The Potential of Some Sub-humid Zone Browse Species as Feed for Ruminants

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Cover: Drawing of leaflet of *A. africana* (on top), *K. senegalensis* (at left) and *P. erinaceus* (at right)(Salifou Ouédraogo).

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Abstract

The overall objective of this study was to determine the most utilized browse species in the sub-humid zone in Burkina Faso, and to evaluate their potential as fodder for ruminants.

The behaviour of sheep, goats and cattle was recorded on natural pasture using a direct observation method and farmers were interviewed concerning use of browse species. The phenological and chemical variations over the year were estimated through observations and collection of foliage samples every second week. The foliage biomass was evaluated using complete cutting and weighing. The nutritive value and the effect of feeding these foliages on growth performance were assessed in sheep using a completely randomised design. The browsing activity was about 25% of the total grazing time for all the animal species during the dry season. During the cool season the time spent browsing by goats (17%) was significantly higher than for sheep (7%) and cattle (5%). The plant species with the highest frequency of consumption by animals and most cited as fodder trees by farmers were *Acacia dudgeoni* Craib. ex Holl., *Ficus gnaphalocarpa* (Miq.) A. Rich, *Dichrostachys cinerea* (L.) Wight & Arn., *Faidherbia albida* A. Chevalier, *Afzelia africana* Sm. ex Pers., *Khaya senegalensis* (Desv.) A. Juss. and *Pterocarpus erinaceus* Poir. The foliage biomass per ha of the last three species differed significantly (0.3, 0.6 and 1.3 t dry matter (DM), respectively). The DM intake and apparent digestibility of DM for *A. africana* were the highest, 571 g/day and 582 g/kg, respectively. Significant relationships were found between the foliage biomass and the circumference of the crown for *A. africana* (R^2=82%) and *P. erinaceus* (R^2=81%). The growth rate was around 60 g/day when feeding a diet including *A. africana* and *P. erinaceus,* higher than with the diet with *K. senegalensis* (48 g/day).

These browse species constitute an important source of nitrogen for domestic ruminants in sub-humid West Africa and should to be promoted in the agrosilvopastoral systems as a dry season fodder reserve and to avoid the risk of extinction.

Keywords: Afzelia africana, Biomass, Browsing, Domestic ruminants, Growth performance, *Khaya senegalensis,* Nutritive values, Phenology, *Pterocarpus erinaceus*, Sub-humid West Africa.

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Dedication

To the memory of my
Father, Alassane Ouédraogo
Grand parents, Bintou Soma and Kalifa Koné;

And to my
Wife, Minata Sanou;
Lovely Mother, Doussou Koné;
Children, Kalifa and Ibaris Ara Ouédraogo.

Contents

List of Publications

This thesis is based on the following papers, referred to by Roman numerals in the text:

I Ouédraogo-Koné, S., Kaboré-Zoungrana, C.Y. and Ledin, I. (2006). Behaviour of goats, sheep and cattle on natural pasture in the sub-humid zone of West Africa. *Livestock Science,* 105(1-3), 244-252.

II Ouédraogo-Koné, S., Kaboré-Zoungrana, C.Y. and Ledin, I. (2008). Important characteristics of some browse species in an agrosylvopastoral system. *Agroforestry systems,* 74(2), 213-221.

III Ouédraogo-Koné, S., Kaboré-Zoungrana, C.Y. and Ledin, I. (2008). Intake and digestibility in sheep and chemical composition during different seasons of some West African browse species. *Tropical Animal Health and Production,* 40(2), 155-164.

IV Ouédraogo-Koné, S., Kaboré-Zoungrana, C.Y. and Ledin, I. Effect of feeding some West African browse foliages on growth and carcass composition in sheep (submitted).

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Abbreviations

ADF	Acid detergent fiber
ADG	Average daily gain
ADL	Acid detergent lignin
a.s.l.	Above sea level
BW	Body weight
CP	Crude protein
CPI	Crude protein intake
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
EBW	Empty body weight
FCR	Feed conversion ratio
GDP	Gross domestic product
GLM	General linear model
LWG	Live weight change
Mcal	Mega-calorie
ME	Metabolizable energy
MJ	Mega-joule
N	Nitrogen
NDF	Neutral detergent fiber
OM	Organic matter
SD	Standard deviation

Introduction

Livestock production is a key element of socioeconomic development in many countries in the tropics (FAO, 2005) and also contributes to nutritional and food security and plays an important role in cultural events (Nianogo and Thomas, 2004).

The sub-humid zone occupies about 5 million (M) km^2 globally, with an annual rainfall ranging between 900 and 1500 mm, and a crop-growing period of between 180 and 270 days (Smith, 1991). In Africa 25% of the people and 22%, 16% and 13% of the cattle, goats and sheep, respectively, can be found in this zone (von Kaufmann, 1986). According to Agyemang (2005), 24% of the global area of this zone is found in West Africa, of which Burkina Faso is a part.

The sub-humid zone in Africa stretches from southern Senegal, Gambia, and Guinea, through southern Mali and Burkina Faso, northern Ivory Coast, Ghana, Togo, Benin, central Nigeria, Chad, Central African Republic, to southern Sudan, most of parts of Uganda and western Kenya. Large parts of Tanzania, Mozambique, northern Zambia, southern Zaire, and Angola are also included (von Kaufmann, 1986). In West Africa, this region is one of the five agroecological zones described by Winrock (1992). It forms a continuous belt, extending roughly parallel to the Equator between latitudes 6° and 12° N.

Burkina Faso is situated in the middle of West Africa at 9°20' to 15°N and 5°30'W and 2°30'E. The contribution of the livestock sector to the GDP is currently estimated at 15% (Nianogo and Thomas, 2004). The livestock sector is the second most important source of income nationally, cotton being the first. The domestic ruminant stock of Burkina Faso is estimated to be 8.7 M cattle, 11.4 M goats and 7.3 M sheep (FAOSTAT, 2008) and the annual growth rate was 4.7%, 3.3% 2.3% and for cattle, goats and sheep, respectively (MRA, 2005).

Most of these animals are found in the arid and semi-arid part of the country. However, the livestock numbers are growing faster in the sub-humid zone (LEAD, 2005) and about 29%, 12% and 17% of the cattle, goats and sheep, respectively, in Burkina Faso can be found in this zone. The extensive production system using low inputs is the most important in the country (MRA, 2004), while the "mixed system" (Seré and Steinfeld, 1996) is the most dominant in the sub-humid zone. The mixed system is a form of agro-pastoral system in which crop and livestock production are jointly practiced (Slingerland, 2000). Natural pastures remain the main source of feed (85%), followed by crop residues (less than 11%) (MRA, 2004). The use of fodder crops and conserved forages is negligible.

The combined effects of fast demographic growth, extensive surface cultivation, bush fires and uncontrolled exploitation have had a negative effect on the natural pastures of the sub-humid zone (Steinfeld *et al.*, 1999; Jamin *et al.*, 2003). There is also an unfavourable seasonal variation, which is characterized by low and irregular rainfall (Grouzis et Albergel, 1989). All these factors have lead to a considerable reduction in area and productivity of the pastures. Therefore, the crucial problem for livestock has become the quantitative and qualitative feed shortage, especially during the long dry period (Breman and De Ridder, 1991). To deal with this challenge, livestock farmers have tried to find different solutions, one of which is the intensified use of browse species (Gautier *et al.*, 2005). As a result, some species are overexploited and threatened (Ouédraogo *et al.*, 2006). This situation contributes to the environmental problems in this part of the tropics (Fries and Heermans, 1992; Wiegand *et al.*, 2006). Consequently, a more sustainable plan for the use of these fodder species has to be developed. However, this can not be done without sufficient knowledge about the species in question.

Most of the studies on browse species for domestic ruminants have been conducted in arid and semi-arid zones (le Houerou, 1980). Previous studies on the nutritional value of the vegetation carried out in the sub-humid zone of Burkina Faso did not take into account the main species frequently lopped (Kaboré-Zoungrana, 1995). The emphasis was mainly on the floristic composition, variability of physical factors of the vegetation (Zoungrana, 1991), development of livestock activities towards the humid zone or the seasonal mobility of the Fulani and the use of trees (Petit, 2000), and the effect of landscape changes on the pastoral practices (Botoni, 2003). The nutritive potential of some sub-humid zone browse species frequently lopped by herders for feeding domestic ruminants has attracted only marginal interest. This study was undertaken to fill this knowledge gap.

Objectives

The overall objective of the study was to determine the most utilized browse species in the sub-humid zone, and to evaluate their potential as fodder for domestic ruminants.

The specific objectives were:

- To investigate the feeding behaviour of cattle, goats and sheep on natural pastures and determine the most consumed browse species (Paper I).
- To analyse important characteristics of production and chemical composition of the most utilized browse species (Paper II).
- To evaluate the voluntary intake and digestibility of selected browse species by sheep (Paper III).
- To assess the effect of feeding foliage from the selected browse species on growth performance and carcass characteristics of sheep (Paper IV).

Background

Some general characteristics of the sub-humid zone

The sub-humid zone in West Africa covers approximately 1.2 M km^2, roughly 16% of the whole of the West African region (Otte and Chilonda, 2003). According to ILCA (1979) the importance of the zone from a national perspective varies widely from 5% of the total area of the country (Mali and Senegal) to 90% (Guinea and Guinea-Bissau). In Burkina Faso, 32% of the total land area is in the sub-humid zone (Kagoné, 2001), which corresponds to the southern soudanian sector (Guinko, 1984). The main factors commonly considered when characterizing the sub-humid zone for the development of livestock production mainly include the vegetation, which reflects the climatic factors, particularly the amount and distribution of rainfall as it affects the temperature and the length of the growing season. The soil and relief conditions are also important and should be taken into account (FAO, 2001).

The annual rainfall in the sub-humid zone was estimated to vary between 900 and 1500 mm. The main part of the soils are classified as lixisols, "Sols ferralitiques faiblement désaturés appauvris" and "Sols ferrugineux tropicaux lessivés" (France), or classified as oxic subgroups of Alfisols from the Soil Taxonomy of USA (FAO, 2001). They are characterized by subsoil clay accumulation, a low cation exchange capacity due to the predominance of kaolinitic clays. Lixisols are also soils with a deep (up to 200 cm thick) horizon of loamy sand or coarser texture overlying the argic horizon (FAO, 2001). The growing season varies from six to nine months. The natural vegetation in the zone is a tree and shrub savannah characterized by many ligneous and herbaceous species. In West Africa, the main tree species are *Isoberlinia spp.*, *Burkea africana* Hook, *Pterocarpus erinaceus* Poir. and *Afzelia* *africana* Sm. Ex Pers.. The protected species are *Parkia biglobosa* (Jacq.) R. Br. ex G. Don f., *Acacia albida* Del. and *Butyrospermum spp.*, the shea butternut, which is widely used as a source of fat and oil (Gijsbers *et al.*, 1994). The herbaceous species include *Andropogon ascinodis* C.B. Cl.*, Andropogon gayanus* Kunth, *Schizachyrium sanguineum* (Retz.) Alston*, Hyparrhenia spp., Hyperthelia dissoluta* (Nees ex Steud.) W.D. Clayton, *Diheteropogon amplectens* (Nees) W.D. Clayton, and *Pennisetum spp.*. The sub-humid zone of Burkina Faso, contains around 75% of the woody species of the country (Fontes and Guinko, 1995) e.g. *Terminalia spp*, *Lannea acida* A. Rich., *Burkea africana* Hook., *Bridelia ferruginea* Benth., *Crossopteryx febrifuga* (Afz. ex G. Don) Benth., *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Daniellia oliveri* (Rolfe) Hutch. & Dalz., *Gardenia spp*, and *Pteleopsis suberosa* Engl. & Diels. The sub-humid zone is considered to be important for livestock production, which is based on the abundant grass cover and the potential for forage and grain production, but is also noted for the yearly bush fires (Toutain, 1980; Orthmann, 2005). Most of the domestic ruminants are owned by pastoralists and smallholder farmers, who are among the poorest of the zone. The main production system is the "mixed sub-humid system" (Otte and Chilonda, 2003). It corresponds to the so-called "mixed rainfed system" as described by Steinfeld *et al.* (2006). A wide variety of food and forage crops, including maize, millet, sorghum, cassava, yams, groundnuts, cowpeas and leguminous forages are grown in the sub-humid zone.

Importance and constraints of the domestic ruminant production in sub-humid West Africa

Cattle, goats and sheep are numerically and economically the most important species of domestic animals (FAO, 2007), and according to Otte and Chilonda (2003), they will continue to be the predominant livestock species in the region. The rearing of cattle, goats and sheep has for centuries been crucial in supporting the livelihoods of the rural population. Cattle are the dominant species and the species to which the livestock farmers pay most attention, while sheep and goats are generally kept as a source of meat and a ready source of cash. The animals constitute an integral part of the smallholder farms in the rural area and make a considerable contribution to the household food security and income generation, and have also traditionally been used as gifts, for dowry, and for cultural or religious events.

Livestock production contributes about 20-25% to the agricultural GDP in sub-Saharan Africa (Agyemang, 2005). Most dietary protein in this region comes from animal sources, and a significant proportion of this is from domestic ruminants. Ruminants have the ability to convert plant material that is unsuitable for human consumption into high quality food products. In Burkina Faso, despite the low production of milk (0.5 to 2 L/cow/day) as reported by Sidibé *et al.* (2004), it plays an important role in the diet of Fulani pastoralists all the year around and of settled farmers during the rainy season in rural areas. For livestock farmers in the sub-humid region of west Africa, cattle keeping is the central livelihood strategy, milk is a major dietary component and the sale of domestic ruminants is the principal source of income. For many smallholder farmers, domestic ruminants are the only ready and significant source of cash to buy items they cannot produce on their own or access free of charge (CGIAR, 1997). The domestic ruminants not only produce food and cash directly, but they also provide key inputs to crop agriculture and vegetation.

One important input is manure, which returns nutrients to the soil in the form that plants can readily use. Hence, the manure and urine of domestic ruminants contribute to soil fertility and the development of sustainable crop and animal production systems. Animal manure is found to increase soil porosity, aggregate stability, water holding capacity, pH, cation exchange capacity, soil infiltrability and nutrient availability (Powell *et al.*, 1999; Savadogo *et al.*, 2007). Schlecht *et al.* (2006) reported that manure and urine from domestic ruminants are important sources of soil organic matter and nutrients for crop production throughout the Soudano-Sahelian West Africa. According to Okike *et al.* (2005) the intensification of agriculture in this part of Africa is occurring mostly through higher livestock stocking rates and application of more manure per hectare. Manlay *et al.* (2004) found that livestock accounted for nearly 80% of C, N and P returns to the soil in a village of southern Senegal. The application of ruminant manure and urine on the fields led to the dissolution of phosphorus from the aluminium-iron complexes of kaolinitic clays and elevated soil pH (Ikpe *et al.*, 1999).

Another important input is the use of draught animals as a source of power in agriculture (FAO, 2007). Draught cattle are used for ploughing, weeding, harvesting and transportation. With draught cattle, smallholder farmers can double or triple the cultivated area, thereby increasing crop output at low cost. For example in Burkina Faso, the cotton revolution, which largely began in the 1970s, was accompanied by the adoption of animal traction, which resulted into the opening of large areas of land.

Crop residues that might otherwise be burnt, leading to carbon dioxide emissions (de Haan *et al.*, 1997), can be used by ruminants. Sawadogo *et al.* (2005) found that domestic ruminants reduce herbaceous biomass in state forests by grazing and thereby reduce the severity of fire. Hence, the presence of domestic ruminants in state forests could represent a valuable option for sustainable management. Domestic ruminants also play a role in the dispersal and germination of fodder tree species by ingesting pods and rejecting them in the manure after acid treatment of the hard seed coat in the abomasum (Acharya and Singh, 1992). Other authors have found that even in urban or peri-urban areas, there are small to medium scale production farms, which help lower-income urban families to meet their basic needs, by providing an additional source of income and savings for emergency or crisis (Waters-Bayer, 1996). This urban and peri-urban agriculture is playing an increasingly vital role in meeting the rising demand for food, and domestic ruminants are playing a considerable role in the sustainability of this production (Okike, 2002). Domestic ruminant production, however, faces many constraints.

The main constraints of domestic ruminant production in the sub-humid zone are feed inaccessibility and shortage, and to a lesser extent diseases, especially trypanosomiasis. In spite of the long term control of the latter through integrated approaches (Hendrickx *et al.*, 2004), livestock farmers still spend significant sums on trypanosomiasis management.

Feed inaccessibility during the rainy season and feed shortage during the dry period remain the crucial constraints. Currently, the sub-humid zone is experiencing socioeconomic, demographic and climatic changes, which have resulted in the reduction of pasture land, productivity and accessibility (Botoni, 2003). In this agro-ecological zone, land use change has accelerated during the last 30 years due to an improvement in the infrastructure and an increase in the population. The favourable characteristics of the sub-humid zone has made it more attractive to people and thus their animals, who moved in from the arid and semi-arid areas of the North after the severe droughts of the 1970s and 1980s. There is an increasing demand for food and income, and thus for space.

According to Winrock (1992), demographic factors are exerting significant pressure on the cultivable land, resulting in increased forest clearing, encroachment on traditionally used pastureland and shortened fallow periods. This situation leads to a continuous cultivation that was found to decrease the soil organic carbon and thus the pastureland productivity (Bationo *et al.*, 2007). The supply of livestock feed is decreasing due to the reduced rangeland areas, and the decline of crop yields, while there is an increase in field weeds, crop residues and even range forages for sale in the markets (in the urban areas). During the rainy season, which is the main cropping season, the local movement of livestock is limited due to the cultivation of the crops. This makes the forage in certain areas inaccessible to animals (Hellemans and Compere, 1990). Another constraint for domestic ruminant production is the accumulation of animals mainly for traditional, customary purposes and as a display. This can lead to overstocking, which has been reported to decrease the infiltrability of the soil (Savadogo, 2007) and contributes to the low productivity of pastures. The ability of livestock farmers to cope with these changes or transformations is limited. Agriculture has expanded into more marginal areas and formerly open communal grazing lands have been transformed into high-density rural settlements of small-scale farmers engaged in cultivation and livestock grazing (Reid *et al.*, 2000). Pastoralists, whose range has become too restricted for traditional livestock grazing practices have increasingly turned to agriculture (Thompson *et al.*, 2002) or have considerably changed their way of using natural resources (Gautier et al., 2005).

Herders are facing new challenges to secure their livelihoods, and, in this context, fodder trees and shrubs are emerging as key resources, allowing herds to subsist up to the end of the dry season (Gautier et al, 2005; Ouédraogo-Koné *et al.*, 2006). The growing importance of browse species, such as *A. africana*, *K. senegalensis* and *P. erinaceus*, in supporting livestock production systems in the sub-humid zone emphasizes the need for their proper utilization to avoid disappearance of species.

Description of the browse plants used in the study

Afzelia africana Sm. ex Pers.

Afzelia africana Sm. ex Pers. is also called *Intsia africana* (Smith ex Pers.) Kuntze and is widely distributed in Africa, from Senegal in West Africa to Sudan, Uganda and Tanzania in the East. The species is also present in India (South Asia) and is occasionally grown in other tropical countries. The tree grows at altitudes between 1100 and 1400 m a.s.l., in moist areas with over 700 mm of annual rainfall. The habitat is various sub-humid savannahs, fringing forests, Guinean forests and woody grasslands on deep sandy and alluvial soils. The seedlings are sensitive to fire, browsing and drought (Bationo *et al.*, 2001; Sacandé, 2007). The species population is reported to be declining in many countries of the sub-humid zone (Bationo *et al.*, 2000, IMPETUS, 2003; BIOTA, 2005).

The mature tree has a spreading and open crown with large branches. In West Burkina Faso, the mean average height reported by Petit (2004) was 10 m for a tree with a 36 cm diameter. The bark is scaly, dark-grey or grey-brown, with pink to brown slash. The leaves comprise of 3-8 pairs of glabrous leaflets widely spaced on the rachis, and are alternate, paripinnate and up to 30 cm long. Leaflets are roughly elliptic, 5-15 cm in length and 3 to 9 cm wide with an acuminate or obtuse tip. The flowers are composed of three elliptic upper petals, 1.0 to1.2 cm long and one lower petal with two divergent round lobes. The fruits or pods are flattened, woody, 10 to18 cm long, 5 to 8 cm wide, 2 to 5 cm thick, and contain 7 to 10 black broadly shiny seeds, which are poisonous, with a sweet edible orange axil at the base (Petit, 2004; Sacandé, 2007).

Khaya senegalensis (Desv.) A. Juss.

The synonym of *Khaya senegalensis* (Desv.) A. Juss. is *Swietenia senegalensis* Desr.. The tree is native to tropical Africa and Madagascar and is exotic to Australia, Cuba, India, Indonesia, Puerto Rico, Singapore, South Africa, Sri Lanka and Vietnam. The species can grow at an altitude between 0 and 1800 m a.s.l., in areas with an annual rainfall ranging from 700 to 1750 mm, temperatures from 24 to 32°C, and a dry season of 4 to 7 months and is drought tolerant and very resistant to flooding. The natural habitat of *K. senegalensis* is riverine forests. The species is scattered within the higher rainfall savannah woodlands, but is mostly found in riparian habitats (Natta, 2003; Jøker and Gaméné, 2003; ICRAF, 2008). It is tolerant to a wide range of soil conditions (from neutral to acidic and from well-drained, coarse sandy loam to poorly drained clay) but grows well on neutral, deep, and sandy loam soils that are well drained. Saplings are very sensitive to fire, while adult trees are relatively resistant.

The tree has a wide dense crown, large branches and thick stems. The bark is dark grey, with small and thin dark pink slash exuding red latex. The leaves are compound and comprise of 3 to 7 pairs of leaflets, each 4 to 12 cm long and 2 to 5 cm wide. The leaf together with the petiole and the rachis can reach 33 cm length (ICRAF, 2008). The flowers are tretramerous and unisexual, about 5 mm long, with pale green calyx and white petals. The fruit is an almost spherical, woody capsule, 4 to 6 cm in diameter, and opens in maturity by four valves from the apex. Each fruit contains more than six brown seeds, transversely ellipsoid to flat of about 2 x 2.5 cm, with narrow winged margins (Jøker and Gaméné, 2003).

Pterocarpus erinaceus Poir.

Pterocarpus erinaceus Poir has been referred to as *Pterocarpus angolensis* DC and *Pterocarpus echinatus* DC. Other synonyms are *Lingoum erinaceum* Kuntze, *Pterocarpus adansonii* DC. and *Pterocarpus africanus* Hook. The tree is widespread in West and Central Africa, from Senegal to the Central African Republic, Southern Africa, Angola and Tanzania. It has been introduced as an exotic species in many tropical countries. *P. erinaceus* grows at altitudes ranging from 0 to 600 m a.s.l. in savannah and dry forests of semi-arid and sub-humid lands where the annual rainfall ranges from 600 to 1200 mm, and the temperature from 15 to 40°C, with a dry season that can last up to 9 month (Bonkoungou, 1999; Petit, 2004). The species is found in well-drained soils, and lateritic as well as poor soils and frequently in acid rather than neutral soils. It is a drought tolerant species and can thrive even on shallow soil.

The tree has an open spreading crown that is less wide and dense compared to *A. africana* and *K. senegalensis*. The branches are light grey and smooth and the boles are straight with grayish-brown to dark grey and rough bark, with some scales that curl up at the end. The leaves are compound, imparipinnate, about 30 cm long composed of 10 to 15 alternate or sub-opposite leaflets (of 6 to 11 cm length and 3 to 6 cm width). *P. erinaceus* has nice golden yellow flowers that completely cover the canopy. The fruit is orbicular, broadly winged with an undulate wing bearing the style basally and also with a mass of long rigid plumose bristles. The young fruits are light green and turn light brown when dry. The seeds are kidney-shaped to oblong (Bonkoungou, 1999).

Contribution of browse plants to domestic ruminant production in the sub-humid zone of West Africa

Availability of browse foliage

Many browse species remain in full leaf and are green even during the driest period of the year. They are in general deep-rooted, resistant to drought, have a long life, act as windbreaks, have low demands on maintenance and can conserve soil moisture (Humphreys, 1994; Hiernaux *et al.*, 1994). Other properties include high foliage productivity and tolerance to pruning. The mean browse foliage production in the sub-humid zone of West Africa was found to vary between 700 and 1000 kg DM/mm/ha/year (le Houerou, 1980). The foliages are particularly valuable as high quality and cheap protein feed for domestic ruminants, all the year around. Browse plants also provide medicine for humans and animals and fences for animals.

The flora of tropical Africa contains about 30,000 species as reported by Brenan (1978). More than 7,000 of theses species are trees or shrubs and at least 75% are browsed to a greater or less extent (Wicken, 1980). A considerable part of the browsed plants is found in the sub-humid zone of West Africa where they constitute a basic component of the woody savannah. In areas with low frequencies of fire and high grazing pressure, the density of plants usually increases and the cover can be very important (Toutain, 1980). The number of plant species browsed by domestic ruminants is high and varies depending on the country. In Burkina Faso, many species have been reported to be less to highly browsed by domestic ruminants (Zoungrana, 1991; Sawadogo, 1996). Ouédraogo-Koné *et al.* (2006) reported 17 to 24 species. In Nigeria, Okoli (2003) found 163 species which were utilized for domestic ruminant feeding. In the same country, other authors listed 27 to 35 species (Wahua and Oji, 1987; Okafor and Fernandez, 1987). This species diversity has been found to play an important role in the diet selection of grazing animals. Rogosic *et al.* (2007) found that sheep consumed more foliage when offered a mixed diet composed of species rich in different types of secondary compounds (as in tannins and saponins).

The savannah of the sub-humid zone of West Africa offers complementary browse plant resources beneficial to domestic ruminant production. The browse plants of the region are phenologically diversified, some being deciduous others being persistent or semi-persistent. The foliage of the deciduous plants appears at the end of the dry season or at the beginning of the rains, when there is a feed shortage. For plants with persistent foliage, the young leaves usually emerge during the cold dry season, just before the period of feed scarcity. The flowering and fruiting periods vary greatly from one species to another (Toutain, 1980; de Bie *et al.*, 1998; Devineau, 1999). At any time of the year, the browse plants can therefore provide some edible forage for domestic ruminants in this region. In addition, the decrease in CP concentration of the foliage with maturity is not abrupt and rapid as in grass, but spreads out in time throughout the year (Kaboré-Zoungrana, 1995; Salem, 2005). Although there are some difficulties in the accessibility and the availability of the foliage, the sub-humid region remains one of the main nitrogen reserves for domestic ruminants, including those coming from the arid and semi-arid zones (Petit, 2000, Orthmann, 2005).

Browse foliage as nitrogen supplement or basal diet

Among the multiple uses of browse foliage in the farming systems of the sub-humid zone of West Africa (Eyog-Matig *et al.*, 2002; Arbonnier, 2004), their utilization as nitrogen supplements to low quality feeds for ruminants remains the most important (Aschfalk *et al.*, 2002). The mean CP content of

125 g/kg DM for all the browse species of West Africa is above the minimum level of 60 g to 80 g/kg DM required in the diet for efficient rumen fermentation (le Houerou, 1980; Van Soest, 1994). Animals receiving foliage as a supplement can also benefit from the positive effect of the secondary compounds in the foliage. The negative effects of these compounds generally depend on the amount, but the nature and activity are also of great importance. Many studies have shown that the secondary compounds can be bound to dietary proteins during mastication or to foliage protein, protecting the protein from microbial attack in the rumen. Then the complex rich in protein will be digested and utilized in the lower gut, thus acting as a by-pass protein source for animals (Terrill *et al.*, 1992; Leng, 1997; Min *et al.*, 2003).

The use of browse foliage to improve diets based on low quality grasses and straws is common among the agro-pastoralists, especially the Fulani (Sinsin *et al.*, 1989; Sinsin, 1993; Onana, 1998; Petit, 2003). Tree foliage is also collected in a cut-and-carry system to feed animals in small to medium scale urban and peri-urban farms. A survey done in Bamako (Mali) showed that home-reared sheep were fed an average daily tree fodder ration of 1.8 kg of *P. erinaceus* and *K. senegalensis* leaves (Anderson *et al.*, 1994). Boukoungou (1999) reported that the amount of fresh leaves of *P. erinaceus* sold in Bamako (capital of Mali) from 1989-1990 was over 1,400 tonnes. The supplementation with tree leaves to grass led to a significant increase of the total feed intake and growth rate of West African dwarf sheep and small East African goats (Kouonmenioc, 1990; Aschfalk *et al.*, 2000, 2002; Rubanza *et al.*, 2007). A twofold increase in the rates of degradation and passage was recorded when low nitrogen feeds were supplemented with foliages (Bonsi *et al.*, 1994). The leaf meal of *Leucaena leucocephala* (Lam.) De Wit. as a supplement has been reported to increase the milk production in grazing dairy cattle in Tanzania (Kakengi, 2001).

The use of tree leaves in complete feeds for bucks resulted in higher voluntary DM intake and digestibility of nutrients (Bakshi and Wadhwa, 2007). Many studies have shown the positive effect of using browse leaves on the productivity and the stocking rate of domestic ruminants in the tropics (Leng, 1997; Van, 2006; Sánchez, 2006). In the sub-humid zone of Africa, resource-poor farmers rely on organic inputs to sustain soil fertility and the browse plants are also used as nitrogen supplements to improve nutrient release in the manure of animals (Batiano and Mokwunye, 1991; Palm, 1995). The use of leaves as protein supplements to goats in Zambia, resulted in higher phosphorus content and rates of phosphorus mineralization in the manure (Mafongoya *et al.*, 2000).

The foliage of trees has been found to contribute to the control of gastrointestinal parasite infestation of domestic ruminants due to the content of secondary compounds (Mui *et al.*, 2005; Mueller-Harvey, 2006). Thus, the use of tree fodder during the dry season, as supplementation or as a sole feed, can improve the productivity and the ability of animals to resist the harmful effects of parasites (Waller, 1999; Hoste *et al.*, 2006).

Constraints in the use of browse foliage for domestic ruminants

The constraint in the utilization of browse foliage, which has been mostly reported, is of nutritional order (Reed, 1995; Min *et al.*, 2003; Aganga and Tshwenyane, 2003). The foliage of a large proportion of tropical browse plants has been found to contain some secondary compounds, usually called anti-nutritional factors, that limit their nutritional potential (Fall-Touré and Michalet-Doreau, 1995; Makkar and Becker, 1998; Shayo and Udén, 1999; Aganga and Tshwenyane, 2003). These anti-nutritional factors include, primarily the polyphenolic compounds (particularly tannins), glycosides (cyanogens and saponins) and the non-protein amino acids (mimosine and indospicine). In addition, other components with strong odours in the leaves of trees and shrubs have been mentioned (Leng, 1997). They often appear in the plants as a defence against herbivores and other predators.

The well known and most widely studied compounds are the tannins, which comprise the hydrolysable tannins (derivatives of gallic acid) and the condensed tannins (polymeric flavanoids), the so-called proanthocyanidin (Hagerman, 2002). According to Silanikove *et al.* (2001), tannins are found in roughly 80% of all the woody plants. The negative effects of tannins (low feed intake, low digestibility, toxicity) have been reported to occur when ruminants consume forage with a high level of condensed tannins, greater than 50-55 g/kg DM (Min *et al.*, 2003), although positive results were obtained with some tannin rich browse species such as Jackfruit (*Artocarpus heterophyllus* Lam.) and *Flemingia macrophylla* (Willd.) Merr. (Mui *et al.*, 2002; Van *et al.*, 2005). Makkar and Becker (1998), in a comparative study, found that foliages from the African region have higher levels of total phenols (15.7 ± 4.27%) and protein precipitation capacity (327.2 ± 113.6 mg bovine serum albumin precipitated/g) than the Himalayan region. In the sub-humid zone of West Africa almost every year livestock farmers lose some animals due to feed adversities that can be attributed to a higher intake of secondary compounds in foliage (personal observation). Many studies have reported the negative effects of anti-nutritional factors on the digestive utilization of nitrogen compounds (Fall-Touré and Michalet-Doreau, 1995; Rittner and Reed, 1992; Makkar and Becker, 1998; Shayo and Udén, 1999; Aganga and

Tshwenyane, 2003). Muetzel *et al.* (2003) attributed the negative effect on the growth of anaerobic rumen fungi (the main cell wall degrading organisms) to saponins when higher levels of *Sesbania pachycarpa* DC. leaf were offered as a supplement. Furthermore, many genera containing some exotic well researched species such as Calliandra, Leucaena, and Flemingia have high levels of tannins (>10%), as reported by Shelton (2001). Although the main constraint of the use of browse foliage is of nutritional order, there are some non-nutritional factors which deserve to be highlighted.

In the sub-humid zone of West Africa many browse plants with a confirmed nutritive value for domestic ruminants are high trees and not accessible directly by animals when grazing (Toutain, 1980; Lawton, 1980). There is a permanent risk for herders and farmers to fall when collecting the leaves by pruning (Petit, 2000), especially since branches of the existing trees are generally weak (too old or too young after a recent pruning). In many of the countries in West Africa there are some governmental laws prohibiting the pruning or the lopping of browse plants. Recently, settled farmers are increasingly protecting the few browse plants inside their fields and fallows in order to be able to sell the foliages during the dry season in the nearest city or to the herders. Despite these constraints, the use of browse plants seems to be vital for livestock farmers, especially during the hardest period of the year (Petit, 2000; Petit and Diallo, 2001; Ouédraogo-Koné *et al.*, 2006). Solutions have to be found to improve forage availability all the year around for the poor agropastoralists, while ensuring environmental sustainability.

Summary of materials and methods

Study sites

The study was carried out in the sub-humid zone of Burkina Faso (Fig. 1). The experiments of Paper I and II were undertaken on natural pasture about 75 km from Bobo-Dioulasso and located between three villages (Guéna, Banfloulaguè, and Sidi) of Orodara, (province of Kénédougou) at about 11°05´N and 4°45′W and 300 m a.s.l.. The experiments of Paper III and IV were conducted at the research station of the Centre International de Recherche-Développement sur l'Elevage en zone Subhumide (CIRDES), about 15 km from Bobo-Dioulasso. The Koppen climate classification is aw, wet/dry, tropical with two distinct seasons; a dry (November to April) and a rainy (May to October). The average annual rainfall and standard deviation (SD), from 1993 to 2003 was 1013 (152) mm and those obtained during the study periods were 1156, 828 and 819 mm in 2003, 2004 and 2005, respectively. The mean monthly temperatures varied between 25 and 33°C. The main activities of the population are agriculture (cotton and sorghum) followed by livestock production. Some important characteristics of the main soil type of the study site are, according to BUNASOL (2002): clay (16±9.7%), total sand (54±16.1%), total organic matter (0.8±0.2), total N (0.04±0.01%), C/N (11.9±1.3%), available P (1.6±1.2 ppm) and pH H_2O (5.7±0.8).

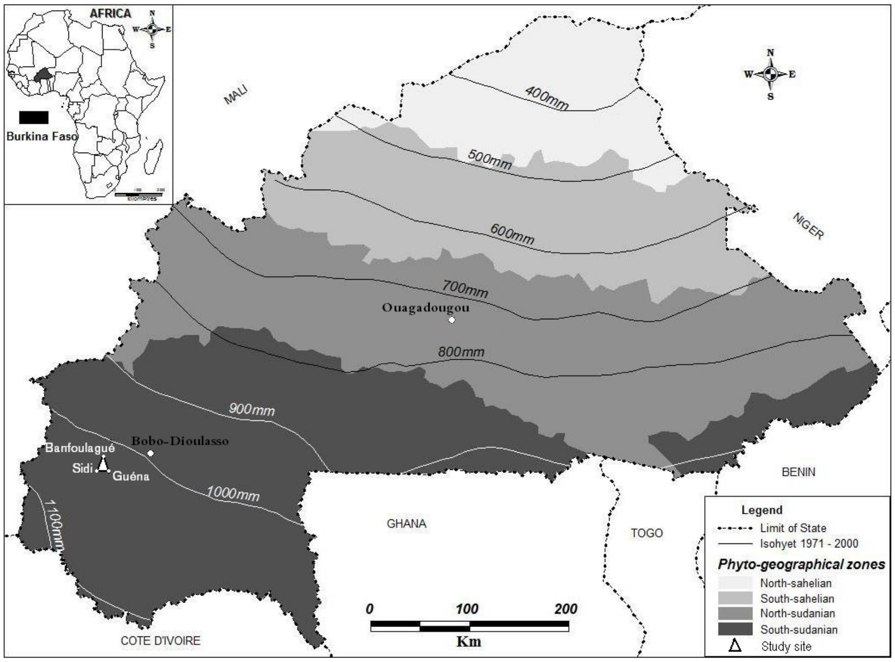

Figure 1. Vegetation map of Burkina Faso with isohyets and location of the study site (Readapted April 2007 by CTIG/INERA/Burkina Faso after Fontes and Guinko (1995) and Direction of the National Meteorology).

Animal behaviour and survey of livestock farmers and pasture

The designs used in this study (Paper I) were a completely randomized design (for the browsing height, frequency of consumption of browse species and density of browse plants in the pasture) and a two factorial design for behavioural activities (animal species, season) and the survey of farmers (sex and main activity).

The direct observation method was used to assess the behaviour of cattle, sheep and goats on natural pasture. The method consisted of observing one randomly selected mature lactating female in the flock during 9 to 10 hours in the daytime and recording the behavioural activities every 15 mn. The activities comprised grazing, browsing (directly of the tree or gleaning), walking without feeding, ruminating, drinking, resting and other activities. For each animal species, observations were made on two individuals during three consecutive days per month. The experiment lasted the whole year, including the dry season (February-May), cool season (October-January) and rainy season (June to September). When browsing, the species consumed were recorded and the height reached by the animal was identified and measured using a tape meter.

One hundred farmers were interviewed using a semi-structured questionnaire. The focus was the number of plant species available in the study area and used as feeds for cattle, sheep and goats. Twenty herders were also asked to rank the three browse species most frequently cited by farmers in terms of importance for livestock production.

The survey of the pasture consisted of the determination of the ligneous species present in the study site and their numerical importance (density and relative frequency) as well as their pruning proportion. For the assessment, three plots of 0.25 ha (50 by 50 m) were set up in each vegetation unit (tree savannah, shrub savannah, riparian vegetation, grass savannah and fallow), identified using aerial photos from 1999 from the Geographic Institute of Burkina Faso. The method of identification and direct counting of trees and shrubs was used in each plot. The height and diameter of the trunk at breast height were measured and the number of trees pruned recorded in the first three vegetation units where the selected browse species were mainly found.

Biomass and phenology of selected browse plants

The method of complete pruning was used to assess the foliage (leaf plus petiole) biomass of *A. africana*, *K. senegalensis* and *P. erinaceus*, as described in Paper II. The method consisted of pruning the trees, then removing the foliage completely from the branches. The total weight of the fresh foliage was recorded and two samples were taken for DM determination and further chemical analysis. Adult trees were used to allow them to grow again after pruning. The biomass was assessed in two consecutive years with 15 trees per browse species in 2004 and 10 per browse species in 2005. The period of the measurement was determined according to the phenology of the browse plants at maximum foliation to ensure that the total production was estimated. Before the pruning, the dendrometric parameters, e.g. the girth of the trunk, diameter of the crown (from which the circumference of the crown was calculated) and total height of each individual, were measured to determine the correlations with the browse production. The potential browse production in the pastures, with regard to the species studied, was estimated by multiplying the edible biomass production per species by their relative proportion (number of plants/ha) in the pasture.

To assess the phenology, ten trees per browse species were selected and marked following two transects (North-South) in the site. The development of the foliation, flowering and fruiting was recorded for each tagged tree every 15 days. The phases were monitored at different stages for each individual tree according to Grouzis and Sicot (1980) and Kaboré-Zoungrana (1995). Stage 1 corresponded to the beginning of the phase, stage 2 to the optimum (the peak) and stage 3 to its declining. The stage of the maximum of individual trees in the group expressed that of the species. The individual phenological behaviour isolated from the group was also noted. The assessment lasted from October 2003 to September 2005. During each observation period, samples were taken from the 10 trees of each species and pooled. Then two samples of 1 kg were taken for the determination of DM and further chemical analysis to assess the variation through the different seasons of the year.

Nutritive value of browse foliage

Experimental designs

The nutritive value of the foliage of the selected browse plants was assessed in Papers III and IV. A completely randomised design was used for voluntary feed intake and the digestibility of nutrients in Paper III, and for feed intake, weight gain, carcass characteristics and parasite egg counts in Paper IV.

In Paper III, the design was a completely randomized changeover with five treatments (diets) allocated to 15 animals in two periods. The diets were hay of *A. gayanus*, foliage of *A. africana* (offered as a sole feed) and foliage of *A. africana, P. erinaceus* or *K. senegalensis* (fed with hay of *A. gayanus* at a level not exceeding 30% of DM in the digestibility experiment). In the voluntary intake trial, the foliages were offered at a level of 15% of refusals based on the intake of the previous day, while in the digestibility trial, the animals were fed according to their individual daily intake based on the results from the intake experiment. Each period lasted 21 days, with 14 days of adaptation and seven days of data collection.

In Paper IV, the design was completely randomised with four treatments (diets) allocated to 32 animals. The treatments were four different sources of protein: cottonseed cake (control), foliage of *A. africana*, *P. erinaceus* or *K. senegalensis*. All animals were fed the same amount of maize bran (200 g DM/d) and hay from *A. gayanus* (200 g DM/d) to ensure adequate nutrient intake. The foliages were offered *ad libitum,* equal to 130% of the individual average DMI of the previous week. The cottonseed cake was distributed at an amount of 200 to 260 g DM from the beginning to the end of the experiment. The trial lasted 91 days.

Experimental animals and management

The animals used in Paper III were adult rams of the West African Djallonké breed, at about 12 months of age, with a mean pre-experimental body weight (BW) and SD of 20.0 (1.6) kg, while in Paper IV they were growing rams of the same breed, about 8 months of age and a mean initial BW of 16.1 (0.7) kg. The experimental animals were vaccinated against pasteurellosis and trypanosomosis and were treated against internal and external parasites, as described in Paper IV.

During the experimental period, the animals were kept in individual cages (Paper III) or pens (Paper IV) and fed twice a day. They had free access to clean water and a commercial mineral lick block. The animals were weighed at the beginning and the end of each experiment (Paper III and IV) and at seven-day intervals, always in the morning (06:00 h) before offering the feed (Paper IV). After the voluntary intake trial in Paper III, the animals were allowed to exercise and graze during two weeks on pasture before being replaced in the cages for the digestibility trial. In Paper IV, the animals could walk and exercise in their individual pen. The feeds (foliages, grass and maize bran) were pre-dried in the sun and thereafter air dried in the shade, and stored in a house.

Measurements and chemical analysis

The foliage and hay offered and refused, in the voluntary intake as well as in the digestibility experiments (Paper III), were recorded and individual samples were taken for chemical analysis. For the digestibility trial only (Paper III), 10% of the daily faecal output was individually sampled for DM determination and a sub sample taken from the rest, pooled and stored in a freezer at -20°C to stop the fermentation, for further chemical analysis. The digestibility of the foliages in the mixed diets was estimated from intakes and digestibilities of the hay and the total diets, assuming that there were no interactions between the hay and the foliages.

In Paper IV, the feeds offered and refused were measured daily and individual monthly sub samples (feed offered) and group monthly sub samples (refused), were taken for chemical analysis. To assess the parasite status of the rams during this study (Paper IV), faecal samples were collected every month and the parasite EPG (eggs per g faeces) were determined using the modified technique of McMaster (MAFF, 1986). Eggs of nematodes, cestodes and oocystes of coccidia were identified and counted according to Hansen and Perry (1994). At the end of the trial, 3 randomly selected animals per treatment group were slaughtered and carcass characteristics were determined as described in Paper IV.

The samples of the studies (Paper II, III and IV) were analysed for DM, CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and ash. The DM (967.03), CP (988.05), ADF and ADL (973.18) and ash (942.05) were analysed according to the standard methods of AOAC (1990) and NDF was determined by the method of Van Soest *et al.* (1991) using sodium sulfite, and was expressed without residual ash.

Statistical analysis

The data were analyzed using the General Linear Model (GLM) procedures of Minitab software Version 13.31 (Minitab, 2002) in Paper I and Version 14.1 (Minitab, 2003) in Paper II, III and IV. Means, of normally distributed data, which showed significant differences at the probability level of $P<0.05$ were compared using Tukey's pairwise comparison procedures.

A regression analysis was performed to test the relationship between the dendrometric parameters of trees and the biomass production (Paper II). Linear regression, polynomial regressions and log10 transformation were tested and the significant regressions showing the highest regression coefficients were retained. Regressions were also used to test the significance of the variation of chemical composition in Paper III.

The non parametric test of Kruskal–Wallis was used to analyze the pruning rate of the selected browse plants (Paper II). In addition, descriptive statistic was used to calculate the frequency of citation of browse species by farmers, the frequency of consumption of browse by animal and the score of each species obtained from herder classification.

Summary of results

Behavioural activities of cattle, goats and sheep, and the survey of livestock farmers and pasture (Paper I)

During the cool season, the behavioural activities of cattle did not differ significantly from those of sheep. For the same period, the browsing (25%), resting (27%) and ruminating (16%) activities of goats did not differ significantly from those of cattle and sheep whose proportions of grazing (67 and 55%, respectively) and walking (21%) were higher ($p<0.05$). During the dry season, the differences between the behavioural activities of goats and sheep were not significantly different. Cattle grazed (31%) and walked (20%) in higher proportion of the time than goats, but had lower resting (12%) activity compared to that of goats and sheep ($P<0.05$). During both cool and dry season, cattle walked longer distance than goats and sheep. During the rainy season, the behavioural activities were recorded only with cattle and sheep. Sheep browsed (20%) and walked (10%) in significantly higher proportions of the time than cattle, whose grazing (66%) activity was higher.

The general behavioural activity was divided into gleaning (collecting from the ground the fallen edible parts of the tree) and browsing (eating directly from the tree) leaves or fruits. The proportion of the gleaning of leaves (7%) and of fruits (33%) during the dry season was higher compared to the cool season, during which the direct browsing of leaves (64%) and fruits (18%) were higher ($P<0.05$). The highest gleaning proportions were recorded with goats and that of direct browsing with cattle. For sheep and goats, in addition to the direct browsing, the gleaning of fruits was important.

The most frequently quoted browse species by livestock farmers coincided with the most frequently consumed by cattle, and were *A.*

africana, *K. senegalensis*, *P. erinaceus*, *Faidherbia albida* A. Chevalier, *Acacia dudgeoni* Craib. Ex holl., *Ficus gnaphalocarpa* (Miq.) A. Rich., *Dichrostachys cinerea* (L.) Wight and Arn. The frequently consumed species by sheep were *A. dudgeoni* (23%), *Acacia hokii* De Willd (7%), *Dioscorea togoensis* Knuth (9%) and *F. gnaphalocarpa* (Miq.) A. Rich. (23%). Goats preferred *A. dudgeoni* (21%), *Cordia myxa* L. (26%), *Manguifera indica* L. (18%) and *F. gnaphalocarpa* (12%). The number of browse plants cited by women did not differ from that of men. The classification of the frequently cited browse plants, according to their importance for domestic ruminant production by herders, gave *A. africana* as the first preferred species followed by *K. senegalensis* and then *P. erinaceus*.

The survey of the pasture showed 90 tree species belonging to 30 families. The most dominant species were *Dichrostachys cinerea* (L.) Wight & Arn., *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Piliostigma thonningii* (Schum.) Milne-Redhead, *Pterocarpus erinaceus* Poir., *Combretum sp., Daniellia oliveri* (Rolfe) Hutch. & Dalz., *Terminalia laxiflora* Engl. & Diles and *Guiera senegalensis* J.F. Gmel.. Except in the grass savannah, the relative frequencies varied from 5 to 20% according to the vegetation unit. The main inventoried families were Mimosaceae, Rubiaceae, Caesalpiniaceae, Combretaceae and Fabaceae. For the selected browse plants, *P. erinaceus* was found in all vegetation units, while *A. africana* was common in tree savannah, shrub savannah and riparian vegetation. *K. senegalensis* was mainly found in tree savannah and riparian vegetation. Among all the categories of trees concerned (seedling, sapling and adults), the mean density of *P. erinaceus* (473±344) was the highest followed by *K. senegalensis* (46±20) and *A. africana* (13±6).

Biomass, phenology and variation in chemical composition of the selected browse plants (Paper II and III)

The foliage production of *K. senegalensis* (41 kg DM tree^{-1}), *P. erinaceus* (30 kg DM tree^{-1}) and *A. africana* (21 kg DM tree^{-1}) differed significantly. When expressed as available foliage biomass on the pasture, the foliage biomass differed in the order *P. erinaceus* > *K. senegalensis* > *A. africana* (1.273, 571 and 276 kg DM /ha, respectively). The available CP yields per ha of the species differed to the same order (133.6, 52.5 and 33.6 kg/ha, respectively).

Significant correlations were found between the total foliage biomass of the trees and their physical parameters (height, circumference of the trunk and circumference of the crown). The best coefficients of correlation (r^2) were recorded with the circumference of the crown for *A. africana and P.*

erinaceus (r^2 = 0.82 and 0.81, respectively). There was also significant relationships between the foliage biomass of the branches and their circumference for all the tree species (0.75, 0.73 and 0.69, respectively).

The phenological phases of the browse plants (foliation, flowering and fruiting) showed similar patterns between the two years (2004 and 2005), and the phases started during the dry season (January to April). The foliation lasted 10–12 months, with an optimum in 7–10 months. The flowering lasted in general 1–2 months. The fruiting lasted 8–10 months for *A. africana* and *K. senegalensis* and 6–8 months for *P. erinaceus*. Trees of *A. africana* and *P. erinaceus* were bare for 2–6 weeks, while *K. senegalensis* trees replaced their leaves progressively and earlier in the cool season. The dissemination of the fruits of *A. africana* and *K. senegalensis* started at the end of the rainy season and was completed during the dry season (January to March). The fruit dispersal of *P. erinaceus* trees took place earlier in the rainy season.

The variation in chemical composition according to season was in general significant. The CP content of *A. africana*, *P. erinaceus* and *K. senegalensis* decreased significantly from the late dry season (220, 218 and 138 g/kg DM) to the cool season (98, 95 and 88 g/kg DM), with a slight tendency of increasing towards the end of the cool season for *K. senegalensis* (130 g/kg DM). In contrast, DM, NDF and ADL contents increased from the late dry season to the cool season. For *A. africana* the variation was significant for all the chemical components, while that of ADF was not significant for *P. erinaceus* and *K. senegalensis*.

Chemical composition, voluntary intake and digestibility of the selected browse foliages (Paper II, III and IV)

The nutrient contents of the foliages studied in Paper II, III and IV were different. The CP contents ranged from 123 to 226 g/kg DM for *A. africana*, 102 to 197 g/kg DM for *P. erinaceus* and 92 to 130 g/kg DM for *K. senegalensis*. The NDF contents ranged between 552 and 593 g/kg DM, 502 to 540 g/kg DM and 508 and 527 g/kg DM, respectively, for *A. africana*, *P. erinaceus* and *K. senegalensis*. The ADL contents were from 162 to 174 g/kg DM, 150 to 156 g/kg DM and 146 to 165 g/kg DM, respectively for the three browse plants. The overall means of the DM, CP, NDF and ADL contents recorded year around (Paper II) were 450 g/kg, 173, 577 and 163 g/kg DM, respectively, for *A. africana*; 447 g/kg, 139, 495 and 153 g/kg DM, respectively, for *P. erinaceus* and 474 g/kg, 114, 491 and 139 g/kg DM, respectively, for *K. senegalensis*.

The DMI recorded with the foliage or the whole diet (Paper III) were significantly higher for animals fed with *A. africana* (571 and 736 g/day, respectively) compared to the animals fed with *P. erinaceus* (428 and 604 g/day, respectively), which in turn had higher DMI than the animals fed *K. senegalensis* (298 and 481 g/day, respectively). The total CPI and NDF intake differed significantly between the browse plants in the order *A. africana* (124 and 448 g/day, respectively) > *P. erinaceus* (65 and 309 g/day, respectively) > *K. senegalensis* (45 and 272 g/day, respectively). The nutrient intakes with the foliage of these browse plants, in Paper IV, differed in the same order. The animals fed with *A. africana* alone as a sole feed had higher DMI (598 g/day) and CPI (116 g/day) than animals fed a mixed diet with *K. senegalensis*.

The highest apparent digestibilities of DM, CP and NDF of the total mixed diet were in animals fed with *A. africana* (595, 772 and 608 g/kg, respectively) and the lowest were in animals fed with *K. senegalensis* (566, 710 and 499 g/kg, respectively). The DM, CP and NDF digestibilities, calculated by difference, of the foliage of *A. africana* (582, 795 and 591 g/kg, respectively) were significantly higher than of *P. erinaceus* (535, 747 and 399 g/kg, respectively) which did not differ significantly from those of *K. senegalensis* (522, 725 and 394 g/kg, respectively). There was no significant difference between the nutrient digestibility with *A. africana* as a sole feed or the mixed diet.

Effects of feeding browse foliage on growth and carcass characteristics in sheep (Paper IV)

The ADG of animals fed diets with *A. africana* and *P. erinaceus* (63 and 59 g/day, respectively) did not differ significantly, but were higher than that of the animals fed diet with *K. senegalensis* (48 g/day). The ADG recorded with the diets including foliage were lower than that of animals fed diets with concentrate. The FCR of DM and CP obtained with animals fed diets with foliage ranged from 9.8 to 11.3 and 1.4 to 1.8, respectively. The FCR of CP was higher with *A. africana*, compared to the other browse plants.

The final live weight of the animals fed diets with *A. africana* (22.3 kg) and *P. erinaceus* (22.9 kg) did not differ, but were higher than that of animals fed the diet with *K. senegalensis* (20.8 kg). Rams offered foliage of *A. africana* had heavier fasted live weight (FLW) at slaughter and consequently heavier empty body weight (EBW), warm carcass weight and dressing percentage compared to animals offered *P. erinaceus* and *K. senegalensis*. However, there was no significant difference between the proportions of commercial cuts in percentage of cold carcass weight according to the browse plants. The weight and proportion (in % of EBW) of the liver of sheep fed foliage of *A. africana* (0.4 kg and 2.2%, respectively) and *P. erinaceus* (0.4 kg and 2.1%, respectively) was significantly higher than of *K. senegalensis* (0.3 kg and 1.9%).

General discussion

Browse plants used and browsing activities in the production of cattle, goats and sheep

Browse species used in the research area

The parts of browse plants used is mainly leaves, pods, fruits or flowers. About 34% of the 90 browse plants recorded in the area was cited as being used. However, only six species (*A. africana*, *K. senegalensis*, *P. erinaceus*, *F. albida*, *F. gnaphalocarpa* and *A. dudgeoni*) were mentioned by more than 50% of the farmers (Paper I). Most of these species were also those with high frequency of consumption by cattle, stressing the importance of this animal species for farmers in the sub-humid zone of West Africa. The frequency of citation of the species did not coincide with the density or availability on the pasture. This may indicate that the six species are nutritionally the best for domestic ruminants and supports the view of many authors that most livestock farmers have a good knowledge of the fodder tree resources available in their environment (Bayer, 1990; Petit and Mallet, 2001; Komwihangilo *et al.*, 2001). These species may also be the browse plants of the sub-humid zone that are able to grow again after the pruning and to provide available fodder during feed shortage (Thapa *et al.*, 1997). The phenological pattern of some of the trees found in this study (Paper II) support this fact. Similar numbers of browse plants has been reported by Bayer (1990) to be quoted as used by herders in Nigeria. However, the number found in this study is lower than that reported by Sanon *et al.* (2007) from livestock farmers in the arid zone. This may be due to the differences between the study areas, and highlights the fact that browse plants are more used in the arid zone compared to the sub-humid zone.

There was no significant difference in the number of browse plants cited by men and women. This is due to the high degree of participation of women in ruminant production in the area. This result differs from that of other authors (Komwihangilo *et al.*, 2001; Sanon *et al.*, 2007) who investigated communities where females were not involved in grazing management. According to Tangka *et al.* (2000) gender division of labour in mixed system livestock production varies from region to region according to culture, religion and socio-economic variables. The rank attributed by herders to each of the three highly quoted browse plants (*A. africana*, *K. senegalensis*, *P. erinaceus*), may reflect the differences in nutritional potential. With regard to the results obtained in this study (Paper II, III and IV), this was true for *A. africana*.

Browsing activities

The results show that the contribution of browse plant fodder to domestic ruminant diets in the sub-humid zone of West Africa is not negligible (Paper I). However, the importance varies with season and animal species (Guerin *et al.*, 1988; Dumont, 1996).

The direct observation method, used in this study, has been one of the oldest and simplest methods utilized by many authors to investigate the feeding behaviour of animals (Arnold, 1981; Schwartz *et al.*, 1985; Guerin *et al.*, 1988; Dicko and Sikena, 1991; Ngwa *et al.*, 2000; Ickowicz et Mbaye, 2001; Sanon, 2007, etc.). However, the variations in study area (arid, semi-arid, sub-humid, humid), the environment of animals (in individual or collective pens, on natural or experimental pasture), and especially in the way the behavioural activities are quantified (in duration, frequency of occurrence, proportion, etc.), make a quantified comparison between the results difficult.

During the dry season, the similar proportion of browsing activity of the animal species may be attributed to: (i) the lack of good quality herbaceous forage such as crop residues and grasses (Gautier *et al.*, 2005; Sanon, 2007), or (ii) the management practices of the herders, who influence the feeding activities of animals by choosing the grazing itinerary and making foliage available to animals, especially cattle (Onana, 1998; Petit, 2000; Gautier et al., 2005). During the cool and rainy season, the reduction in the proportion of browsing activity was compensated by an increase in the proportion of grazing activity (paper I). This indicates the importance of the herbaceous fodder for ruminant production in this area. Unfortunately, during the driest period, this fodder fraction disappears with regular bush fires or the nutritive value decreases, resulting in a low content of CP and minerals (le Houerou, 1980; Guérin *et al.*, 1988). The woody species become in fact the main protein source for animals during the dry season.

Variation in the proportion of browsing activities between the animal species has been reported by many authors (Dumont, 1996; Van, 2006; Sanon, 2007). The results from Paper I are in line with the general agreement that goats are more browsers, sheep intermediate browsers and cattle more grazers (Rutagwenda *et al.*, 1990). The differences between the animal species have often been attributed to the differences in anatomy and physiology (Arnold, 1981; Dumont, 1996; Van, 2006). There are also the physical and biological characteristics of the vegetation, which varies with the season (Dumont, 1996; Omphile *et al.*, 2004). According to Gordon and Illius (1988), animal species with a broad and flat muzzle seem to have a weaker aptitude for selection than those having a small and lengthened muzzle. In Paper I goats and sheep were able to select the main browse plants consumed, while for cattle the herders had an influence on the selection by making the foliage from the trees available. In the paper the term "browse plants consumed" is therefore used instead of "browse plants preferred or selected". The type of browsing activities and the height reached by animals when browsing confirm the anatomical and physiological assets of the animal species. Goats did not exhibit their browsing skills very well in this study because they were tethered during the rainy season for crop protection. The browse plants with the highest frequency of consumption were browsed during the cool and dry season. Among the browse plants highly consumed by animals and cited as valuable by farmers (Paper I), only *A. africana*, *K. senegalensis*, *P. erinaceus* were pruned and are likely to be subjected to overexploitation. Other authors (Petit, 2000; Ickowicz and Mbaye, 2001; Petit and Mallet, 2001; Gautier et al., 2005) have reported the use of these three species during the dry season by herders through pruning or lopping. This was the reason as to why these species were selected for further experiments in this study (Papers II, III and IV).

Phenology and foliage production of the browse plants

Phenology

The importance of the browse plant fodder in the diets of domestic ruminants seen in Paper I, lead to further investigations of the availability in time of the edible parts, primarily leaves, although fruits and flowers are also important. The phenological patterns recorded (Paper II) give an insight to the utilisation of the fodder from these browse plants. The beginning of the phenophases coincided with the period of feed scarcity. According to Ngwa *et al.* (2000) herbivores frequently preferred young leaves, and the consumption of fodder trees seemed to be linked to the phenological stage of the plants. The inter-species variation reported by other studies (Fournier, 1991; Sanon, 2007) was found and two distinct phenological groups were identified. *A. africana* and *P. erinaceus* are deciduous trees and *K. senegalensis* is an evergreen.

The phenology patterns have been found to be the phylogenetic responses of the trees, which adapt to the environmental characteristics of the ecosystem (Seghieri *et al.*, 1994; Williams *et al.*, 1997). However, the phenophases can be strongly influenced by other factors such as anthropogenic activities (Sun *et al.*, 1996; Root *et al.*, 2005), such as the pruning practices of herders. Devineau (1999) found that the role of the biotic components, particularly the coexistence with other plants, should not be neglected. During the field observations of this study individual trees which did not follow the general phenological behaviour of the species were found. However, they did not influence the average of the group because of low numbers of diverging individuals per species. Generally, the timing of flushing and shedding of the leaves, the onset of the flowering and the fruiting were attributed to climatic and environmental conditions (rainfall, atmospheric conditions, subsoil water availability or supply, soil moisture,…) and biotic factors (root system) (Jolly and Running, 2004; Badeck *et al.*, 2004). Many studies from tropical soudanian savanna have reported similar phenological behaviour of these species (Onana, 1995; de Bie *et al.*, 1998; Devineau, 1999).

Foliage biomass and prediction

With regard to the total above ground biomass of the trees studied, the biomass of foliage represents the lowest proportion after the branches and the bole. However, it has been an element of importance to investigate, because of the utilization for animal feeding, especially cattle (Paper I). During the late dry season, the foliage of the trees studied is one of the final strategies of livestock farmers for improving the diet of cattle in order to get minimum milk production from cows for auto-consumption and for improving the quality of manure and urine for their fields (personal observation). The method of complete pruning (Paper II) was used because it is accurate and non-destructive compared to the felling of the tree.

Factors influencing the phenology, outlined in the previous paragraph, have been found to influence foliage production (Swamy *et al.*, 2004). The availability of nutrients and the morphological characteristics of trees, especially the structure of crown and branches are also influenced by the same factors. Individual trees for all the species were selected in more or less similar environmental conditions and have roughly similar morphological characteristics. So the difference in foliage biomass (Paper II) may be attributed to their genera. This is consistent with the argument about the deeper root system of *K. senegalensis*, which gave the highest foliage biomass per tree, compared to the two other species. In addition, *K. senegalensis* may recover quickly from the influence of anthropogenic factors because of its favourable root system (Orou and Tamara, 2008). Bayer and Waters-Bayer (1999) have found that pruning and coppicing strongly influence the quantity of leaves in proportion to the branches. The results obtained with *A. africana* (Paper II) support this finding. This species was the most pruned and consequently had the lowest foliage biomass. The highest foliage yield obtained per ha with *P. erinaceus* can be attributed to the high density of this tree on pasture, compared to that of *A. africana* and *K. senegalensis* (Paper II).

Several statistical models, with the single parameter of tree or the combination, were used to explore the best correlation with foliage yield. The allometric equations reported in Paper II were those which gave significant relationships and higher r^2 between the foliage biomass and the tree parameters. With regard to the characteristics of the browse plants studied (Paper II) and the environmental conditions of the study site, the models found are reliable and can be applied with the same or similar species, the same site conditions and with plants exempted from lopping for at least two years. The available studies on allometric relationships between the foliage biomass and the physical parameters of trees were carried out on different species and in different agro-ecological conditions (Bille, 1980; Sanon, 2007), and make the comparison difficult. Nevertheless, many of these studies have reported regression equations with the height and the diameter of trunk. The results of this study, showed weak relationships obtained with these parameters, which may be attributed to the anthropogenic factors (Petit and Mallet, 2001; Sinsin, *et al.*, 2004), which may have had influenced the current morphological characteristics of the crown and the height.

Chemical composition and variation during the year

The chemical composition of the foliage (leaves plus petiole) reported was analysed on material collected at the beginning of the rainy season (Paper III, IV) and at the end (Paper II), because of the high availability of the foliage, as shown in the phenogram (Paper II). The periods of sample collection and handling, may give an explanation for the variations in the chemical values between the different experiments. The DM contents presented in Paper III and IV were decided in the laboratory from sun and air-dried samples, while those reported in Paper II were from fresh foliage samples. The most important element of the importance of these foliages in such mixed sub-humid farming systems, is by far their role in nitrogen supplementation. Emphasis has, therefore, been on CP content, although content of DM and fibers (NDF and ADL) are also important.

The CP and NDF contents of *A. africana* were highest in all the experiments. Except in Paper IV, the differences between *K. senegalensis* and *P. erinaceus* were narrower and non-significant. A number of factors have been reported to influence the chemical composition of foliage from browse plants (le Houerou, 1980; Rittner & Reed, 1992; Kaboré-Zoungrana, 1995). The higher CP content of *A. africana* may be due to the fact that it is a legume and furthermore to the genera. Legume trees were found to fix at least 60% of their N requirement from the atmosphere and to have a high concentration of N in the tissues (Peoples *et al.*, 1995; Deans *et al.*, 2003). *A. africana* is known to have a mutualistic symbiosis with at least 37 ectomycorrhizal fungi species (Thoen and Bâ, 1989; Sanon *et al.*, 1997; Sacandé, 2007). Generally, the ectomycorrhizal fungus facilitates the availability and the accessibility of nutrients, especially P, N and K, to the mycorrhizal host plant (Deans *et al.*, 2003). The high CP content of *A. africana* found in all the experiments (Paper II, III, IV) supports its rank as the most preferred species by herders found in Paper I.

The variation in nutrient contents (Paper III) depends on the stage of maturity, season and browse species (Salem, 2005). In the late dry season, leaves seem to have a higher CP content and lower DM and NDF, while the lowest CP content and higher DM and NDF were in the cool season (Kaboré-Zoungrana, 1995). According to Hagen-Thorn *et al.* (2006), the decrease of CP content with the mature stages of the foliages corresponds to the nitrogen absorption or re-translocation for other uses in the plant. The variation pattern of *K. senegalensis* did not follow exactly that of *A. africana* and *P. erinaceus*, probably due to the specific behaviour of an evergreen to progressively replace the mature leaves (de Bie *et al.*, 1998).

Whatever the species and periods, the CP content of the feeds in this study (114-173 g/kg DM) was above the critical level of 80 g/kg DM for ruminant diets (Minson, 1990). With the exception of *K. senegalensis* (114 ± 17 g/kg DM), the overall mean contents of CP obtained with *A. africana* (173 ± 50 g/kg DM) and *P. erinaceus* (139 ± 47 g/kg DM) were higher than the mean value of 125 g/kg DM reported by le Houerou (1980) for all the West

African browse species. The CP contents were in the range of 101 g to 292 g/kg DM reported by other authors for the same and similar species (Larbi *et al.*, 1998; Makkar and Becker, 1998; Ammar *et al.*, 2004). Differences may mainly be attributed to the browse plant species, the maturity stage of the foliages and the environmental conditions. Thus, these plants can be considered as good protein supplements to low quality roughages in this region, especially during feed shortage, though it should be noted that CP content is not the sole criteria for judging the relative importance of a particular feedstuff (Ammar *et al.*, 2004).

The overall mean values of NDF (491-577 g/kg DM) and ADL (139-163 g/kg DM) found for the browse plants in this study, were comparable to the mean values of NDF (445-572 g/kg DM) and ADL (121-194 g/kg DM) reported by Pamo *et al.* (2007), but were higher than the mean values of NDF (436-457 g/kg DM) and ADL (93-105 g/kg DM) found by Rittner and Reed (1992) for over 28 plant species of the humid and sub-humid zone. This difference is likely to be due to species effects. Drying has also been shown to increase the NDF and lignin content in browse foliage (Aregheore, 2002; Van, 2006). The mean contents of NDF and ADF in this study were lower than in the main grass species (*A. gayanus*) used in Papers III and IV (Kaboré-Zoungrana et al, 1999). The mean DM contents (447-474 g/kg) were higher than those (ranging from 270 g to 300 g/kg) reported by Toutain (1980) for young leaves of the same species. The difference may be due to the maturity stage of the foliage.

Voluntary feed intake and digestibility of the browse foliage

Although the chemical composition is essential for understanding the nutritional potential of plant species, information about the voluntary intake and digestibility is necessary for a better understanding. Generally, studies that have dealt with the nutritive value of browse plants, especially voluntary intake and digestibility, have focused on the supplementation aspects with a view to increase the intake of low quality forages or the total diet. The evaluations include the differences between plant species, levels of inclusion of browse fodder in the diet and/or methods of processing the plant foliage (Goromela *et al.*, 1997; Ben Salem *et al.*, 1997; Sangaré *et al.*, 2003; Van *et al.*, 2006). The results in Papers III and IV provide information concerning voluntary intake and digestibility of *A. africana*, *K. senegalensis* and *P. erinaceus*. Sheep were used in the experiments because of their intermediate skills as browsers, as found in Paper I, and also reported in other studies (Rutagwenda *et al.*, 1990; Sanon, 2007). In addition, sheep are easy to handle and it is likely that sheep depend less on feed variation or selection (Van, 2006).

There are many factors affecting the intake and digestibility of browse foliage, comprising mainly the plants species, chemical composition, taste, odour, secondary compounds, etc (Arnold *et al.*, 1980; Fall-Touré *et al.*, 1998; Van, 2006). The differences between the intake (Paper III, IV) and digestibility (Paper III) of the browse plants studied may thus be attributed not only to their genera but also to their chemical composition, which is in line with the statement made in the previous paragraph (chemical composition and variation during the year). Many studies have reported the negative correlation between the level of NDF and lignin and the intake and digestibility of browse foliage (Norton and Poppi, 1995; Sanon, 2007). In contrast, this study showed that the intake and digestibility of foliage were highest with *A. africana*, which had the highest content of NDF and lignin. A possible explanation is that the fiber fractions of this species may have good rumen degradation characteristics and have been a good source of energy for the rams. The intake and digestibility obtained in Paper III with *A. africana* used as a sole feed support these assumptions. According to Jung and Deetz (1993), the utilization of forage cell wall components as an energy source is regulated by their cross-linked nature. It has also been found that NDF corresponds to the coarse insoluble fiber that is adequate for promoting rumen function and is better related to intake and gastrointestinal fill (Van Soest *et al.*, 1991).

The secondary compounds such as tannins were not evaluated in this study. However the lowest values of intake (Paper III, IV) found with *K. senegalensis* is likely to be due to the bitter taste of its foliage, which has often been attributed to secondary compounds such as terpenoids and azadirachtin found in other browse species (Aganga and Tshwenyane, 2003). Although a non-leguminous tree, and in spite of its low intake, *K. senegalensis* had similar digestibility to that of *P. erinaceus*. This showed the nutritive importance of this foliage. The results in Papers III and IV are in line with the general agreement that a high CP content in feed is often positively correlated to rumen ammonia concentration and thereby to microbial growth and cellulytic activities in the rumen and so to the rate of nutrient digestion and intake (Leng, 1990; McDonald *et al.*, 1995). The low intake recorded with the hay of *A. gayanus* may be due to its high fiber content (Paper III and IV). However, the digestibility of the hay was comparably high which can be attributed to the early harvest stage during which the CP content was still high. The values in this study were comparable to those found by other authors (Kaboré-Zoungrana *et al.*, 1999; Phengvichith and Ledin, 2007a)

There were no recent data found on the intake and *in vivo* digestibility of these browse species for comparison. Values of intake and digestibility obtained in this study (Papers III and IV) were comparable to those of previous studies on other tropical browse plants (Kaboré-Zoungrana, 1995; Fall-Touré *et al.*, 1998). With regard to nutrient intake and digestibility the studied browse plants could constitute a cheaper alternative source of nitrogen for domestic ruminants.

Effects of browse foliage on the growth, carcass characteristics and gastrointestinal parasites in sheep

Many studies using foliage from shrubs or trees as a supplement to low quality grasses or crop residues for ruminants, have reported positive responses with respect to the productivity, especially growth, carcass characteristics and gastrointestinal parasite status (Goromela *et al.*, 1997; Sánchez and Ledin, 2006; Hue *et al.*, 2008). The browse foliage was used as the main part of the diet to ensure that the response of the animals reflected the nutritive characteristics of these plants (Fall-Touré *et al.*, 1998). The cottonseed cake was used as a positive control because it is the main concentrate produced in Burkina Faso. The intake results recorded (Paper IV) are in line with the previous statements with regard to the difference in CP content of browse plants. In contrast, the expected difference in growth and carcass characteristics was not found between *A. africana* and *P. erinaceus* or *K. senegalensis* and *P. erinaceus*, respectively.

The LWG and ADG of animals offered *A. africana* were lower than expected. However the ME and CP intakes recorded with this browse plant were sufficient to meet the daily requirements (5.62 MJ and 97 g CP/day) of a growing male sheep weighing 15 kg and growing at 100 g/d under tropical conditions (Paul *et al.*, 2003). It was observed in many studies that adequate energy intake should accompany a CP intake for an efficient use of nitrogen by microorganisms in the rumen, thereby for a better response of animals (Hristov *et al.*, 2005). According to Phengvichith and Ledin (2007b) an increased N intake without an adequate energy supply leads to increased N losses in the urine. The results obtained with *A. africana* may support this finding, which is in line with the high DM and CP conversion ratio recorded in Paper IV with this browse plant. The livers of animals offered diets with *A. africana* and *P. erinaceus* were heavier, which may suggest an inefficient use of dietary nitrogen metabolised in the liver (Atti *et al.*, 2004).

The carcass characteristics, especially the EBW and dressing percentage, recorded with animals fed *K. senegalensis* (Paper IV), despite the low intake, supports the level of digestibility found in Paper III. In addition, this browse species resulted in a better DM and CP conversion ratio than *A. africana*. One explanation of this nutritive potential may be the presence of high levels of anthraquinone in the foliage of *K. senegalensis* found by Ojo *et al.* (2006). It has been reported that this substance reduces the production of methane and increase that of propionate in the rumen, thereby reducing energy losses and contributing to higher overall efficiency of utilization of dietary energy for BW gain (Kung *et al.*, 2003).

The results in Paper IV show the clear difference between the browse foliage and the concentrate. However, potential characteristics of the browse foliage have been highlighted. The ADG (48-63 g/day) and dressing percentage (39-44%) obtained with animals fed diets with foliage were comparable to values reported by other authors who used tree foliage as supplements or other local feedstuffs (Bonsi *et al.*, 1996; Zoundi *et al.*, 2002). The browse plants studied may give a better response in animal growth and carcass characteristics with adequately balanced energy and protein levels in the diet.

A number of studies have reported the contribution of browse foliage to improve the productivity and the ability of animals to withstand the effects of gastrointestinal parasites due to their content of secondary compounds and/or CP (Waller, 1999; Wallace, 2004; Mui *et al.*, 2005; Mueller-Harvey, 2006). The effect of browse foliage on the evolution of gastro-intestinal parasites in the rams was studied in Paper IV, but since the animals were treated before the experiment, nematode and cestode eggs were not found in the faeces and only low numbers of coccidia oocysts were recorded. This suggested a high efficiency of the drug used and/or the absence of drug resistance. The mean numbers obtained were 6469 with the control diet, 4695 with *A. africana*, 3478 with *P. erinaceus* and 3339 with *K. senegalensis*. These numbers did not constitute any health problems for the animals and this information was therefore not included in the results in Paper IV. However, the variation in these numbers, from the beginning of the experiment to the end, highlighted the potential of the browse plants to contribute to the control of gastrointestinal parasites in ruminants. The numbers varied from 7938 to 4713 for the control, 7363 to 3825 for *A. africana*, 6288 to 2213 for *P. erinaceus* and 6806 to 925 for *K. senegalensis*. The effect was more clear with *K. senegalensis*, which may contain more secondary compounds than the two other species. This opens a new area for further research.

General conclusions and implications

- The behavioural activities of domestic ruminant on natural pasture in the sub-humid zone varied according to animal species and season. Browsing activities of the animals increased from the rainy season to the dry season in relation to the increasing shortage of grass forage. Browse species make an important contribution to the diet of cattle, goats and sheep in the sub-humid zone, especially during the dry season, and farmers are familiar with the species consumed by ruminant animals. The browse plants most consumed by animals and cited by farmers as being used for animals were *A. africana*, *A. dudgeoni*, *A. hokii*, *C. myxa*, *D. cinerea*, *D. togoensis*, *F. albida*, *F. gnaphalocarpa*, *K. senegalensis*, *M. indica* and *P. erinaceus*.

- The browse plants studied have appreciable characteristics in terms of foliage production, availability over a long period of time and nutrient content for domestic ruminants in the sub-humid zone. The foliage biomass of the trees and the branches was correlated to the physical parameters e.g. the circumference of the crown and the circumference of the branches, and regression equations were found as possible tools for pasture evaluation and management programs in this agro-ecological zone. The availability of the maximum browse biomass with the highest protein content (young leaves, flowers, and pods) was, in general, from April to June and coincided to the period of feed scarcity.

- The nutrient contents of the browse foliage changed slowly throughout the year according to season. The protein content of the browse foliages was sufficiently high, e.g. higher than 80 g/kg DM, even in the mature stage, for them to be used as supplements to low quality diets. The nutrient intake and digestibility, especially of CP and NDF, were higher for

A. africana, followed by *P. erinaceus* and *K. senegalensis*. The results indicate the possibility of using *A. africana* as a main feed for ruminants.

- *A. africana*, *K. senegalensis* and *P. erinaceus* can provide valuable foliage that has a high potential nutritive value and can be used to reduce the negative effects of feed scarcity on the performance of domestic ruminants in the humid and sub-humid zone of West Africa.

- The results from these studies will help in developing strategies to optimize range resources for sustainable animal production in the sub-humid zone of West Africa. For example, with regards to the importance of browse plants in the feeding system of goats, farmers should be advised to collect the fruits, pods or leaves of trees in order to improve the diets of the goats during the rainy season. Alternatively, advice can be given to mix goats with the cattle and sheep in the same flock to be herded. The use of *P. erinaceus*, which had the highest available foliage biomass per ha, can be encouraged with the aim of decreasing the pressure on *A. africana* trees, which were intensively pruned on pasture. The foliage from the selected browse plants, especially *A. africana*, can be used by farmers in small to medium size farms in urban, peri-urban and rural areas, as well as in large farms in rural areas, as an alternative source of protein during feed shortage. Livestock farmers in the rural areas can easily plant these species around the house and on the fields to prevent their disappearance and to increase the availability for animals. In addition, plantation of these browse plants in alley farming by crop farmers, even in smaller numbers, should be encouraged. The promotion of fodder banks with these tree species, especially in peri-urban areas can improve feed availability and income of the farmer organizations responsible for fodder bank management. In short, collaborative research between different services acting in the area in soil restoration, tree plantation and animal production should be undertaken on the selected trees and other plant resources of the zone for environmental protection and sustainable crop and animal production.

Further research

- Research should be conducted to evaluate the effect of different pruning systems (amount and frequency) on the biomass production and survival of the trees. The regression models for biomass evaluation can be developed for other height classes of the browse species and the models developed could be tested for similar browse plants in the sub-humid zone.

- Studies should be undertaken to establish the optimum level of incorporation of the foliage of the browse plants in the diet for maximum intake of roughage and to evaluate the cost/benefits of this supplementation.

- Research to evaluate the content of secondary compounds in the foliage, especially for *K. senegalensis* and *P. erinaceus*, and to investigate methods for improving the intake and digestibility of the foliage, e.g., use of polyethylene glycol, clay, charcoal or mixed foliage of different secondary compounds, should be done. Further diet formulation with addition of other energy sources is necessary to better evaluate the nutritive potential, especially of the foliage of *A. africana* and *P. erinaceus*.

- Further studies can be conducted to test the adoption of browse plant plantations and protection by farmers, to improve the fodder production and availability in the area. The effect of including the leaves of these browse plants in the diet of domestic ruminants on the quality of manure and urine for soil management should be investigated.

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Potentialités de Quelques Espèces Ligneuses de la Zone Subhumide pour l'Alimentation des Rumiants.

Résumé

L'exploitation des espèces ligneuses pour l'alimentation des ruminants en zone subhumide de l'Afrique de l'Ouest s'intensifie et l'étude des espèces fréquemment élaguées s'avère nécessaire pour une meilleure gestion. L'Objectif général de la présente étude était d'apprécier, au cours de l'année, les activités de consommation des fourrages ligneux des bovins, caprins et ovins sur le pâturage naturel, d'identifier les principales espèces ligneuses utilisées et d'évaluation leurs potentialités fourragères pour les ruminants domestiques.

Le comportement alimentaire des bovins, caprins et ovins sur le pâturage naturel a été étudié à l'aide de la méthode d'observation directe. Les éleveurs ont été interviewés pour déterminer les espèces ligneuses fourragères présentes et exploitées dans la zone. La phénologie et la valeur bromatologique ont été suivies au cours de l'année à travers des observations couplées aux prélèvements d'échantillons toutes les deux semaines. La biomasse foliaire a été évaluée par la méthode d'élagage intégrale. Les valeurs nutritives et l'effet de l'utilisation des feuilles sur la croissance et les parasites gastro-intestinaux ont été déterminés chez les ovins dans un dispositif en block complètement randomisé.

Les résultats ont montré des variations du comportement alimentaire entre les trois espèces animales en fonction de la saison. L'activité de consommation des ligneux a été d'environ 25% du temps de pâture pour toutes les trois espèces animales en saison sèche chaude. Pendant la saison sèche froide la proportion du temps consacré à la consommation des ligneux par les caprins (17%) a été significativement plus élevée que celle des ovins (7%) et bovins (5%). En saison pluvieuse, cette proportion a augmenté avec la disponibilité de jeunes feuilles et a été plus élevée chez les ovins (20%) que chez les bovins (7%). Durant cette periode pluvieuse les caprins ont été confinés ou gardés au niveau des jachères pour éviter des domages qu'ils pourraient causer dans les champs. Les espèces ligneuses fourragères fréquemment citées par les éleveurs et consommées par les animaux sur le pâturage ont été essentiellement *Acacia dudgeoni* Craib. ex Holl., *Ficus gnaphalocarpa* (Miq.) A. Rich, *Dichrostachys cinerea* (L.) Wight & Arn., *Faidherbia albida* A. Chevalier, *Afzelia africana* Sm. ex Pers., *Khaya senegalensis* (Desv.) A. Juss. et *Pterocarpus erinaceus* Poir. L'étude des trois dernières espèces choisies, à cause de leur exploitation massive par les éleveurs, a montré des phases phénologiques qui debutent en général pendant la saison sèche chaude et finissent vers la fin de la saison pluvieuse. Contrairement à *A. africana* et *P. erinaceus*, l'apparition de nouvelles feuilles au niveau des arbres de *K. senegalensis* a été effectué plus tôt et progressivement. Les biomasses foliaires par arbre de *K. Senegalensis*, *P. erinaceus* et *A. africana* ont été significativement different (41, 30 et 21 kg MS, respectivement). Rapporté à l'ha, les valeurs obtenues ont différé dans le sens *P. erinaceus* (1.3 t MS)> *K. senegalensis* (0.6 t MS)> *A. africana* (0.3 t MS). Les teneurs en

MAT des feuilles de *A. africana* et *P. erinaceus* ont diminuées de la fin de la saison sèche chaude à la saison sèche froide quand celles de *K. senegalensis* avaient tendance à augmenter avec l'apparition de jeunes feuilles. La MS ingérée et la digestibilité apparante de la MS obtenues avec *A. africana* (571 g/jour et 582 g/kg, respectivement) ont été les plus élevées suivies par celles enregistrées avec *P. erinaceus* (428 g/jour et 570 g/kg, respectivement) et *K. senegalensis* (298 g/jour et 566 g/kg, respectivement). Des équations d'estimation de la biomasse foliaire à l'aide de la circonférence du houppier ont été obtenues avec *A. africana* (R^2=82%) et *P. erinaceus* (R^2=81%). Le gain de poids vif a été autour de 60 g/jour pour les animaux ayant recu les rations contenant *A. africana* et *P. Erinaceus*, et a été supérieur à 48 g/jour obtenu avec la ration contenant *K. senegalensis* ($P<0.05$).

Ces espèces ligneuses constituent une importante source d'azote pour les ruminants domestiques dans la zone subhumide de l'Afrique de l'Ouest et sont à promouvoir dans les systèmes agrosilvopastoraux comme reserve fourragère de saison sèche pour diminuer les risques liés à leur disparition.

Mots clés: Afzelia africana, Biomasse, Burkina Faso, Ligneux fourrager, Ruminants domestiques, Croissance, *Khaya senegalensis,* Valeurs nutritives, Phénologie, *Pterocarpus erinaceus*, West Africa.

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