forage was higher than STF (427 vs. 317 g kg^{-1} DM; $P < 0.001$).

On average woody forage had higher IVOMD than pasture plants in spring (0.898 vs. 0.840 g kg^{-1} DM; $P < 0.01$), but the opposite was observed in early (0.721 vs. 0.872; $P < 0.001$) and late (0.699 vs. 0.799; $P < 0.01$) summer. These values show that the overall STF IVOMD decreased over time ($P < 0.001$) while it was the highest in early summer for pasture ($P < 0.01$).

Faecal chemical composition, in vivo organic matter digestibility and dry matter intake of the diet

Faecal chemical composition, DMI and in vivo OMD data are summarized in Table 3. Overall, the faecal NDF content was higher in late summer (468 g kg^{-1} DM; $P < 0.001$) than in spring (404 g kg^{-1} DM) and early summer (393 g kg^{-1} DM), while CP content was greater in early summer (203 g kg^{-1} DM; $P < 0.001$) compared to spring (173 g kg^{-1} DM) and late summer (160 g kg^{-1} DM). Faecal ADL content was higher ($P < 0.001$) for the BG than the CPG (119 and 98 g kg^{-1} DM, respectively). Although OMD did not differ between groups, the overall OMD decreased with time (spring, 0.780; early summer, 0.749 and late summer, 0.720; $P < 0.001$). Across seasons, predicted DMI for CPG heifers was higher than for BG heifers (91 vs. 79 g kg^{-1} LW$^{0.75}$ d^{-1}; $P < 0.01$). No differences on the above parameters were found between heifers ($P > 0.05$).

Live weight

Body weight increased with time over the grazing season ($P < 0.01$). Compared to the CPG heifers, BG had similar LW during spring (479 vs. 479 kg), early (496 vs. 497 kg) and late summer (535 vs. 539 kg).

Heifers behaviour

The BG heifers browsed throughout the duration of the experiment (Table 4). Time spent grazing varied between heifers groups and seasons ($P < 0.05$). Irrespective of the season, the CPG animals spent more time grazing than their counterparts ($P < 0.05$). Across seasons, grazing time increased ($P < 0.001$), while browsing time decreased ($P < 0.001$). Browsing behaviour was correlated to the pre-grazing herbage mass on pasture ($r = 0.50$; $P < 0.001$). The maximum browsing height reached by the BG was 2.14 ± 0.07 m. Total time for forage intake was lower ($P < 0.05$) in the CPG (49.6%) than in the BG (53.2%). In spring, CPG ingested for a shorter time (44.4%; $P < 0.05$) than the BG (50.7%) but this difference was not significant in both summer seasons (49.1 vs. 50.8% and 55.2 vs. 58.0% in early and late summer respectively; $P > 0.05$). The average intake increased from spring to late summer (47.5, 50.0 and 56.6%; $P < 0.001$). In both groups, rumination time was influenced by the season ($P < 0.05$; Table 4). The CPG heifers (16.6%) ruminated longer than the BG (13.5%; $P < 0.01$). In early summer, rumination time was higher in the CPG than the BG ($P < 0.001$) while it was similar in spring and late summer ($P > 0.05$). The cumulated time for intake, searching for food and rumination was higher in the BG (61.6%; $P < 0.05$) than in the CPG (54.9%) in spring while it was similar during the summer months ($P > 0.05$).

Resting time was higher ($P < 0.05$) in spring (33.0%) than in early (23.6%) and late summer (22.0%). BG heifers rested on average longer in lying position (16.7%; $P < 0.01$) than CPG heifers (14.1%), whilst the difference was the highest in early summer (18.4 vs. 13.1%). Social, grooming, drinking and all other activities were influenced neither by the treatment group nor by the season ($P > 0.05$).

Browsing selectivity

Each browse species was consumed at least once along the experimental programme (Table 5; $P < 0.001$),

Table 2 Chemical composition (g kg^{-1} DM) and in vitro organic matter digestibility (IVOMD) of browse species in the experimental hedge and BG pasture samples at each season (n = 3)

	OM	CP	CF	NDF	ADF	ADL	IVOMD
Early spring							
Herbaceous species—BG	906^{ef}	186^{cde}	192^{a}	424^{a}	220^{abc}	26^{qr}	0.836^{ghi}
Woody species†	910	178	135	280	122	56	0.898
A. campestre	905^{ef}	194^{c}	116^{lmn}	323^{hi}	101^{op}	60^{klm}	0.895^{cdef}
A. pseudoplatanus	911^{def}	194^{bc}	165^{cdefg}	322^{hi}	128^{n}	48^{mno}	0.954^{ab}
C. betulus	912^{cdef}	182^{cdef}	103no	307^{ij}	73^{r}	35^{pqr}	0.923^{abc}
C. sanguinea	883^{gh}	179^{cdefgh}	111^{mn}	269^{klmn}	118^{n}	47^{nop}	0.841^{ghi}
C. avellana	910^{def}	188^{cd}	150^{ghi}	282^{klm}	149^{lm}	67^{ijk}	0.853^{efghi}
C. monogyna	924^{bcd}	121^{jklmn}	136^{ij}	210^{p}	128^{n}	104^{abcd}	0.872^{defg}
F. excelsior	919^{cde}	200^{bc}	155^{efg}	259^{mno}	150^{lm}	63^{jk}	0.896^{cde}
P. nigra	918^{cde}	177^{cdefgh}	165^{cdef}	287^{kl}	172^{ijk}	74^{ghij}	0.869^{defgh}
Q. robur	913^{cdef}	196^{bc}	119^{klm}	303^{ij}	78^{qr}	26^{qr}	0.966^{a}
S. nigra	904^{ef}	152^{efghij}	131^{kl}	238^{o}	120^{n}	37^{opq}	0.910^{bcd}
Early summer							
Herbaceous species—BG	915^{cde}	206^{bc}	159^{efg}	389^{cdef}	198^{efg}	24^{r}	0.887^{cdefg}
Woody species†	911	142	147	320	165	85	0.721
A. campestre	907^{ef}	126^{ijklm}	154^{fgh}	365^{fg}	183^{ghij}	98^{bcd}	0.639^{pq}
A. pseudoplatanus	899^{f}	122^{ijklmn}	165^{cdefg}	396^{bcde}	175^{hijk}	76^{ghi}	0.667^{opq}
C. betulus	915^{cde}	155^{defghij}	110^{mn}	339^{gh}	113no	64^{ijk}	0.750^{klmn}
C. sanguinea	867^{ij}	119^{klmn}	89^{op}	282^{klm}	93^{pq}	51^{lmn}	0.756^{klmn}
C. avellana	912^{def}	97^{mn}	137^{ij}	295^{jk}	167^{k}	94de	0.674^{op}
C. monogyna	928^{abc}	110^{klmn}	134^{jk}	269^{klmn}	149^{lm}	110^{a}	0.770^{k}
F. excelsior	919^{cde}	148^{fghij}	164^{defg}	260^{lmno}	165^{kl}	74^{ghij}	0.769^{kl}
P. nigra	911^{def}	177^{cdefgh}	189^{ab}	341^{gh}	224^{ab}	93^{def}	0.708^{no}
Q. robur	942^{a}	106^{klmn}	162^{defg}	379^{ef}	189^{fgh}	109^{ab}	0.621^{q}
S. nigra	911^{def}	259^{a}	169^{cde}	272^{klmn}	187^{fghi}	80^{gh}	0.855^{efghi}
Late summer							
Herbaceous species—BG	912^{cdef}	184^{cdef}	184^{ab}	432^{a}	210^{bcde}	31^{qr}	0.783^{jk}
Woody species†	902	133	140	317	165	89	0.699
A. campestre	905^{ef}	93^{mn}	139^{hij}	341^{gh}	168^{jk}	107^{abc}	0.642^{pq}
A. pseudoplatanus	878^{hi}	97^{mn}	128^{kl}	384^{def}	148^{m}	83^{efg}	0.640^{pq}
C. betulus	898^{f}	138^{ijklm}	107^{mn}	328^{hi}	126^{n}	68^{hijk}	0.718^{lmno}
C. sanguinea	852^{j}	123^{ijklmn}	86^{p}	257^{mno}	100^{op}	61^{kl}	0.763^{klm}
C. avellana	910^{def}	89^{n}	130^{kl}	306^{ij}	168^{k}	95^{cd}	0.644^{pq}
C. monogyna	919^{cde}	111^{klmn}	131^{k}	295^{k}	159^{klm}	112^{a}	0.717^{mno}
F. excelsior	904^{ef}	145^{ghijk}	157^{efg}	253no	163^{klm}	79^{gh}	0.758^{klmn}
P. nigra	908^{ef}	157^{defghi}	188^{ab}	346^{gh}	231^{a}	10^{abcd}	0.654^{pq}
Q. robur	937^{ab}	144^{hijk}	175^{cbd}	389^{cdef}	203^{def}	104^{abcd}	0.638^{pq}
S. nigra	905^{ef}	230^{ab}	155^{efg}	272^{klmn}	188^{fghi}	81.2^{fg}	0.819^{hij}
SEM	1.77	4.44	2.89	5.89	4.21	2.83	0.010

Table 2 continued

	OM	CP	CF	NDF	ADF	ADL	IVOMD
P value							
Forage	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Season	0.003	<0.001	0.023	<0.001	<0.001	<0.001	<0.001
Forage × season	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within a column, values with different letters are significantly different (P < 0.05)

ADL acid detergent lignin, *ADF* acid detergent fiber, *BG* browsing group, *CF* crude fiber, *CP* crude protein, *DM* dry matter, *IVOMD* in vitro organic matter digestibility, *NDF* neutral detergent fiber, *OM* organic matter, *SEM* standard error of the mean

† Average of woody species was not included in statistical analysis

Table 3 Chemical composition (g kg^{-1} DM) of the faeces, dry matter intake (g kg^{-1} $LW^{0.75}$ d^{-1}) and in vivo organic matter digestibility estimated by NIRS for both groups of heifers (n = 6)

	Late spring		Early summer		Late summer		SEM	*P* value		
	BG	CPG	BG	CPG	BG	CPG		Group	Season	Group × season
Chemical composition										
OM	784^{ab}	685^{c}	803^{a}	795^{ab}	773^{ab}	763^{b}	7.89	<0.001	<0.001	0.001
CP	179^{b}	166^{bc}	206^{a}	200^{a}	157^{c}	162^{c}	3.91	0.301	<0.001	0.342
NDF	417^{b}	392^{b}	385^{b}	402^{b}	474^{a}	463^{a}	7.85	0.558	<0.001	0.307
ADF	300^{ab}	222^{c}	229^{c}	226^{c}	302^{a}	272^{b}	6.94	<0.001	<0.001	0.007
ADL	136^{a}	95^{c}	99^{c}	93^{c}	123^{a}	107^{bc}	3.62	<0.001	0.005	0.031
DMI	66^{c}	75^{c}	97^{ab}	107^{a}	73^{c}	91^{b}	3.14	0.005	<0.001	0.615
OMD	0.789^{a}	0.770^{ab}	0.746^{bcd}	0.752^{bc}	0.717^{d}	0.723^{cd}	0.006	0.783	<0.001	0.451

Within a row, values with different letters are significantly different (P < 0.05)

ADF acid detergent fiber, *ADL* acid detergent lignin, *BG* browsing group, *CP* crude protein, *CPG* control pasture group, *DM* dry matter, *DMI* diet dry matter intake, *LW* live weight, *NDF* neutral detergent fiber, *OM* organic matter, *OMD* diet in vivo organic matter digestibility, *SEM* standard error of the mean

except *R. pseudoacacia*. Across seasons, *C. monogyna* represented the highest proportion of the browsed diet (P < 0.01). On average, *C. monogyna* (0.472), *C. avellana* (0.203), *C. betulus* (0.129), and *C. sanguinea* (0.101) accounted for the greatest proportion of the browsed plants (P < 0.001).

In spring, heifers showed a greater preference for *C. monogyna, C. betulus* and *C. avellana* (Table 5). *C. sanguinea* was selected more in early and late summer while *A. pseudoplatanus* and *P. nigra* were only selected during these seasons. Independent of seasons only *C. sanguinea* (0.545), *C. avellana* (0.149) and *C. monogyna* (0.144) were on average always positively selected.

The proportion of STF species in the browsed diet varied between heifers (P < 0.001; data not shown). Out of 11 species composing the hedge, *C. avellana, C. betulus, C. monogyna* and *C. sanguinea* were browsed by all heifers, while *Q. robur* and *P. nigra* were only chosen by two heifers. One heifer ate all the species, except *R. pseudoacacia*, whilst 2 other heifers browsed only 4 species. One of these 2 heifers consumed mainly *C. monogyna* (0.710) and less *C. avellana* (0.040) while these species ranged respectively from 0.407 to 0.486 and 0.172 to 0.302 in the other heifers' diet.

Discussion

This study aimed to assess the selective behaviour of heifers towards woody species on pasture and to relate their behaviour to the evolution of forage nutritive value over the grazing season. The main finding was that heifers browsed woody forage throughout the

Table 4 Percentage of time spent displaying a behaviour in animals grazing a pasture with (BG) and without (CPG) access to a hedge composed of shrubs and trees during the grazing season of 2013 (n = 18)

	Late spring		Early summer		Late summer		SEM	*P* value		
	BG	CPG	BG	CPG	BG	CPG		Group	Season	Group × season
Grazing	31.4^{d}	44.4^{c}	44.9^{c}	49.1^{bc}	52.6^{ab}	55.2^{a}	1.11	<0.001	<0.001	0.030
Browsing	19.3^{a}	NA	5.9^{b}	NA	5.4^{b}	NA	1.11	NA	<0.001	NA
Searching for food	1.7^{a}	1.5^{ab}	0.3^{c}	0.8^{bc}	0.8^{bc}	0.3^{c}	0.12	0.768	<0.001	0.186
Rumination (total)	9.2^{d}	9.0^{d}	17.4^{b}	24.3^{a}	13.8^{c}	16.6^{bc}	0.71	0.003	<0.001	0.018
Resting (total)	29.7^{b}	36.4^{a}	25.9^{bc}	21.3^{c}	21.6^{c}	22.4^{c}	0.92	0.538	<0.001	0.013
Social activities	0.5	0.1	0.3	0.4	0.0	0.2	0.06	0.552	0.210	0.214
Grooming	1.2	1.1	1.6	1.0	1.7	1.5	0.14	0.335	0.456	0.742
Walking	6.6^{a}	6.0^{a}	2.5^{b}	2.4^{b}	2.9^{b}	2.4^{b}	0.29	0.394	<0.001	0.898
Drinking	0.3	1.2	0.8	0.8	1.1	1.5	0.14	0.120	0.185	0.386
Other activities	0.1	0.3	0.3	0.0	0.0	0.0	0.04	0.432	0.104	0.072

Within a row, values with different letters are significantly different (P < 0.05)

BG browsing group, *CPG* control pasture group, *NA* not applicable, *SEM* standard error of the mean

entire grazing season, from May to September (P < 0.001). They spent between 9 and 38% of the observed intake time browsing the hedge. However, the constant daily observation period (i.e. 6AM-8PM) should be considered when comparing heifer's behaviour between seasons. The nocturnal behaviours were not recorded here and changes in day/night length between seasons might have interfered with the heifers' behaviour. *Carpinus betulus, C. sanguinea, C. avellana, C. monogyna* were the most browsed plants (proportion of the browsed diet of 0.129, 0.101, 0.203 and 0.472, respectively). Previous studies reported that cattle rely on STF when the availability of the herbaceous stratum declines, for example during prolonged droughts (Lefroy et al. 1992; Katjiua and Ward 2006; Liagre 2006). Interestingly, in the present study, the interaction did not follow the same pattern because heifers browsed for longer periods when pasture availability was greatest in late spring ($r = 0.50$; P < 0.001). Heifers browsed 19.3, 5.9 and 5.4% of their time in spring, early and late summer, respectively, while the pre-grazing biomass on pasture was 2025, 1863 and 1398 kg DM ha^{-1} respectively. This probably emphasises heifers' ability to adapt to environmental changes and include those that functionally interact with selective browsing behaviour such as specific nutritional, sanitary or hedonic requirements, rather than merely by forage availability. For example, STF have been shown to supplement low quality herbage throughout the year, notably by providing highly digestible biomass, protein, energy, vitamins or minerals (Hirata et al. 2008; Leng 1992). In this study, STF in spring was on average more digestible than the pasture with similar CP contents, which may be one of the reasons why heifers browsed longer during this season.

There is also evidence that browsing does influence heifers' intake and nutrition since the DMI was reduced in the BG compared to CPG (79 vs. 91 g kg^{-1} $LW^{0.75}$ d^{-1}; P < 0.01). Browse species had higher ADL content than pasture forage (77 vs. 27 g kg^{-1} DM; P < 0.001), an effect between treatments that was addressed by FNIRS (119 vs. 98 g ADL kg^{-1} DM; P < 0.001). The woody foliage in spring was characterised by low ADL content, but greater IVOMD and CP concentration than in summer. Therefore, based on these results, it seems that the linear decline in STF nutritive value could explain the greater time spent browsing in spring compared to the following seasons since the herbaceous samples did not show such a sharp decrease.

Although rumination time was similar in spring, the time for total intake (grazing for CPG treatment, and grazing and browsing for BG treatment) cumulated with the time for searching for food and for rumination was higher in BG (61.6%; P < 0.05) than in CPG (54.9%), with 15 h and 13 h, respectively in the context of a 24-h day. This greater cumulated time for

Table 5 Proportions of woody species in the browsed diet and in the hedge and selectivity index during the three seasons of feeding behaviour observations in 2013 (n = 18)

	Proportion in heifers' diet	Proportion in the hedge	Jacob's selectivity index
Late spring			
A. campestre	0.026[fgh]	0.026	−0.011
A. pseudoplatanus	0.015[gh]	0.026	−0.292
C. betulus	0.206[cd]	0.136	0.245
C. sanguinea	0.019[gh]	0.018	0.028
C. avellana	0.195[cd]	0.158	0.128
C. monogyna	0.534[a]	0.399	0.266
F. excelsior	0[h]	0.123	−1
P. nigra	0[h]	0.031	−1
Q. robur	0.003[h]	0.009	−0.482
R. pseudoacacia	0[h]	0.066	−1
S. nigra	0.003[h]	0.009	−0.502
Early summer			
A. campestre	0.028[fgh]	0.026	0.028
A. pseudoplatanus	0.038[fgh]	0.026	0.190
C. betulus	0.083[efg]	0.136	−0.271
C. sanguinea	0.132[de]	0.018	0.790
C. avellana	0.188[cd]	0.158	0.105
C. monogyna	0.488[a]	0.399	0.178
F. excelsior	0.028[fgh]	0.123	−0.657
P. nigra	0.016[gh]	0.031	−0.332
Q. robur	0[h]	0.009	−1
R. pseudoacacia	0[h]	0.066	−1
S. nigra	0[h]	0.009	−1
Late summer			
A. campestre	0.020[gh]	0.026	−0.149
A. pseudoplatanus	0.012[gh]	0.026	−0.388
C. betulus	0.098[ef]	0.136	−0.186
C. sanguinea	0.152[cde]	0.018	0.818
C. avellana	0.225[c]	0.158	0.214
C. monogyna	0.394[b]	0.399	−0.010
F. excelsior	0.043[fgh]	0.123	−0.512
P. nigra	0.049[fgh]	0.031	0.239
Q. robur	0.8[gh]	0.009	−0.022
R. pseudoacacia	0[h]	0.066	−1
S. nigra	0[h]	0.009	−1
SEM	0.008	NA	ND
P value			
Species	<0.001	NA	ND
Season	1.000	NA	ND
Species × season	0.003	NA	ND

Within a column, values with different letters are significantly different ($P < 0.05$)

NA not applicable, *ND* not determined, *SEM* standard error of the mean

BG, possibly driven by more digestible browse fodder, might result from the heifers' mouth structure that is less effective in consuming STF per bite (Gordon and Illius 1988) than grass when grazing. The CPG heifers ruminated on average longer than those of the BG (16.6 vs. 13.5%; $P < 0.01$). This result is particularly relevant because rumination is a physiological process that reduces forage particle size (Chai et al. 1988) and is regulated by physical and chemical composition of the diet (Welch and Smith 1970), feeding time (Schirmann et al. 2012) and grazing management (Gibb et al. 1997; Gregorini et al. 2012). As NDF and ADF contents of the most ingested species *C. betulus, C. sanguinea, C. avellana* and *C. monogyna* were lower than the pasture whatever the season, it could be assumed that the BG ruminate less than the CPG grazing exclusively because of the higher digestibility of the forage. Alternatively, this may indicate that STF allows for more efficient energy utilization since at the same time the overall DMI was reduced with similar levels of OMD of the diet in both groups. Nevertheless, the ADL content of STF was higher than the pasture. Furthermore, intake prediction from FNIRS has been previously reported to be unreliable (Coleman 2010; Decruyenaere et al. 2015) and in our study, the DMI predicted from a FNIRS methodology developed with a diet of a different type (grass and legume vs. combination of pasture and browse species) should be considered cautiously. Therefore, additional research is needed to support these results and validate that the energy requirement might be a significant driver encouraging grazing cattle to browse shrubs and trees.

Along with decreasing feeding value of the browse species, it can be expected that bio-active secondary metabolites concentrations such as condensed tannins (CT) will increase with time (Feeny 1970; Makkar et al. 1991; Riipi et al. 2002), reducing the palatability of browse forage between seasons. Although CT contents of browse and pasture forage were not measured in the present study, Kamalak et al. (2004), Mebirouk-boudechiche et al. (2014) and Paolini et al. (2004) have reported CT concentrations of 20, 19 and 14 g kg^{-1} DM in *C. betulus, C. monogyna and C. avellana* respectively. This could explain why faecal CP content of BG heifers, although not significant ($P > 0.05$), was higher than CPG in spring (179 vs. 166 g kg^{-1} DM). Condensed tannins bound to leaf protein after mastication and the CT-protein complexes are stable in the rumen at pH 5.5–7.0 (Jones and Mangan 1977), which protects the CT-bound molecules from microbial degradation (McLeod 1974; Min et al. 2005). However, the protein is released for hydrolysis and absorption in acidic conditions in the abomasum and small intestine (Jones and Mangan 1977). Consequently, a shift from N excretion in urine to faeces occurs (Waghorn et al. 1987; Grainger et al. 2009) since less ammonia is released from dietary protein fermentation in the rumen. There, N is mainly organic and so less volatile (Carulla et al. 2005; Grainger et al. 2009). Therefore, further research is required to quantify the urine N concentration to determine if browsing of ligneous fodder might lead to such change.

With the progressing season, heifers grazed longer as the herbage availability decreased, but did not seem to be influenced by outside weather conditions and temperature. Observational data indicate that with high temperature, grazing time decreases and conversely resting time increases (Hejcmanová et al. 2009). In this study, grazing time increased during summer months when the temperature was higher (on average 10.8 °C in spring vs. 19.6 and 14.2 °C in early and late summer). Furthermore, in early summer, when temperature was the highest, our records showed that the BG rested longer (lying 18.4% of their time) mainly in the shade along hedgerows while the CPG rested lying 13.1% of their time. Those results are in agreement with research that assessed the effect of woody species' shade on grazing cattle welfare (Gregory 1995; Liagre 2006). However, as already mentioned, the nocturnal behaviours were not recorded in our study which might influence the results.

There is strong evidence (Villalba and Provenza 2009) that besides social learning, feeding behaviour is influenced by the individual's past experiences leading to postingestive feedbacks. Although it cannot be concluded from this study that past experiences influenced the selectivity by individuals, it clearly showed strong selectivity differences between animals. The selectivity of STF by heifers in our study was measured using the availability of woody plants in terms of numbers of plants in the hedge, which might have underestimated species with high biomass but not numerically important and vice versa. However, some heifers selected every species offered in the hedge, except *R. pseudoacacia*, whereas others rejected most of the STF species a priori. Typical research focuses rather on group averages than individuals, while food intake and preference of individuals within a group can differ strongly (Provenza et al. 2003; Manteca et al. 2008). Therefore, in agreement with Searle et al. (2010) the depth of understanding of differences in selectivity by livestock could be useful to manipulate forage resources on pasture and develop animal selection indexes aimed at improving efficiency of silvopastoral systems.

Conclusion

The presence of a hedge composed of diverse temperate shrubs and trees species fencing a pasture influenced grazing heifers' feeding behaviour. Browsing woody species was observed throughout the grazing study with a peak in late spring when most browse plants displayed high nutritive value, but also when herbaceous forage was plentiful. Though almost all woody species have been ingested at least once during the experiment, *C. betulus, C. sanguinea, C. avellana* and *C. monogyna* were preferred and the selection towards the STF was markedly driven by individual choice. This study indicates that integrating trees and shrubs as an extra source of forage for the grazing herd could enhance the individual intake diversity, presumably leading to improved welfare and conversion efficiency of the available biomass. However, the different heifers activities spent during the night might have been underestimated in summer due to the contrasting light regime across seasons. Therefore, further research in such temperate silvopastoral systems are needed to integrate this resource properly in grazing managements combining pasture and STF.

Acknowledgements The expert technical assistance of the staff of the Centre des Technologies Agronomiques is gratefully acknowledged. Dr Robert D. Kinley from CSIRO (Townsville, Australia) is thanked for his proofreading. Sophie Vandermeulen was funded by the Research Foundation for Industry and Agriculture (FRIA)-National Fund for Scientific Research (F.R.S.-FNRS).

References

Carulla JE, Kreuzer M, Machmüller A, Hess HD (2005) Supplementation of *Acacia mearnsii* tannins decreases methanogenesis and urinary nitrogen in forage-fed sheep. Aust J Agric Res 56:961–970

Chai K, Milligan LP, Mathison GW (1988) Effect of muzzling on rumination in sheep. Can J Anim Sci 68:387–397

Coleman S (2010) Historic Overview for Fecal NIRS Analysis. In: Walker J, Tolleson D (eds) Shining light on manure improves livestock and land management, technical bulletin, 1st edn. Texas Agrilife Research and Society for Range Management, Jefferson City, pp 9–22

Decruyenaere V, Lecomte P, Demarquilly C, Aufrere J, Dardenne P, Stilmant D, Buldgen A (2009) Evaluation of green forage intake and digestibility in ruminants using near infrared reflectance spectroscopy (NIRS): developing a global calibration. Anim Feed Sci Technol 148:138–156. doi:10.1016/j.anifeedsci.2008.03.007

Decruyenaere V, Planchon V, Dardenne P, Stilmant D (2015) Prediction error and repeatability of near infrared reflectance spectroscopy applied to faeces samples in order to predict voluntary intake and digestibility of forages by ruminants. Anim Feed Sci Technol. doi:10.1016/j.anifeedsci.2015.04.011

Feeny P (1970) Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. Ecology 51:565–581. doi:10.2307/1934037

Gibb MJ, Huckle CA, Nuthall R, Rook AJ (1997) Effect of sward surface height on intake and grazing behaviour by lactating Holstein Friesian cows. Grass Forage Sci 52:309–321

Gordon IJ, Illius AW (1988) Incisor arcade structure and diet selection in ruminants. Funct Ecol 2:15–22. doi:10.2307/2389455

Grainger C, Clarke T, Auldist MJ, Beauchemin KA, McGinn SM, Waghorn GC, Eckard RJ (2009) Potential use of *Acacia mearnsii* condensed tannins to reduce methane emissions and nitrogen excretion from grazing dairy cows. Can J Anim Sci 89:241–251

Gregorini P, DelaRue B, McLeod K, Clark CEF, Glassey CB, Jago J (2012) Rumination behavior of grazing dairy cows in response to restricted time at pasture. Livest Sci 146:95–98. doi:10.1016/j.livsci.2012.02.020

Gregory NG (1995) The role of shelterbelts in protecting livestock: a review. N Z J Agric Res 38:423–450. doi:10.1080/00288233.1995.9513146

Halford M, Heemers L, Mathys C, Vanderhoeven S, Mahy G (2011) Socio-economic survey on invasive ornamental plants in Belgium. http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=ALTERIAS_socioeco_sur_EN.pdf. Accessed 25 May 2015

Hejcmanová P, Stejskalová M, Pavlů V, Hejcman M (2009) Behavioural patterns of heifers under intensive and extensive continuous grazing on species-rich pasture in the Czech Republic. Appl Anim Behav Sci 117:137–143. doi:10.1016/j.applanim.2009.01.003

Hirata M, Hasegawa N, Takahashi T, Chowdappa R, Ogura S, Nogami K, Sonoda T (2008) Grazing behaviour, diet selection and feed intake of cattle in a young tree plantation in southern Kyushu, Japan. Trop Grassl 42:170–180

Jacobs J (1974) Quantitative measurement of food selection. Oecologia 14:413–417

Jones WT, Mangan JL (1977) Complexes of the condensed tannins of sainfoin (*Onobrychis viciifolia* Scop.) with fraction 1 leaf protein and with submaxillary mucoprotein, and their reversal by polyethylene glycol and pH. J Sci Food Agric 28:126–136

Kamalak A, Filho JMP, Canbolat O, Gurbuz Y, Ozay O, Ozkan CO (2004) Chemical composition and its relationship to in vitro dry matter digestibility of several tannin-containing trees and shrub leaves. Livest Res Rural Dev 16. http://www.lrrd.org/lrrd16/4/kama16027.htm. Accessed 20 Feb 2015

Katjiua M, Ward D (2006) Cattle diet selection during the hot-dry season in a semi-arid region of Namibia. Afr J Range Forage Sci 23:59–67. doi:10.2989/10220110609485887

Le Houérou HN (2006) Agroforestry and sylvopastoralism: the role of trees and shrubs (Trubs) in range rehabilitation and development. Sécheresse 17:343–348

Lefroy EC, Dann PR, Wildin JH, Wesley-Smith RN, McGowan AA (1992) Trees and shrubs as sources of fodder in Australia. Agrofor Syst 20:117–139

Leng RA (1992) Tree foliage in ruminant nutrition. FAO, Rome

Liagre F (2006) Les haies rurales, rôles—création—entretien, 1st edn. Editions France Agricole, Paris

Makkar HPS, Dawra RK, Singh B (1991) Tannin levels in leaves of some oak species at different stages of maturity. J Sci Food Agric 54:513–519

Manteca X, Villalba JJ, Atwood SB, Dziba L, Provenza FD (2008) Is dietary choice important to animal welfare? J Vet Behav 3:229–239. doi:10.1016/j.jveb.2008.05.005

McLeod MN (1974) Plant tannins—their role in forage quality. Nutr Abstr Rev 44:803–815

Mebirouk-boudechiche L, Cherif M, Boudechiche L, Sammar F (2014) Teneurs en composés primaires et secondaires des feuilles d'arbustes fourragers de la région humide d'Algérie. Rev Méd Vét 165:344–352

Meuret M, Dardenne P, Biston R, Poty O (1993) The use of NIR in predicting nutritive value of Mediterranean tree and shrub foliage. J Near Infrared Spectrosc 22:45–54

Min BR, Attwood GT, McNabb WC, Molan AL, Barry TN (2005) The effect of condensed tannins from *Lotus corniculatus* on the proteolytic activities and growth of rumen bacteria. Anim Feed Sci Technol 121:45–58. doi:10.1016/j.anifeedsci.2005.02.007

Mupeyo B, Barry TN, Pomroy WE, Ramírez-Restrepo CA, López-Villalobos N, Pernthaner A (2011) Effects of feeding willow (*Salix* spp.) upon death of established parasites and parasite fecundity. Anim Feed Sci Technol 164:8–20. doi:10.1016/j.anifeedsci.2010.11.015

Murgueitio E, Calle Z, Uribe F, Calle A, Solorio B (2011) Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. For Ecol Manag 261:1654–1663. doi:10.1016/j.foreco.2010.09.027

Nerlich K, Graeff-Hönninger S, Claupein W (2013) Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. Agrofor Syst 87:475–492. doi:10.1007/s10457-012-9560-2

Nguyen TM, Binh DV, Ørskov ER (2005) Effect of foliages containing condensed tannins and on gastrointestinal parasites. Anim Feed Sci Technol 121:77–87. doi:10.1016/j.anifeedsci.2005.02.013

Nijland GO (2000) A variant of the dry-weight rank method for botanical analysis of grassland with dominance-based multipliers. Grass Forage Sci 55:309–313

Paciullo DS, de Castro CR, de Miranda Gomide CA, Maurício RM, Pires MD, Müller MD, Xavier DF (2011)

Performance of dairy heifers in a silvopastoral system. Livest Sci 141:166–172. doi:10.1016/j.livsci.2011.05.012

Paolini V, Fouraste I, Hoste H (2004) In vitro effects of three woody plant and sainfoin extracts on 3rd-stage larvae and adult worms of three gastrointestinal nematodes. Parasitology 129:69–77

Papanastasis VP, Yiakoulaki MD, Decandia M, Dini-Papanastasi O (2008) Integrating woody species into livestock feeding in the Mediterranean areas of Europe. Anim Feed Sci Technol 140:1–17. doi:10.1016/j.anifeedsci.2007.03.012

Pitta DW, Barry TN, Lopez-Villalobos N, Kemp PD (2005) Effects on ewe reproduction of grazing willow fodder blocks during drought. Anim Feed Sci Technol 120:217–234. doi:10.1016/j.anifeedsci.2005.02.030

Pollard JC (2006) Shelter for lambing sheep in New Zealand: a review. N Z J Agric Res 49:395–404. doi:10.1080/00288233.2006.9513730

Provenza FD, Villalba JJ, Dziba LE, Atwood SB, Banner RE (2003) Linking herbivore experience, varied diets, and plant biochemical diversity. Small Rumin Res 49:257–274. doi:10.1016/S0921-4488(03)00143-3

Ramírez-Restrepo CA, Barry TN, López-Villalobos N, Kemp PD, McNabb WC (2004) Use of *Lotus corniculatus* containing condensed tannins to increase lamb and wool production under commercial dryland farming conditions without the use of anthelmintics. Anim Feed Sci Technol 117:85–105. doi:10.1016/j.anifeedsci.2004.05.005

Ramírez-Restrepo CA, Barry TN, López-Villalobos N, Kemp PD, Harvey TG (2005a) Use of *Lotus corniculatus* containing condensed tannins to increase reproductive efficiency in ewes under commercial dryland farming conditions. Anim Feed Sci Technol 121:23–43. doi:10.1016/j.anifeedsci.2005.02.006

Ramírez-Restrepo CA, Barry TN, Pomroy WE, López-Villalobos N, McNabb WC, Kemp PD (2005b) Use of *Lotus corniculatus* containing condensed tannins to increase summer lamb growth under commercial dryland farming conditions with minimal anthelmintic drench input. Anim Feed Sci Technol 122:197–217

Ramírez-Restrepo CA, Pernthaner A, Barry TN, López-Villalobos N, Shaw RJ, Pomroy WE, Hein WR (2010a) Characterization of immune responses against gastrointestinal nematodes in weaned lambs grazing willow fodder blocks. Anim Feed Sci Technol 155:99–110. doi:10.1016/j.anifeedsci.2009.10.006

Ramírez-Restrepo CA, Barry TN, Marriner A, López-Villalobos N, McWilliam EL, Lassey KR, Clark H (2010b) Effects of grazing willow fodder blocks upon methane production and blood composition in young sheep. Anim Feed Sci Technol 155:33–43. doi:10.1016/j.anifeedsci.2009.10.003

Riipi M, Ossipov V, Lempa K, Haukioja E, Koricheva J, Ossipova S, Pihlaja K (2002) Seasonal changes in birch leaf chemistry: are there trade-offs between leaf growth and accumulation of phenolics? Oecologia 130:380–390. doi:10.1007/s00442-001-0826-z

Sanderson MA, Rotz CA, Fultz SW, Rayburn EB (2001) Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. Agron J 93:1281–1286

Schirmann K, Chapinal N, Weary DM, Heuwieser W, von Keyserlingk MAG (2012) Rumination and its relationship to feeding and lying behavior in Holstein dairy cows. J Dairy Sci 95:3212–3217. doi:10.3168/jds.2011-4741

Searle KR, Hunt LP, Gordon IJ (2010) Individualistic herds: individual variation in herbivore foraging behavior and application to rangeland management. Appl Anim Behav Sci 122:1–12. doi:10.1016/j.applanim.2009.10.005

Vandenberghe C, Freléchoux F, Moravie M-A, Gadallah F, Buttler A (2007) Short-term effects of cattle browsing on tree sapling growth in mountain wooded pastures. Plant Ecol 188:253–264. doi:10.1007/s11258-006-9160-1

Villalba JJ, Provenza FD (2009) Learning and Dietary Choice in Herbivores. Rangel Ecol Manag 62:399–406. doi:10.2111/08-076.1

Waghorn GC, Ulyatt MJ, John A, Fisher MT (1987) The effect of condensed tannins on the site of digestion of amino acids and other nutrients in sheep fed on *Lotus corniculatus* L. Br J Nutr 57:115–126

Walloon Government (2014) Decree of 13 February 2014 on the granting of agri-environmental aids. Belgian Official Journal of 10 April 2014

Welch JG, Smith AM (1970) Forage quality and rumination time in cattle. J Dairy Sci 53:797–800