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Contribution of browse to ruminant nutrition across three agro-ecological zones of Burkina Faso

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ABSTRACT

We determined the contribution of ligneous species to the diet of cattle, sheep and goats across three agro-ecological zones of Burkina Faso, and assessed their ethno-veterinary uses by livestock keepers. Regular observation and GPS-tracking of one cattle, one sheep and one goat herd each in three villages served the investigation of browsing activities on pasture. Livestock keepers (25 per village) were interviewed on the use of ligneous plants by livestock and for disease treatment, and on changes in use over the past two decades.

Across the three zones 75 species were of importance. Cattle preferred *Afzelia africana*, *Pterocarpus erinaceus* and *Piliostigma* sp., while small ruminants primarily fed on *Balanites aegyptiaca*, *Ziziphus mauritiana* and *Acacia* sp. Contribution of browsing to daily eating time was highest for goats across seasons and zones; for sheep and cattle browsing was important during the hot dry season with no differences between zones. Livestock keepers reported increasing browse use by their animals, while browse species use for traditional animal health care has decreased. The combination of anthropogenic pressures and climate change affect survival and regeneration of the most preferred trees and shrubs, and threaten livestock keepers' current management practices; this needs to be counteracted adequately.

1. Introduction

Nutrition of cattle, sheep and goats in the agro-silvo-pastoral livestock farming systems of the Sahelian and Sudanian regions of West Africa is essentially based on the exploitation of naturally occurring herbaceous and ligneous plant species, and crop residues. Qualitative and quantitative forage shortage, particularly in the dry season, is the major constraint to this farming system (Fernández-Rivera et al., 2005). In this period of the year, fodder trees and shrubs play an important role for ruminant nutrition, providing proteins, minerals, vitamins and energy (Ickowicz and Mbaye, 2001; Ouédraogo-Koné, 2008), thus complementing herbaceous plants of low nutritive value. After the severe droughts of the years 1973–1974 and 1983–1984, much information has been accumulated on the potential of trees and shrubs as sources of feed for the extensive livestock systems in the West African Sahel (Ickowicz et al., 2005; Ouédraogo-Koné et al., 2006; Sanon et al., 2008). However, ligneous plants and plant parts are also used for human nutrition and health care, in ethno-veterinary medicine and for household energy supply (Kristensen and Balslev, 2003; Tamboura et al., 1998).

Due to the high spatio-temporal variability of forage availability in Burkina Faso, ruminants' foraging behavior on common pasture, and particularly their browsing activities, vary widely across seasons (Ouédraogo-Koné et al., 2006; Sanon et al., 2007), ruminant species (Botoni, 2003; Sanon, 2007) and agro-climatic conditions (Hansen et al., 2008), and depend to some extent on herd management (Turner and Hiernaux, 2008). Variations concern time spent browsing in general, browse species selection and qualitative and quantitative intake from browse. Several of the aforementioned independent variables partly interact, such as region and season which determine the botanical composition of the pasture vegetation, that is plant occurrence, abundance, accessibility, palatability and nutritive value (Ngwa et al., 2000). Apart from the effects of climate, variation is also determined by land use patterns and anthropogenic pressure. Considering climate, landscape and flora, Wittig et al. (2007) observed a partial Sahelisation of the Sudanian zone of Burkina Faso, and pointed out that changes in landscape characteristics and floristic composition are mainly

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driven by anthropogenic pressure. Studies in the West African Sudanian and Sahelian regions have also identified recurrent droughts, cropland expansion and grazing pressure as drivers of vegetation degradation and even desertification, leading to the reduction of biomass production and species diversity (Kaspersen et al., 2011; Maranz, 2009; Turner, 1999; Wezel and Lykke, 2006). Recent studies in the Sahelian and Sudanian zones of Burkina Faso reported a noticeable decline of woody vegetation over time (Ariori and Ozer, 2005; Paré et al., 2010; Sop and Oldeland, 2011). Although this should induce changes in the use of browse species by ruminants on pasture, information on the occurrence, extent and consequences of such changes is lacking for the different agro-ecological zones of Burkina Faso and the neighboring Sahelian and Sudanian countries.

Against this background, this study aimed to determine the present contribution of ligneous species to the nutrition and health care of cattle, sheep and goats in three major agro-ecological zones of Burkina Faso. Specific objectives were to (i) identify the most preferred browse species of cattle and small ruminants in each zone; (ii) evaluate their relative importance for the animals' nutrition; and (iii) investigate the significance assigned to major browse species by Fulani livestock keepers, and their perception of changes in browse use over the past twenty years.

2. Material and methods

2.1. Study locations

This study covered the sub-Sahelian, northern and southern Sudanian zone of Burkina Faso, which were represented by the village territories of Tougouri/Taffogo (13°26.56′ N, 0°34.17′ E), Noberé (11°28.82′ N, 1°10.50′ W), and Sokouraba (10°50.49′ N, 5°09.99′ W), respectively, as permanent study locations (Fig. 1). The sub-Sahelian zone receives 300–600 mm of rain annually during 3–4 months; the northern and southern Sudanian zones receive 600–800 mm/a and more than 1000 mm/a of rain in about 5–6 months, respectively. Average annual temperature and relative humidity are 29 °C, 28 °C, 27 °C and 70%, 85%, 90%, for the sub-Sahelian, northern and southern Sudanian zones, respectively. The vegetation in the sub-Sahelian zone is a thornbush savannah with mostly deciduous trees and shrubs, and riparian forests found at riversides. The most common ligneous species are *Balanites aegyptiaca*, *Acacia seyal*, *Acacia dudgeoni*, *Acacia tortilis*, *Acacia raddiana*, *Leptadenia hastata*, *Pterocarpus lucens*, *Combretum micranthum*, *Combretum nigricans*, *Feretia apodanthera*, *Gardenia sokotensis*, and *Guiera senegalensis* (authorities are given in Appendix 1). The herbaceous layer of natural pastures and fallows is mostly patchy with many bare spots. It is dominated by annual grasses such as *Aristida mutabilis* Trin. et Rupr., *Schoenefeldia gracilis* Kunth and *Loudetia togoensis* (Pilg.) C.E. Hubb. The prevailing vegetation types in the Sudanian zone are woodlands and savannas; in the northern zone agro-forestry parklands with *Vitelaria paradoxa* or *Faidherbia albida* are found, and the important grass layer is dominated by the *Poaceae* family. The trees in this zone are dominated by the *Combretaceae* family. Noberé has the particularity to border the natural reserve "Park National Kaboré Tambi" of which one part is located in the southern Sudanian zone. There the grass layer is essentially composed of annual and perennial grass species such as *Pennisetum pedicellatum* Trin., *Andropogon gayanus* Kunth and *Andropogon ascinodis* C.B. Clarke. Ligneous species such as *Afzelia africana*, *Pterocarpus erinaceus*, and *Khaya senegalensis*, which are rare in the other zones, are found here. In addition important plantations of mango (*Mangifera indica* L.), sweet orange (*Citrus sinensis* L.) and cashew nut (*Anacardium*

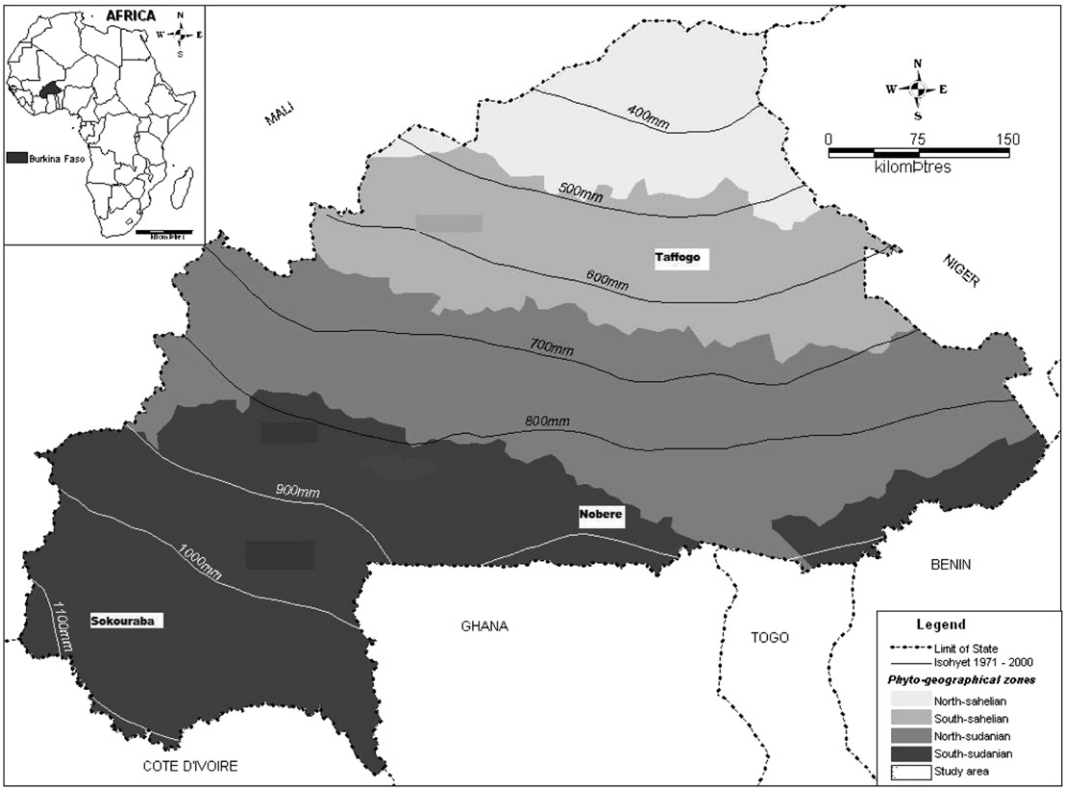

Fig. 1. Agro-ecological (phyto-geographical) zones of Burkina Faso with isohyets and location of the six study sites. (Map readapted in April 2007 by CTIG/INERA/Burkina Faso after Fontes and Guinko, 1995 and Direction of the National Meteorology).

occidentale L.) are also found in this area, which is the most humid part of the country.

2.2. Monitoring of grazing behavior on pasture

The grazing activities of cattle, sheep and goats were monitored from June 2009 to May 2010, covering the rainy season (June–September 2009), cool dry season (October 2009–January 2010) and hot dry season (February–May 2010) in all three locations. In each zone three different herds of cattle, sheep and goats were randomly selected from the total of herds of Fulani livestock keepers – mainly transhumant pastoralists – who had been identified during a baseline survey. Cattle were mostly of the Fulani breed (*Bos indicus*) and crossbreds of zebu with humpless *Bos taurus*. Sheep were of Mossi and/or Djallonké breed and goats were mostly of Sahelian type in Tougouri, and of Djallonké dwarf breed in Noberé and Sokouraba. The number of animals per herd ranged from 10 to 60 for goats, 35 to 75 for sheep, and from 50 to more than 100 for cattle. After an initial 2 days observation at the beginning of the study, the animal to follow was identified in cooperation with the herder, based on the following criteria: socially, the female should be in the upper third of the herd, and its foraging behavior should reflect the behavior of the majority of the herd. It should not be sick at the onset of the study, and not be envisaged for sale/removal from the herd for the next one and half years (monitoring period). With the help of the herder the selected animal was marked with an identification tag to be easily visible in the group on pasture and clearly identifiable throughout the monitoring period.

In each agro-ecological zone, the monitored cattle, sheep and goat herds were herded and grazed natural pasture areas and, in the dry season, harvested crop fields. To our knowledge, animals did not receive supplement feeds at the homestead. Distances traveled per day by the herds ranged from 7.5 to 17.4 km, 7.3 to 18.8 km and 4.5 to 10.5 km for cattle, sheep and goats, respectively. All herded animals were watered one or two times a day at watering points (wells; sometimes also temporary ponds during rainy and early dry season) within the grazed area, mostly around 2–3 p.m. Decisions on watering were taken by the herders. None of the monitored herds was taken on rainy or dry season transhumance, and none practiced night grazing.

Within each herd of cattle, sheep and goats, the selected female animal (see above) was followed by an observer during its daily time on pasture and all its activities were instantaneously recorded every 5 min from the departure to the pasture areas in the morning (between 7 and 9 a.m.) until its return to the night resting place (around 6 or 7 p.m.), thereby assuming that the observed activity was representative for the 5-min window centered by the moment of observation. The following activities were differentiated: grazing (defined as the consumption of grasses, dicotyledonous herbs and crop residues), browsing (consumption of fresh or dry leaves, flowers, fruits, and pods of trees and shrubs), short-distance movements between feeding stations, larger-scale directional movements, and resting (resting and/or ruminating, including also social activities and idling). However, time spent on the activities walking and resting is not further considered in this paper.

At each event of browsing, the apprehended plant species was identified and noted down by the observer; in case of doubt a characteristic part of the plant was collected for later identification. Botanical names for the different ligneous species were taken from Arbonnier (2002). Additionally, all ligneous species browsed at least once by any animal of the herd during the daily grazing time was also noted. Each herd was followed during three consecutive days per season, resulting in a total of 81 daily grazing itineraries.

From the different observations and measurements, the following parameters were derived:

2.2.1. Browse species diversity in the pasture area

The inventory of browse species consumed by any animal of the herd was used to determine the major fodder trees and shrubs per village territory, livestock species and season.

2.2.2. Daily browsing and grazing time and preference index of browse species

From the total number of recorded activities during daily time on pasture, the proportion of time spent by the observed animal on grazing [Eq. (1)] or browsing [Eq. (2)] as well as the total time spent feeding [Eq. (3)] was calculated. For each browse species, the sum of the prehension time was divided by the total daily browsing time; the resulting value was used as indicator for the animals' preference for the particular species in relation to all browsed species [Eq. (4)].

$$\text{Grazing time } (\%) = \sum_{i=1}^{n} \text{Gi}/T^{*}100 \quad (1)$$

$$\text{Browsing time } (\%) = \sum_{i=1}^{n} \text{Bi}/T^{*}100 \quad (2)$$

$$\text{Feeding time } (\%) = \left(\sum_{i=1}^{n} \text{Bi} + \sum_{i=1}^{n} \text{Gi}\right) \Big/ T^{*}100 \quad (3)$$

$$\text{Preference index } (\%) = \frac{\text{Bk}}{\sum_{i=1}^{n} \text{Bi}}{}^{*}100 \quad (4)$$

where Bi is the recorded observation time spent by an animal browsing on any tree or shrub species, Bk is the recorded observation time spent on a particular ligneous species k, Gi is the recorded observation time spent by an animal grazing on grasses, herbs or crop residues, and T is the total time spent on pasture.

The preference index was used to rank the browsed species on a year-round basis, for each agro-ecological zone and ruminant species separately. The overlap coefficient (between goats and sheep) was determined by dividing the number of browsed species selected by both animal species by the total number of browse species selected by either goats or sheep in each zone separately.

2.3. Proximate composition and nutritive value of browse species

The air-dried samples of leaves and pods of 17 preferred browse species, collected during the monitoring period, were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and the concentration of total phenols (TP) and condensed tannins (CT). NDF, ADF and ADL were determined by a modification of the method of Van Soest et al. (1991) using a semi-automated Ankom 220 Fiber Analyzer (ANKOM Technology, Macedon, NY, USA) without using decalin or sodium sulphite, while the nitrogen concentration was determined with an automatic N analyzer (Leco®, FB-328). Determination of TP concentrations was done using the Folin–Ciocalteu method (Makkar et al., 1993), and CT were extracted according to Porter et al. (1986). The *in vitro* OM digestibility and metabolizable energy (ME) content of 12 browse samples were evaluated according to Menke and Steingass (1988).

2.4. Ligneous plants use by livestock keepers

From February to May 2009, focus group discussions on the use of ligneous plants by livestock keepers were held in each of the three villages. A total of 15–30 persons per village – mainly Fulani herders and livestock owners – were asked on their perception of the use of ligneous plants as fodder by their grazing animals, and on their own application of such plants for animal health treatments. In addition to the group discussions, interviews using structured questionnaires were conducted with 76 individual Fulani livestock keepers (25 or 26 per village) from January to May 2010. All these interviewees had been identified during the focus group discussions; owing to cultural reasons all were male heads of pastoralist households, and their age ranged from 40 to 50 years.

The questionnaire addressed details on the use of ligneous plants (i) as feed by animals, (ii) for the treatment of animal diseases, and (iii) the perception of the respondents on changes in browse use by livestock and its relation to reported vegetation degradation in Burkina Faso.

2.5. Statistical analyses

Differences in the number of browse species selected and their relative contribution to browsing time across seasons and agro-ecological zones, the perception of livestock keepers on the uses of browse for different purposes and respective changes during the past twenty years were analyzed using the non-parametric Kruskal–Wallis test. The Chi-square test was used to compare the contribution of browsing time to daily eating time across the three livestock species. A binary logistic regression with a stepwise backwards elimination of predictors was performed to identify the most determinant variables affecting ruminants' browsing activities on pasture. Factors tested in the model were season ($n = 3$, rainy, cool and hot dry) and agro-ecological zone ($n = 3$, sub-Sahelian, northern and southern Sudanian). The fit of the final model was assessed by the model Chi-square (Model χ^2) and the goodness-of-fit test of Hosmer and Lemeshow (Archer and Lemeshow, 2006). Well-fitting models show significance ($P \leq 0.05$) on the Model χ^2 and non-significance ($P > 0.05$) on the goodness-of-fit test. In addition, a multiple linear regression analysis was performed for the relationship between the proximate constituents of an overall number of 20 browse species and their preference (in %, year-round) by cattle, sheep and goats; hereby, missing data on proximate constituents were completed from Guérin (1994).

All statistical analyses were performed using IBM® SPSS® Statistics 19; significance was declared at the 0.05 level.

3. Results

3.1. Nutritive value and preference of browse species by cattle and small ruminants

A total of 75 ligneous species distributed across 24 families (Appendix 1) were browsed by goat, sheep and cattle herds across the three study locations during the monitoring period. The most preferred ligneous families were Mimosoideae (15 species), Combretaceae (9 species) and Caesalpiniaceae (8 species). The preference for browse species varied according to season, agro-ecological zone and animal species. The total number of browse species selected by goats throughout the year was 20 in the northern Sudanian zone, 14 in the southern Sudanian zone and 9 in the sub-Sahelian zone. Similar to goats and in contrast to cattle, sheep browsed on a large variety of woody species (Table 1). However, regardless of animal species and zone, browse species were less frequently selected in the cool dry season than in the rainy and hot dry season. The overlap coefficient for browse species preferred by goats and sheep was 0.46, 0.35 and 0.32 in the northern Sudanian, southern Sudanian and sub-Sahelian zone, respectively. Regardless of season, the proportion of total browsing time spent by goats and sheep, respectively, on their five most preferred browse species was 87% for both species in the sub-Sahelian zone, 87% and 66% in the northern Sudanian zone, and 61% and 52% in the southern Sudanian zone. For cattle in the northern and southern Sudanian zone, respectively, the proportion of total browsing time spent on *A. africana* was 40% and 24%, while the values were 11% and 46% for *P. erinaceus*, 21% for *Acacia sieberiana* (only present in the northern Sudanian zone) and 11% for *Prosopis africana* (only present in the southern Sudanian zone). In the sub-Sahelian zone, browsing time of cattle was exclusively concentrated on *Piliostigma reticulatum* (92%) and *Anogeissus leiocarpa* (8%).

The crude protein concentration (in DM) of the pods or fruits of the most important browse species selected by goats, sheep and cattle (Table 2) ranged from 7% to 13%, and from 10% to 18% for foliage. The concentration of digestible organic matter of preferred browse species mostly ranged from 40% to 60%, and the concentrations of total phenols, condensed tannins and acid detergent lignin were low. From Pearson correlation analyses, the following correlation coefficients (r) were obtained between preference of a browse species by goats and its CP, DOM, OM, NDF and ADF concentration: $r_{CP} = 0.64$, $P < 0.05$; $r_{DOM} = 0.46$, $P < 0.05$; $r_{OM} = -0.35$, $P < 0.05$; $r_{NDF} = -0.26$, $P > 0.05$; $r_{ADF} = -0.33$, $P > 0.05$. The multiple linear regression analysis also showed a significant and positive relationship between goats' preference of browse species and their concentrations of CP and NDF, while correlations with the concentrations of DOM and ADF were negative (Table 3). Due to lack of sufficient data, no correlations could be determined for cattle and sheep.

3.2. Contribution of browse species to ruminants' diet on pasture

Table 4 presents the relative contribution of browsing time to ruminants' daily eating time across seasons and agro-ecological zones. Compared to the southern Sudanian zone, goats spent a significantly higher proportion of their eating time on browsing in the sub-Sahelian and northern Sudanian zones ($P < 0.01$). In the two latter zones, browsing also contributed significantly more ($P < 0.05$) to goats' eating time than grazing of herbaceous forage in all seasons. Nevertheless, the proportion of browsing time was significantly ($P < 0.05$) higher in the hot dry season than in the cool dry and rainy season.

Across the three zones and a yearly cycle, sheep and cattle spent a low to moderate proportion of their feeding time on browsing (5.0–25.5%) as compared to goats (34.4–90.1%). However, this proportion was significantly ($P < 0.05$) higher in the hot dry season than in the cool dry and rainy season. The results of the logistic regression analysis (Table 5) indicated that season and agro-ecological zone were the most important factors determining browsing time of goats, sheep and cattle on communal pastures: in the rainy and cool dry season browsing activities of all ruminant species were reduced ($P < 0.01$); yet, in the sub-Sahelian and northern Sudanian zones cattle were more likely to browse than in the southern Sahelian zone. The use of browse species by small ruminants was however less likely to occur in the southern Sudanian zone as compared to the sub-Sahelian and northern Sudanian zone.

3.3. Livestock keepers' use of woody plants, and perceptions of changes in the recent past

Without significant differences across agro-ecological zones, all Fulani livestock keepers affirmed that goats were the animal

Table 1
Average daily time (min/d) spent foraging on different browse species by small ruminants and cattle, and rank (Rk) of browse species across the different seasons[a] of a year in three agro-ecological zones of Burkina Faso. The values minute/day were obtained by multiplying the grazing records of animals. For example: if browsing, which was registered every 5 min, was recorded 20 times during a day for an animal, the total browsing time was assumed to be 100 min/day.

Browse species	Goats				Sheep				Cattle			
	RS	CDS	HDS	Rk	RS	CDS	HDS	Rk	RS	CDS	HDS	Rk
Sub-Sahelian zone												
Acacia dudgeoni	18	0	0	7	0	3	0	5	0	0	0	
Acacia laeta	10	0	19	6	0	0	0		0	0	0	
Acacia seyal	105	12	250	1	0	3	0	7	0	0	0	
Anogeissus leiocarpa	0	0	2	13	0	0	0		0	7	0	2
Balanites aegyptiaca	7	79	48	2	0	70	14	2	0	0	0	
Combretum micranthum	10	37	17	3	3	0	0	4	0	0	0	
Piliostigma reticulatum	0	19	15	4	0	3	85	1	0	0	78	1
Ziziphus mauritiana	12	17	4	5	0	0	0		0	0	0	
Other browse species	20	15	9		6	21	0		0	0	0	
Sum (min/d) for all browses	182	179	364		9	100	99		0	7	78	
Number of browse species	12	8	9		2	8	2		0	1	1	
Northern Sudanian zone												
Acacia dudgeoni	3	0	0	15	0	18	0	2	0	2	0	9
Acacia gourmaensis	38	8	50	2	0	16	37	1	0	2	0	10
Acacia seyal	25	100	18	1	3	5	5	5	0	0	0	
Acacia sieberiana	0	0	0		0	0	0		0	32	0	2
Afzelia africana	0	0	0		0	0	0		0	0	60	1
Anogeissus leiocarpa	15	2	50	4	0	3	8	6	0	0	0	
Balanites aegyptiaca	63	12	10	3	0	10	7	3	0	18	0	3
Piliostigma reticulatum	9	23	5	6	0	10	0	7	0	0	0	
Pterocarpus erinaceus	0	0	13	6	0	0	3	11	0	0	16	4
Ximenia americana	0	0	8	7	0	0	15	4	0	2	0	14
Other browse species	25	6	15		7	14	16		0	9	8	
Sum (min/d) for all browses	178	151	169		10	76	91		0	65	84	
Number of browse species	15	9	12		3	12	12		0	10	5	
Southern Sudanian zone												
Acacia sieberiana	0	0	0		0	0	0		0	0	7	4
Afzelia africana	0	0	0		0	0	0		0	0	34	2
Combretum nigricans	14	0	0	4	0	0	2	9	0	0	0	
Guiera senegalensis	38	0	0	1	0	0	0		0	0	0	
Piliostigma reticulatum	20	0	0	3	0	0	0		0	0	0	
Prosopis africana	0	0	0		0	0	0		0	14	2	3
Pterocarpus erinaceus	0	0	12	5	0	0	15	1	0	0	64	1
Zanthoxylum zanthoxyloides	10	18	1	2	0	0	2	12	0	0	2	13
Other browse species	30	1	41		10	0	25		0	8	9	
Sum (min/d) for all browses	112	19	54		10	0	44		0	22	118	
Number of browse species	15	2	12		4	1	11		3	4	10	

[a] RS = rainy season, CDS = cool dry season, HDS = hot dry season, Rk = Rank (within all browses selected year-round).

species browsing most across all seasons (Table 6). According to them, sheep and cattle mostly browse during the cool and hot dry season, with significant differences ($P < 0.05$) perceived between seasons for cattle. Overall, a significant proportion of the respondents, ranging from 64% in the southern Sudanian zone to 80% in the sub-Sahelian zone, reported that they used browse species for ethno-veterinary purposes. Across all agro-ecological zones, the most common use of browse species in ethno-veterinary applications was disease treatment (Table 6); as detailed in Appendix 1, a total of 36 woody species were used to treat 13 of the most frequent animal diseases at the different study locations. Although the majority of interviewed livestock keepers had a good knowledge of woody plant species and of their uses in traditional animal health care, most of them mentioned that they also relied on modern veterinary medicine to prevent and to cure some complicated cases of disease.

Livestock keepers perceived changes over the past two decades regarding their animals' intake of browse species, and in their own applications of ligneous plants for animal health care purposes (Table 7). While they reported an increased intake of browse species by ruminants across the three different zones over the past 20 years, they noticed a significant decrease in their own use of ligneous plants for animal health care, and the disappearance of the use of browse plants to stimulate cows' milk production. According to the respondents, the main driving factors behind those changes were the decline over time of the herbaceous biomass, the negative impacts of drought and desertification, and the expansion of cropping areas. Respondents further identified the development and systematic use of modern veterinary medicine and veterinary services, combined with the decline in the availability of the most commonly used browse species, as main reasons for the observed decrease in the use of woody plants for animal health care purposes.

4. Discussion

4.1. Browse species selection by cattle and small ruminants

Our results indicate that domestic ruminants make use of a considerable number of browse species across the various agro-ecological zones of Burkina Faso. The highest diversity of browsed species was found in the Sudanian zone, where the vegetation consists of dry and sub-humid tree savannas and forests (Schmidt et al., 2010). In this zone the browsed species are essentially

Table 2
Concentrations of crude protein (CP), digestible organic matter (DOM), metabolizable energy (ME), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), total phenols (TP) and condensed tannins (CT) in the dry matter (DM) of samples of fruits (Fr) and foliage (Fl) of browse species selected by domestic ruminants in three agro-ecological zones of Burkina Faso (means and (SD)).

Browse species, plant part		*n*	CP (%)	DOM (%)	ME (MJ/kg DM)	NDF (%)	ADF (%)	ADL (%)	TP (g/kg)	CT (g/kg)
Acacia dudgeoni	Fr	2	12.4 (0.00)	47.3 (0.00)	5.8 (0.00)	46.7 (1.00)	31.7 (0.68)	12.9		
Acacia macrostachya	Fr	6	12.9 (4.07)			44.0 (3.46)	31.7 (3.36)	11.1	7.0	0.3
Acacia sieberiana	Fr	2	8.5 (0.00)	47.2 (0.00)	6.2 (0.00)	31.7 (1.36)	24.2 (1.00)	10.7		
Cassia sieberiana	Fr	6	7.9 (1.09)			33.0 (1.38)	24.4 (1.28)	13.1		
Faidherbia albida	Fr	2	8.3 (0.00)	59.7 (9.40)	8.6 (1.62)	41.6 (0.00)	32.4 (0.09)	9.4		
Piliostigma reticulatum	Fr	6	7.5 (1.36)			32.6 (0.86)	24.4 (0.86)	17.5	7.7	0.4
Piliostigma thonningii	Fr	2	7.2 (0.00)			36.7 (0.07)	26.5 (0.19)	18.4		2.4
Prosopis africana	Fr	2	8.7 (0.00)			32.9 (0.13)	23.4 (0.23)	12.6		
Acacia gourmaensis	Fl	2	12.8 (0.14)	56.9 (0.00)	7.4 (0.00)	35.6 (0.25)	21.9 (0.45)	6.4	1.2	0.3
Acacia macrostachya	Fl	2	14.5 (0.00)			40.6 (3.55)	30.2 (1.73)			7.0
Acacia seyal	Fl	2	15.6 (0.04)	54.4 (3.70)	7.6 (0.92)	20.4 (0.92)	12.8 (0.60)	5.3		0.1
Afzelia africana	Fl	4	18.4 (0.62)	50.9 (3.60)	8.1 (0.73)	43.7 (3.35)	30.5 (2.50)	12.6	0.1	n.d.
Anogeissus leiocarpus	Fl	4	10.5 (0.38)	36.3 (0.00)	4.7 (0.00)	20.3 (3.16)	13.7 (1.40)			
Balanites aegyptiaca	Fl	8	14.2 (3.30)	59.8 (4.20)	7.8 (0.56)	32.4 (4.49)	20.5 (3.61)	15.5	1.0	n.d.
Combretum glutinosum	Fl	4	10.5 (0.40)			36.8 (8.99)	25.6 (5.70)	10.7	7.5	2.5
Combretum micranthum	Fl	2	24.5 (0.00)			21.9 (0.13)	15.3 (0.00)	6.4	8.9	0.4
Faidherbia albida	Fl	6	16.7 (3.73)	47.8 (6.10)	6.6 (1.11)	35.5 (2.88)	24.8 (1.97)	11.1	1.3	0.7
Gardenia erubescens	Fl	6	7.8 (0.95)	46.7 (0.00)	6.2 (0.00)	27.8 (6.26)	18.9 (4.56)	31.3		
Piliostigma reticulatum	Fl	4	10.2 (1.32)	40.7 (5.20)	5.9 (0.88)	32.9 (0.71)	22.2 (0.60)			
Pterocarpus erinaceus	Fl	6	15.3 (1.30)	46.2 (8.20)	6.5 (1.28)	50.2 (3.03)	35.5 (4.20)	13.0	0.2	n.d.
Ximenia americana	Fl	2	11.2 (0.00)	37.0 (0.00)	4.9 (0.00)	19.5 (1.69)	14.9 (2.24)	16.1		
Ziziphus mauritiana	Fl	6	13.3 (0.59)	48.6 (4.60)	6.5 (0.85)	34.2 (2.62)	23.4 (2.10)	16.1	3.3	1.2

n.d. = not detectable.

Combretaceae, the genus also dominating the zone's ligneous vegetation (Thiombiano et al., 2006). In the semi-arid sub-Sahelian zone, *Acacia* species, *C. micranthum* and *B. aegyptiaca*, which are the dominant woody species there (Sop et al., 2011), were frequently browsed, especially by goats and sheep. Surprisingly, the browse species preferred by small ruminants in the sub-Sahelian zone were not used by cattle, while goats and sheep had nine preferred browse species in common. In some species, such as *Piliostigma* sp. and *F. albida*, especially the pods were preferred and used by all ruminant species across zones, particularly during the cool and hot dry season, which correspond to their fructification period (Heuzé and Tran, 2011). Our multiple linear regression analysis showed a significant relationship between the proximate constituents of browse species and their preference by goats, indicating that beyond physical browse characteristics the nutritive value affects preference by ruminants on pasture (Baumont et al., 2000), although the negative – though weak – correlation between preference and organic matter digestibility cannot be explained. The results of the logistic regression analyses underline that on pasture browse preferences by a specific ruminant species are strongly related to the occurrence and phenological stage (and thus nutritive value) of the ligneous plants (Ngwa et al., 2000), factors that vary with environmental conditions (agro-ecological zone and season) but also land uses (Fischer et al., 2011). The heterogeneity of Sahelian and Sudanian pastures (Schmidt et al., 2010) is thus

Table 3
Multiple linear regression coefficients for the relation between goats' preference (see Eq. (4)) for the fruits or leaves of a browse species and the respective concentrations of proximate constituents.

Predictors	β	SE_β	Sig.[a]	Model r^2	r^2 change[a]
Step 1					
Constant	−39.78	13.98		0.64	0.410**
Crude protein (%)	3.90	1.10	**		
Step 2					
Constant	−32.73	11.43		0.80	0.231*
Crude protein (%)	4.55	0.91	**		
Acid detergent fiber (%)	−0.73	0.22	**		
Step 3					
Constant	−31.54	10.10		0.87	0.096*
Crude protein (%)	4.13	0.82	**		
Acid detergent fiber (%)	−3.94	1.35	**		
Neutral detergent fiber (%)	2.30	0.95	**		
Step 4[b]					
Constant	−17.97	9.82		0.91	0.089*
Crude protein (CP, %)	5.71	0.89	**		
Acid detergent fiber (ADF, %)	−6.21	1.40	**		
Neutral detergent fiber (NDF, %)	3.76	0.96	**		
Digestibility of OM (DOM, %)	−0.67	0.24	**		

OM = organic matter.
[a] Sig. and r^2 change: *$P < 0.05$; **$P < 0.01$.
[b] Final equation: Preference (%) = $-17.97 + 5.71CP - 6.21ADF + 3.76NDF - 0.67DOM$.

Table 4
The relative contribution of browsing to daily eating time, and the number of browse species selected per day by small ruminants and cattle across three seasons and three agro-ecological zones of Burkina Faso (means and (SD)).

Variable	Goats	Sheep	Cattle	*P*<
Browse contribution to daily eating time (%)				
Agro-ecological zone				
Sub-Sahelian	81.7 (21.60)	25.5 (22.67)	5.0 (7.75)	0.01
Northern Sudanian	90.8 (11.93)	23.9 (17.54)	15.5 (14.17)	0.01
Southern Sudanian	34.4 (20.58)	8.4 (13.38)	15.1 (16.16)	0.01
P<	0.01	ns	ns	
Season				
Rainy	66.3 (23.13)	8.5 (13.89)	0.5 (0.82)	0.01
Cool dry	60.0 (38.01)	28.3 (23.99)	11.9 (11.87)	0.01
Hot dry	86.4 (24.24)	30.3 (12.47)	26.8 (10.34)	0.01
P<	0.05	0.05	0.01	
Browse species selected daily (*n*)				
Agro-ecological zone				
Sub-Sahelian	8.3 (3.00)	3.4 (2.13)	1.6 (1.31)	0.01
Northern Sudanian	12.2 (4.03)	8.1 (1.66)	5.9 (4.34)	0.05
Southern Sudanian	5.9 (4.51)	5.0 (3.04)	4.9 (3.55)	ns
P<	0.05	0.01	0.01	
Season				
Rainy	11.0 (6.01)	6.7 (3.34)	2.2 (1.52)	0.01
Cool dry	5.9 (2.08)	5.0 (3.19)	6.2 (4.38)	ns
Hot dry	9.9 (2.61)	6.2 (2.04)	6.7 (2.97)	0.01
P<	0.01	ns	0.01	

ns = non significant.

Table 5
Results of the binary logistic regression on the effects of agro-ecological zone and season on browse use by goats, sheep and cattle on communal pastures in Burkina Faso.

Predictors	β	SE_β	Wald's χ^2	df	$P\leq$	e^β (odds ratio)
Goats ($n = 1242$)[a]						
Constant	2.665	0.212	157.76	1	0.001	14.37
Agro-ecological zone			230.77	2	0.001	
Sub-Sahelian (1)	1.135	0.225	25.36	1	0.001	3.11
Northern Sudanian (2)	−1.852	0.159	136.34	1	0.001	0.16
Season			75.11	2	0.001	
Rainy season (1)	−1.705	0.217	61.93	1	0.001	0.18
Cool dry season (2)	−1.896	0.230	68.00	1	0.001	0.15
Test			χ^2	df	$P\leq$	
Overall model evaluation (Model χ^2)			409.84	4	0.001	
Goodness of fit (Hosmer & Lemeshow)			143.16	7	1.000	
Sheep ($n = 1300$)[a]						
Constant	−0.369	0.191	3.74	1	0.053	0.69
Agro-ecological zone			40.67	2	0.001	
Sub-Sahelian (1)	0.014	0.229	0.00	1	0.950	1.01
Northern Sudanian (2)	−1.399	0.232	36.22	1	0.001	0.25
Season			95.34	2	0.001	
Rainy season (1)	−2.899	0.327	78.72	1	0.001	0.06
Cool dry season (2)	−0.230	0.228	1.02	1	0.312	0.79
Test			χ^2	df	$P\leq$	
Overall model evaluation (Model χ^2)			200.38	4	0.001	
Goodness of fit (Hosmer & Lemeshow)			62.08	6	1.000	
Cattle ($n = 1572$)[a]						
Constant	−1.835	0.179	105.19	1	0.001	0.16
Agro-ecological zone			23.20	2	0.001	
Sub-Sahelian (1)	0.863	0.218	15.71	1	0.001	2.37
Northern Sudanian (2)	1.016	0.217	21.88	1	0.001	2.76
Seasons			64.33	2	0.001	
Rainy season (1)	−4.040	0.587	47.33	1	0.001	0.02
Cool dry season (2)	−0.839	0.178	22.34	1	0.001	0.43
Test			χ^2	df	$P\leq$	
Overall model evaluation (Model χ^2)			202.06	4	0.001	
Goodness of fit (Hosmer & Lemeshow)			39.63	7	1.000	

[a] n is the total number of recorded feeding activities of each animal herd during 3 days per season in each agro-ecological zone.

certainly a further explanation of the observed variability in browse preference across agro-ecological zones. In addition, regional as well as livestock-specific differences in the use of browse plants may be explained by herders' practice to loop tree branches for their animals, especially in the hot dry season, and to the – though officially banned – practice of burning the vegetation of natural pastures and fallows, especially in more humid regions, which leads to a resprouting of perennial grasses and thus the supply of highly nutritious herbaceous fodder (Ouédraogo and Delvingt, 2007).

Although the overall number of selected browse species was high, only a few species contributed significantly to daily browsing time. Irrespective of season, *Acacia* sp. (e.g. *A. seyal*, *A. dudgeoni*, and *A. gourmaensis*), *C. micranthum* and *B. aegyptiaca* were highly preferred by small ruminants in the sub-Sahelian and the northern Sudanian zone, while *A. africana* and *P. erinaceus*, *A. sieberiana* and *P. africana*, which were only found in the two Sudanian zones (Ouédraogo-Koné, 2008), were preferred by cattle. The relative importance of *Acacia* sp. and *B. aegyptiaca* for small ruminants might be due to their abundance, their easy accessibility on pasture and their relatively good nutritive value (Abdulrazak et al., 2000; Kaboré-Zoungrana et al., 2008). Although woody vegetation cover in the Sahelian zone declined since the last severe drought (Sop and Oldeland, 2011; Wezel and Lykke, 2006), *A. seyal* and *B. aegyptiaca* are still abundant and among the most important woody species in this zone (Sop and Oldeland, 2011). The high density of these species also in the northern Sudanian zone might be explained by the gradually changing climatic and edaphic conditions (Sahelisation of the Sudanian zone; Wittig et al., 2007) that provide comparative advantage for their establishment and persistence in this area (Wittig et al., 2007). In contrast, the abundance of *A. africana* and *P. erinaceus* is currently declining in the parklands of Burkina Faso (Nacoulma et al., 2011), which seems to be a consequence of the combination of their multipurpose uses by farmers with their low capacity of self-promoted regeneration and difficulties of establishment and development of juvenile trees (Ouedraogo et al., 2006).

4.2. Contribution of browse species to livestock nutrition and health care

Our results from the monitoring of grazing behavior underlined the important contribution of browsing to ruminants' daily eating time (Cisse et al., 2002; Sanon et al., 2007). Irrespective of season, browse contribution to goat feeding was high in the sub-Sahelian and the northern Sudanian zone, but only moderate in the southern Sudanian zone, where cattle spent more time browsing than goats during the cool and hot dry seasons. This observation has different reasons: Firstly, goats in the southern Sudanian zone grazed primarily on crop residues near the homesteads during the cool and hot dry season (Table 1), which manifested in their short daily grazing itineraries. Secondly, at both Sudanian study locations, there was abundance of browse species such as *P. erinaceus*, *A. africana* and *P. africana*, which were preferably consumed by cattle during the hot dry season. During this period of the year herders cut

Table 6
Interview-based information on the proportion (%) of pastoralists' confirming the use of browse plants by their grazing animals, and their own use of ligneous plants for health care purposes across three agro-ecological zones of Burkina Faso.

Purpose		Sub-Sahelian ($n = 26$)	Northern Sudanian ($n = 25$)	Southern Sudanian ($n = 25$)
Use for ruminant nutrition				
Goats	RS*	84.6	92.0	92.0
	CDS	96.2	92.0	100
	HDS	100	100	100
Sheep	RS	61.5	52.0	44.0
	CDS	84.6	80.0	76.0
	HDS	92.3	100	100
Cattle	RS	50.0	28.0	16.0
	CDS	76.9	44.0	68.0
	HDS	100	100	96.2
Use for animal health care and milk production stimulation				
All ruminants	Disease prevention	26.9	24.0	20.0
	Disease treatment	73.1	60.0	60.0
	Stimulation of cow milk production	0	16.0	12.0
	Overall use for treating animals	80.0	72.0	64.0

* RS = rainy season, CDS = cool dry season, HDS = hot dry season.

Table 7
Pastoralists' perception (% of respondents) of the changes in browse use as forage by their animals, and for animal health care purposes during the past 20 years across three agro-ecological zones of Burkina Faso.

Browse use	Use tendency	Sub-Sahelian ($n = 26$)	Northern Sudanian ($n = 25$)	Southern Sudanian ($n = 25$)	Overall ($n = 75$)
By animals[a]	Increased	82.1	56.0	70.7	69.7
	Decreased	15.4	6.7	24.0	15.4
	No change	2.6	37.3	5.3	14.9
For animal disease prevention	Increased	0	0	0	0
	Decreased	95.5	94.6	100	96.9
	Disappeared	4.5	0	0	1.6
	No change	0	5.6	0	1.6
For animal disease treatment	Increased	0	0	0	0
	Decreased	95.5	91.3	100	95.7
	Disappeared	4.5	0	0	1.4
	No change	0	8.7	0	2.9
For stimulating milk production in cows	Increased	0	0	0	0
	Decreased	0	100	100	66.7
	Disappeared	100	0	0	33.3
	No change	0	0	0	0

[a] Cattle, sheep and goats.

branches of these trees to feed their animals, thus increasing browse use; during the cool dry season, cattle ingested the then available pods of *P. africana*. On the other hand, cattle in the sub-Sahelian zone were mostly herded on harvested fields where crop residues were abundantly available during the cool dry season. On these surfaces, browse fodder was rarely available due to farmers' cropping practices that remove all shrubs and even some major trees from cropland. Often only a few *F. albida* are kept in fields for their fruits and shadow in the dry season.

As far as the relative browsing time of cattle and sheep is concerned, the present values are higher than those reported in previous studies conducted in the region. Botoni (2003) reported an average rainy season value of 6% browsing time for cattle in the southern Sudanian zone, which increased to 10–13% in the cool dry season and to 30% in the hot dry season. For the Sudanian site of Dossin, Nianogo and Thomas (2004) found that the average proportion of feeding time spent browsing was 82% for goats and 15% for sheep. Yet, in our case the modest contribution of browse to the daily eating time of sheep in the southern Sudanian zone can be explained by the fact that, like already discussed for the goats, herders primarily conducted their sheep to harvested crop fields (which are relatively abundant in this zone) with ample crop residues. In addition, the (illegal) dry season practice of burning the natural vegetation induces a resprouting of the prevailing perennial C4 grasses on natural pastures, fallows and field borders, and such reduces the animals' need for browsing.

However, a direct comparison of published data with those obtained in our study is not possible because of sources of variation such as methods used, observer error, intra- and inter-annual variation of forage availability, and land use changes over time. In the present study, Fulani livestock keepers and herders reported an increased use of browse by ruminants on pasture especially during the dry season when herbaceous forage is scarce. This perceived increase in the duration of ruminant browsing time might be related to the steady decline in primary production and species richness of the herbaceous vegetation during the past 40 years (Gonzalez, 2001; Hiernaux et al., 2009; Paré et al., 2010). Hiernaux et al. (2009) showed that from 1994 to 2006, the overall herbaceous biomass in southern Niger decreased at an annual rate of 5%, which could not be explained by changes in rainfall. Turner and Hiernaux (2008) argued that this decline has probably induced changes in pastoralists' grazing management strategies and in their use of pasture resources. In Burkina Faso, the expansion of cropland reduced pasture availability and access to watering points especially during the rainy season. This might explain the important use of browse species by small ruminants during that period of the year. In the case of sedentary livestock keepers, lack of labor for herding during the rainy season triggered stall-feeding of small ruminants with collected browse foliages at the Sudanian sites of Safané and Sokouraba. During the cool dry season, crop residues are often not accessible any more to pastoralist herds because they are systematically collected by crop farmers who feed their own animals, or are being sold (Powell et al., 2004). In consequence, especially goats grazing harvested fields relied on fresh sprouts or seedlings of ligneous plants re-emerging on cultivated land and fallow. The results of our logistic regressions confirmed these observations, indicating that a decrease in the spatio-temporal availability and accessibility of herbaceous forages (in the cool dry season) increases the odds of the contribution of browse to the diet of grazing ruminants, in particular of cattle and sheep. Yet, for the southern Sudanian zone of Burkina Faso this expectancy of an increasing browse use is not supported by our results, even though the livestock keepers perceived an increase in their animals' browse use. However, for the sub-Sahelian and northern Sudanian zone our results on mean browsing time per day and per season are considerably higher than those previously reported for the region (Nianogo and Thomas, 2004; Sanon et al., 2007). According to our interviewees intensified use-practices for browses are establishing in these two zones, such as the systematic collection and storage of the pods of *P. reticulatum* and *F. albida* by children and women for sale at local fodder markets, and a rainy season cut-and-carry browse feeding system for sheep and goats (especially in the northern Sudanian zone) that emerges due to the lack of labor for herding. These issues do however require further research.

In contrast to the acknowledged value of browse for animal nutrition, the use of woody species for traditional animal health care has decreased over time according to the interviewed Fulani livestock keepers, probably due to the increased use of modern veterinary medicine provided by extension services and private veterinary services, but also due to the decline of the most commonly used woody species. Indeed, since the colonial period modern animal health care has been strongly promoted by authorities, which has helped to cure and even eradicate some important zoonotic diseases in the region. Today veterinary extension services are available all across Burkina Faso and livestock keepers systemically use their services for animal heath care.

4.3. Implications of climate change and anthropogenic factors on browse use by livestock

As discussed above, the increased use of browse by ruminants on pasture points to a reduced availability and/or accessibility of herbaceous forages including crop residues. Although this situation seems to be more strongly influenced by anthropogenic pressure on land and natural resources in general, than by climate variability and change, these phenomena are of course interrelated and it is very difficult to disentangle them. With respect to historical trends in rainfall during the past five decades, Wittig et al. (2007) pointed to the appearance of the 400 mm isohyet in the northern part of Burkina Faso and the disappearance of the 1200 mm isohyet in its Sudanian zone, phenomena that translate to a reduction of the average amount of annual rainfall in a large part the country. These changes together with the intrinsically high rainfall variability might further reduce availability of herbaceous forages on pasture and scatter their distribution, rendering browse fodder an even more important (dry season) fodder supplement for livestock, especially in the sub-Sahelian and northern Sudanian zones. Furthermore, the above-mentioned Sahelisation of the Sudanian zone as observed in Burkina Faso (Wittig et al., 2007) has enlarged the distribution area of some palatable and preferred browse species especially for goats and sheep. This situation seems to show in the results of the logistic regression analysis presented in Table 5, where for small ruminants across agro-ecological zones the odds of using browse fodder was <1 for the rainy and cool dry season (and 1 for the hot dry season, which was chosen as reference season for the regression and is therefore not appearing in Table 5). Across seasons, the odds ratio of using browse forages was >1 for the sub-Sahelian zone compared to the northern Sudanian and southern Sudanian zone (the latter was chosen as reference zone for the regression and is therefore not appearing in Table 5; its odds would be 1). For cattle, similar results were obtained with respect to season, while with respect to agro-ecological zone the odds using of browse fodder was >1 for the sub-Sahelian and the northern Sudanian zone. Irrespective of this we agree with Nardone et al. (2010) that further climate change might significantly and negatively affect the feeding practices and animal performances in the agro-silvo-pastoral systems of the Sahelian and Sudanian zones which are already facing serious problems such as reduced availability of drinking water for animals, shortage of forage resources, reduced pasture areas and shrinking transhumance routes that reduce transregional livestock mobility.

Another foreseeable change is an increase of goat numbers relative to sheep and cattle especially in the drier parts of the region (MRA, 2005), due to the goat's good adaptation to harsh and hot environments (Seo et al., 2010). Nevertheless, the use of browse as a source of protein could also help cattle and sheep to cope with aggravated nutritional stress under future climate change (Craine et al., 2010). *A. africana* and *P. erinaceus*, the species most frequently used by cattle, can be cultivated and yield a high amount of leaf biomass in Burkina Faso and Mali; they should therefore be introduced in local agro-forestry systems to reduce dry season fodder scarcity (Kandji et al., 2006; Ouédraogo-Koné, 2008). In view of the above-mentioned increasing pressure on forage resources in the region, propagation and yield studies as well fodder bank establishment and management should also be envisaged with other preferred browse species of high nutritional value that are drought tolerant and adapted to the regional conditions, especially *B. aegyptiaca* and *P. reticulatum*.

5. Conclusions

Our results on pasturing livestock's selection of browse in general and of individual tree and shrub species in particular, as well as on the perceived importance of browse fodder by pastoralists indicate its intensifying use by and for cattle, sheep and goats in Burkina Faso. This applies particularly for the sub-Sahelian and the northern Sudanian zone that are already experiencing a reduction in the amount of annual precipitation and increased climate variability. Additionally these zones suffer from high anthropogenic pressure on natural resources, notably crop and range land, natural vegetation and crop residues. Therefore policies should address the protection and valorization of prominent browse species as important and low cost sources of crude protein and energy for ruminant nutrition. Future studies should particularly investigate the potential of integrating *B. aegyptiaca*, *P. reticulatum* and *Piliostigma thonningii* in the local feeding systems. Moreover, species such as *A. dudgeoni*, *A. seyal*, and *Acacia senegal* seem to be promising candidates for agro-forestry systems to secure dry season fodder supply to domestic ruminants in the Sahelian and the northern Sudanian zone. Even though establishment of browse fodder banks is a very critical issue much related to land titles and use rights, it is theoretically feasible and would greatly help to provide quality fodder supplements for livestock in the explicitly defined pastoral zones delineated by the government of Burkina Faso.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2013.03.011.

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