The Importance of Some Sahelian Browse Species as Feed for Goats

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Doctoral thesis
Swedish University of Agricultural Sciences
Uppsala 2007

Acta Universitatis Agriculturae Sueciae
2007: 84

ISSN 1652-6880
ISBN 978-91-576-7383-1

Tryck: SLU Service/Repro, Uppsala 2007

Abstract

Sanon H. O. 2007. The importance of some Sahelian browse species as feed for goats. Doctor's dissertation.
ISSN 1652 6880, ISBN 978-91-576-7383-1

Browse species contribute substantially to the availability of feed for livestock in the Sahelian zone of Burkina Faso. This study aimed to identify the most appreciated and utilized browse species, to evaluate their potential for fodder production and nutritive value, and to test the possibility of using them in intensive animal production.

In the first experiment the behaviour of cattle, sheep and goats was studied and a survey was undertaken in the study area to estimate the indigenous knowledge of browse species and their utilisation by ruminants. In the second experiment, *Acacia senegal*, *Guiera senegalensis* and *Pterocarpus lucens*, species that were found to be well utilized, were studied by estimating the phenological variation over time and the edible biomass production, total and directly accessible to sheep (0.87 m), goats (1.65 m) or cattle (1.47 m). Biomass production was also estimated using dendrometric parameters. The chemical composition of biomass (leaves and green pods) was determined in the third experiment, followed by measurement of the voluntary intake and apparent digestibility of the leaves and pods (except for *G. senegalensis*) using goats. Their effect (except for *A. senegal* leaves) on growth and carcass characteristics was evaluated in the fourth experiment, feeding the browses ad libitum with a fixed amount of bran and hay and compared with a control diet containing cottonseed cake.

The farmers classified the browse species according to their availability, their nutritive value, and several other usages. The feeding activities of all animal species decreased from rainy to dry season, with the decline in fodder availability, while resting and ruminating activities were increasing at the same time. Cattle browsed (leaves and litter) during the whole the study period for around 5% of the time spent on pasture. Sheep and goats made a shift in their feeding activities from grazing to browsing (28% and 52% of the time spent on pasture, respectively, for sheep and goats) when the herbaceous biomass decreased. *A. senegal*, *G. senegalensis* and *P. lucens* started the foliation phase as soon as the rains started, while *A. senegal* lost leaves earlier. The proportion of accessible biomass was higher for *G. senegalensis*, but *P. lucens* had higher total edible biomass. Goats browsing at higher height had more edible biomass at their disposal than cattle and sheep, although the chemical composition was similar for biomass accessible by all three animal species. The crown diameter predicted well the total edible biomass production of the three browse species. The crude protein (CP) content was 114, 157 and 217 g/kg dry matter (DM) and the neutral detergent fibre content 604, 534 and 412 g/kg DM for *G. senegalensis, P. lucens* and *A. senegal*, respectively. The highest intake was of the *P. lucens* leaves diet (864 g) and the lowest of the *G. senegalensis* diet (397 g). Pods from *A. senegal* were more consumed than pods from *P. lucens.* The leaves of *A. senegal* and *P. lucens* had similar digestibilities of CP, while *A. senegal* pods had higher digestibility of all nutrients than *P. lucens* pods. Goats fed *A. senegal* pods showed higher growth rate (56 g/day) The carcass weight, dressing percentage and weight of the primal cuts were higher for goats fed *A. senegal* pods, *P. lucens* leaves and the control diet.

In conclusion *A. senegal* pods and *P. lucens* leaves can be recommended as supplemental feed to poor quality roughages.

Keywords: *Acacia senegal*, Carcass characteristics, Cattle, Chemical composition, Digestibility, Edible biomass production, Feed intake, Feeding behaviour, Goats, Growth rate, *Guiera senegalensis*, Indigenous knowledge, Phenology, *Pterocarpus lucens*, Sheep

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To the memory of
My father Sanny Sanon
My grandmother Fatoumata Coulibaly

Contents

Appendix

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

I. Sanon H.O., Zoungrana-Kaboré C., Ledin I., 2007. Behaviour of goats, sheep and cattle and their selection of browse species on natural pasture in a Sahelian area. *Small Ruminant Research 67, 64-74.*

II. Sanon H.O., Zoungrana-Kaboré C., Ledin I., 2007. Edible biomass production from some important browse species in the Sahelian zone of West Africa. *Journal of Arid Environments (in press).*

III. Sanon H.O., Zoungrana-Kaboré C., Ledin I., 2007. Nutritive value and voluntary feed intake by goats of three browse fodder species in the Sahelian zone of West Africa. *(Submitted).*

IV. Sanon H.O., Zoungrana-Kaboré C., Ledin I., 2007. Growth and carcass characteristics of male Sahelian goats fed leaves or pods of *Pterocarpus lucens* and *Acacia senegal*. *(Submitted)*

Papers I and II are included with the kind permission of the journals concerned.

List of abbreviations

ADF	Acid detergent fibre
ADG	Average daily gain
ADL	Acid detergent lignin
BW	Body weight
CP	Crude protein
CPD	Crude protein digestibility
CSC	Cottonseed cake
DCP	Digestible crude protein
DE	Digestible energy
DM	Dry matter
DMD	Dry matter digestibility
DOM	Digestible organic matter
EBW	Empty body weight
FCR	Feed conversion ratio
FEC	Fecal eggs count
GDP	Gross domestic product
GLM	General linear model
LWC	Live weight change
Mcal	Mega-calorie
ME	Metabolisable energy
MJ	Mega-joule
NDF	Neutral detergent fibre
OMD	Organic matter digestibility
SD	Standard deviation
SSA	Sub-Saharan Africa
TLU	Tropical livestock unit
$W^{0.75}$	Metabolic weight

Introduction

Livestock production in Burkina Faso constitutes a key activity in the livelihoods of the population and contributes actively to income generation. Being a tropical dry country, landlocked and located in the middle of West Africa, Burkina Faso has more than 80% of its population involved in agricultural production, both livestock and crops, which contribute 34.5% of the GDP (FAO, 2003). The livestock sector alone accounts for 12.3% and constitutes the second export product after cotton.

The livestock population in Burkina Faso is estimated to include 7.3 M cattle, 6.7 M sheep and 10 M goats according to the national livestock census of 2004. The Sahelian zone includes the largest number, with 20.6 % of the cattle, 14% of the sheep and 17% of the goats (MRA, 2004). These animals are kept in two main types of production system, based on one hand on the management strategies of the herd and the use of external inputs and natural pastures, and on the other hand on social, cultural and economic factors. The traditional extensive production system using low inputs is the most important and includes the transhumant Fulani system, sedentary agro-pastoral systems and planned pastoral areas systems (Kagone, 2004). The transhumant Fulani system is dominant numerically, involving about 70% of the cattle and 40% of all livestock (Gning, 2005). The semi-intensive to intensive production systems are found where producers make more or less greater investments in input and labour, thus allowing the animals to better express their production potential; these are the urban and peri-urban dairy farms, and specialized cattle and sheep fattening in the countryside. With the cycle of drought in the 1970s and 1980s, the pastoral Fulani population lost a significant number of livestock and migrated more or less permanently from the North to the South and West regions. Those who remained underwent profound changes in their production strategies and Ouedraogo (1991) concluded that the agro-pastoral system is currently dominant in the Sahel of Burkina Faso.

Overall, natural pastures constitute about 85% of the feed, followed by crop residues, which account for less than 11%, while fodder crop and conserved forage utilization are negligible (MRA, 2004). However, Burkina Faso as other Sahelian countries, faces the crucial problem of feed shortage, especially in the arid and semi-arid areas. Degradation of natural resources, problem of competition between resources available and the needs of both the human and livestock population, and the variability and fluctuation of rainfall inherent to the arid and semi-arid areas are the main constraints affecting the productivity of animals.

The strategic position of the country makes it of regional importance for livestock production, in providing for the countries in the coastal area, which are depending on imported livestock products. Burkina Faso, together with other Sahelian countries, are the main exporters of livestock and livestock products in West Africa and their share of exports in the regional livestock trade in 2003 was 95% for cattle and 79% for small ruminants (SWAC/OECD, 2007)

Despite its social and economic importance, the livestock sector is not well developed due to political decisions, which have been more focused on cotton production (Gning, 2005). To make livestock production more productive, the state currently prioritises intensification of both livestock and crop production, hence promoting mixed farming systems. On the other hand, the strategic plan of agricultural research and its component animal production has among its objectives the improvement of traditional livestock production through sustainable use of locally available feeds.

For a sustainable development of livestock production one must take a crucial look at the actual situation in order to find favourable solutions adapted to the realities of the rural population. One component of natural pasture, which has attracted marginal interest compared to the research efforts on herbaceous cover, is constituted by browse forages. This resource, due to the diversity of species, the length of the production cycle, the variety of feed components (fresh and dry leaves, flowers and fruits/pods) and the high content of protein and some minerals constitutes a key resource for grazing animals (also in cut and carry systems) especially in the dry season insofar as they are shown less dependant on rainfall compared to herbaceous plants. Despite the importance of browse during periods of drought being well known by farmers, and recognized by many authors (Le Houerou, 1980, Breman and Kessler, 1995), the potential of many locally available browse species is not well exploited. In addition, goats are the most important numerically among ruminant species and often kept by marginalized people. The ability of goats to better utilize the value of browse forages could be used to improve their production, which could facilitate rapid access to cash income for the poor people and contribute to poverty reduction. They could also contribute to meeting the increasing demand of livestock products being apparent in most developing countries.

Objectives

The objectives of this thesis were to find the most appreciated and utilized browse species in the Sahelian area of Burkina Faso, evaluate their potential for fodder production and their nutritive value, and test the possibility of using them in the production system. More specifically the aims were:

- To study the feeding behaviour of the main ruminant species in the area and their selection of browse species (Paper I).

- To assess the availability of the most appreciated browse species (Paper II).
- To evaluate the edible biomass production of selected species and their accessibility to different animal species (Paper II).
- To determine voluntary intake and nutritive value of the selected browse species (Paper III).
- To evaluate growth performance, carcass characteristics and parasite resistance of goats fed the selected browse species (Paper IV).

Background

Livestock production in Sub-Saharan Africa: potential – constraints – opportunities

Livestock production contributes substantially to the agricultural GDP in Sub-Saharan Africa (SSA), up to 35% according to Winrock (1992). The population of livestock is estimated to be 216.6 M cattle, 176.8 M sheep and 210.5 M goats (FAO, 2006), representing 16%, 17 % and 27% of the world population of these species, respectively. About 30% of all TLU (tropical livestock units) in tropical Africa can be found in the arid zone, including 90% of the camels, 30% of the cattle and 40% of the small ruminants (De Leuw *et al.*, 1995). Most of the livestock in SSA (about 70%) is handled by rural people, who own and manage multipurpose enterprises in which livestock is an integral part (Winrock, 1992). Hence livestock production contributes to food security through direct production of food (animal products) as well as through non-food functions (Sanon, 1999).

With regard to the food function, ruminant animals have the ability to convert plant material that is unsuitable for human consumption into high quality food products. Proteins from animal sources are rich in essential amino acids, and the use of animal products has been linked to the level of wealth among people. For instance the per capita consumption of meat was 80.3 kg/year in developed countries in 2003, compared to 28.9 kg/year in developing countries. For SSA the figure is even lower, 11.4 kg/year (FAO, 2006).

The greatest contribution of livestock in rural areas in SSA is in the form of non-food functions. Livestock are important for crop production through manure and draught power and is a key factor in mixed farming systems. For most smallholder farmers, animal draught power and nutrient cycling through manure compensate for lack of access to modern inputs, such as tractors and fertilizers, and help to maintain the viability and environmental sustainability of the production. The provision of manure increases nutrient retention capacity, improves physical properties of the soil by increasing water holding capacity and improving soil structure. Moreover, studies have shown that the application of chemical fertilizers to tropical soils leads to a stagnation of crop yields, while a combination of manure and NPK resulted in sustainable increases in crop yields (Sédogo, 1993). In the Sahelian area manure is systematically spread on the field either directly by animals grazing crop residues after harvest or by the farmers. In the area of transit or stopping places of transhumant herds, there is a form of contract between livestock keepers and farmers. The farmers allow the livestock keepers to graze their animals in cropland against some nights of resting in this field to benefit from the manure produced. Approximately 22% of the total nitrogen fertilizer and 38% of phosphate is estimated to be of animal origin, representing US $ 1.5 billion worth of commercial fertilizer (Steinfeld *et al.*, 1997).

Animal draught power is still a main component of many smallholder farms in developing countries. The draught power provided by buffalo, cattle, horses, donkeys, mules and occasionally other species spares people some of the harder labor, and increases the amount of crops that can be produced by an individual or a family, increasing food supply and income. It is estimated that the work performed annually by draught animals would require 20 million tons of petroleum, valued at US $6 billion, if performed by motorized machines (Steinfeld *et al.*, 1997). This represents a major saving for countries which have to import petroleum products, and also results in less production of CO_2, the most important greenhouse gas.

Livestock also represent a mean of saving, a food reserve in times of crop scarcity, and an important asset for investment and insurance. Hence it contributes to the flexibility and the stability of the food production systems and the total agricultural economy (Bradford, 1999). In the Sahelian area almost all farmers keep animals, which remain closely associated with the social habits and welfare of the rural households. The use of livestock as gifts, for dowry or slaughtering for traditional feasts or religious ceremonies reinforces family and social links.

However, livestock production in SSA faces many constraints, the most important being feed shortage. Livestock use almost exclusively natural pastures as the main feed resource. The productivity of these pastures is subjected to high variability between and within years, related to rainfall and seasons. The increase in human population has lead to an increase in cropland area, decreasing the area used for grazing and encroaching on better pastures. In addition, Sahelian countries since 1969, have experienced the appearance in a random way of dry periods and movement of the isohyets toward the south (Grouzis *et al.*, 1986), which results in a reduction in rainfall. The combined effect of dryness and extensive production have resulted in tree mortality, appearance of bare spaces and simplification of the flora composition toward species which are well adapted to harsh conditions, and also the disappearance of some fodder species. According to Powell *et al.* (2004) a specialized form of agricultural production has been prevailing traditionally in the West African drylands. Crops and livestock were ethnically and operationally separate but functionally linked enterprises, with exchanges of grain, crop residues and water for manure between sedentary crop farmers and migratory pastoralists. However, this form is shown to be under transition, as Winrock (1992) stressed, and more sedentary, mixed farming enterprises are developing.

The production of livestock and the demand for livestock products in developing countries are predicted to double over the next 20 years due to human population growth, increasing urbanization and rising incomes (Delgado *et al.*, 1999). Livestock production is predicted to produce more than half of total global agricultural output in value terms by 2020, a process which is referred to as the "Livestock Revolution". This offers good opportunities for the rural poor, as the majority of animal products consumed in developing countries is still produced by semi-subsistent farmers, and would contribute to poverty reduction (PPLPI, 2004).

Increasing livestock production in developing countries is crucial. At the national level, it will reduce the need for high cost imports and save foreign exchange, which can then be diverted to productive investments. The resources needed for this intensification could come primarily from improvement of available local sources.

Availability of feed resources for ruminants in the Sahelian zone

The Sahel (from Arabic *sahil*, shore, border or coast of the Sahara desert) is a transition zone between the Sahara desert in the north and the more humid savanna zone in the south. The mean annual rainfall varies from 100 mm (in 1 to 2 months) at the border of the Sahara to 600 mm (3 to 4 months) at the southern border, with the peak occurring in August (Le Houerou, 1980). The area covers about 40% of SSA, in which 36% of the total population lives. The countries of the Sahel include Burkina Faso, Chad, Eritrea, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan. The Sahelian zone has been divided into 3 sub-regions based on climate, vegetation and land use practices: Saharo-sahelian subzone (100 to 200 mm rainfall), typical Sahelian (200 to 400 mm) and Sudano-sahelian (400 to 600 mm). High variability of rainfall is recorded, from 40% in the north to 25% in the south. Land use is exclusively pastoral nomadism in the north, while some cultivation take place in the typical sahelian and sudano-sahelian sub-zone (Le Houerou, 1980). Goats and sheep are important species numerically in the arid zone, followed by cattle, which become dominant in the semi-arid area (Otte & Chilonda, 2002).

Natural pastures

Rangeland production in the Sahel is highly seasonal, with a rainy season occurring from June to September. The herbaceous layer is composed almost exclusively of annual plants, the composition and growth rate of which are strongly influenced by the pattern and amount of seasonal rainfall (Hiernaux, 1996). In general, C4 grasses dominate, although in wet years, the share of leguminous and other dicotyledonous species in the plant cover increases. Most of the shrubs and trees are deciduous but have longer leaf-production cycles than the herbaceous plants. The availability of the pasture resources is characterised by a peak in herbaceous production in the rainy season, with high nitrogen and energy content, while in dry season, the resources gradually decrease in quantity as well as in quality, and are then unable to meet the maintenance requirement of the animals. The woody fodders are diversified, have various fodder components (green and dry leaves, flowers and fruits) and have a longer period of availability. Hence they constitute an essential resource for livestock during the long dry season.

Overall the consumable yield of natural pasture in the arid and semi-arid zones is estimated at 200 to 500 kg DM/ha (Winrock, 1992). However, high variability is reported between the sub-zones, also depending on the geo-morphological units differentiating pasture vegetation (Boudet, 1977): dune, sandy soil, colluvial glacis, thin soil and flooded meadow. For instance, in the typical Sahel, woody cover is seldom above 5% in sandy soil, with 2 main species, *Acacia senegal* and *A. raddiana*. The productivity of the herbaceous layer increases from North to South with the rainfall and varies along the topo-sequences, from 500 to 650 kg DM in the North and 1500 to 2000 kg DM in the South, on top sequence and gentle slopes, respectively. In colluvial glacis, woody cover is heterogeneous and the herbaceous cover is dense, dominated by *Schoenefeldia gracilis* or *Panicum laetum*, with biomass varying from 1000 to 3000 kg DM/ha. On thin soil, the vegetation is of shrubby steppe type with distribution in spots within micro-depressions. Woody cover is dominated by *Pterocarpus lucens* and *Grewia bicolor*, while herbaceous biomass is estimated at 500 kg DM/ha, making this range mostly suitable for browse production (green and dried leaves). The flooded meadows of the rivers and the large ponds that are exploitable after decrease in water level have high productivity, reaching 7000 kg DM/ha, corresponding to 0.6 ha/TLU during the dry season grazing.

Crop residues

Crop residues are the plant materials that remain after food crops have been harvested. The main crops in the Sahelian zone are millet, sorghum, cowpea and some tubers. Millet is the principal grain crop in the dry semiarid zone (sole-cropped or intercropped with cowpea), comprising 65% of total output of 7 West African countries, with yields of the residues estimated to be 1000 to 2000 kg DM/ha (Williams *et al.*, 1997).

As a greater proportion of the land is brought under cultivation to meet the needs of a growing population, crop residues have become an important source of livestock feed (Harris, 2002). However, their availability depends on the proportion of land under crops and the yield of the relevant plant parts. In the Sahelian area, especially in the dry season, they can constitute 40 to 60% of the total DM intake by cattle (de Leeuw, 1997). The estimated stocking densities on cropland vary widely, from 21 TLU/ha in arid/semiarid Somalia to 0.9 to 1.1 TLU/ ha in Niger and Burkina Faso (de Leeuw, 1997).

The management of crop residues for livestock feed differs depending on the type. Most of the cereal straws are grazed in situ, while leguminous residues are collected as haulm for sale or for stall-feeding (Tarawali & Hiernaux, 2002). The collection of legume haulms can be related to their high quality as feed and also to their low availability compared to cereal straws. Cowpea haulms are reported to yield 400 to 1200 kg/ha of forages in Mali and 200 to 500 kg/ha in Burkina Faso when intercropped with sorghum (de Leuw, 1997). For groundnut, 400 to 700 kg/ha have been recorded in Mali and 700 to 1500 kg/ha in Nigeria. The nutritive value, as reported by Savadogo (1999), was 156 and 126 g/kg DM of CP, 610 and 570 g/kg digestible organic matter, and 9.7 and 9.0 ME, respectively, for cowpea and groundnut haulms. With regard to cereal straws, the common practice in the Sahelian area is to remove a part, that is stored in the homestead or between branches of trees in the field before the animals are allowed to graze. In more intensive systems in densely populated areas, all crop residues may be harvested for livestock feed and or for sale (Powell *et al.*, 2004). Thus, Bourn & Wint (1994) reported a strong association between livestock concentration and the percentage of land under cultivation across the Sahel and the adjacent agro-ecological zones in Nigeria. The residues stored are used in the dry season to maintain productive animals (lactating or weak) or for fattening animals in association with legume haulms, agro-industrial by-products or browse fodder. The grazing period in the field extended by 3 to 4 months, from November/December to February/March. On their way towards more humid zones, transhumant pastoralists make arrangements with crop farmers to graze their cattle directly on fields after harvest, exchanging feed for the provision of manure.

Some conflicting interests exist for the utilization of cereal straws, since they are also used as fuel, for fencing and roofing and as building materials, and to protect the soil against erosion or as sources of organic matter. One the other hand, the utilization of cereal straws as feed is limited by the low nutritive value (44 to 54g/kg DM of CP, 450 to 510 g/kg DOM and 7.1 to 8.1 MJ ME/kg OM, for millet and sorghum respectively, according to Savadogo (1999)). Many studies have been done on improving their use for ruminant feeding, including physical treatments by chopping and treatment with urea or ammonia (Fall, 1990).

Fodder crops

Fodder crops refer to crops that are cultivated primarily as feeds for animals. Many types of fodder crop can be distinguished: permanent fodder crop such as perennial grasses or legumes usually established in permanent meadows, temporary fodder crops including highly productive annual grasses and legumes, allowing multiple cuttings per year, crops for both food and fodder such as sorghum and cowpea and shrubs and tree fodder. Fodder crops can improve the production and quality of forages substantially and they have many advantages e.g. constitution of a fodder reserve to be used in periods of forage scarcity, intensification of animal production by increasing animal productivity (per animal and per ha), and improving animal management (LEAD, 2005). Positive impacts on the environment have also been recorded, by protecting the soil against erosion and improving soil fertility (legumes). However, the establishment, maintenance and use require technical tools comparable to other crops. In SSA the concept of cultivated forage has evolved since the early 1900s to avoid the negative environmental impacts of nomadic livestock production (Thomas & Sumberg, 1995). Pasture and fodder research was intensified after World War II, strongly influenced by the pioneering work on tropical pasture plants in Northern Australia. The introduction and screening of legumes and grasses for forage and soil regeneration were undertaken in the 1950s and 1960s in many countries, to improve the quantity and quality of feed as a prerequisite for the development of the livestock sector. Over the last 40 years considerable resources have been devoted to screening and testing forage legumes in Sub-Saharan Africa, and species which are adapted to a range of environmental conditions have been identified (Thomas & Sumberg, 1995).

In Burkina Faso, many institutions have been involved since 1961 in the introduction and testing the adaptability of fodder plants, as a result technical papers have been elaborated for 22 species that were shown to be more interesting (MRA, 1999; Sanon & Kanwe, 2004). An assessment of the fodder bank technology developed by ILCA and its national research partners, identified about 27,000 smallholder farmers covering an area of about 19,000 ha for the whole of West Africa (Elbasha *et al.*, 1999). The main species were *Vigna unguculata* (cowpea), *Dolichos lablab*, *Macroptilum atropurpureum* (Siratro), *Panicum maximum*, *Cenchrus ciliaris*, *Chloris gayana*, *Cajanus cajan*, *Leucaena leucocephala*, *Stylosanthes* and *Brachiaria riziziensis*. However, most of the adoption was concentrated to the subhumid zone, maybe in relation to the adaptability of the species. Cowpea is a species expanding in the Sahelian zone as a multi-purpose crop, the grain being used for human consumption while the haulms are used for feed. In Niger, 5,600 kg of seeds were distributed each year to farmers (Williams *et al.*, 1997).

In general, however, the cultivation of legumes specifically for forage is minimal. Many constraints have been identified to deal with the low adoption e.g. lack of extension in training, inappropriate land tenure, cost of fencing materials, shortage of labour due to overlapping of the farming calendar with the main crop, cost of phyto-sanitary products, credit and seed availability, land scarcity, invasion by grasses and weeds and fires. Recently, attention has been focused on fodder trees, either naturally occurring or introduced, due to the many advantages they provide, such as longevity and availability to produce when herbs and grasses are dormant (Paterson *et al.*, 1998).

Agro-industrial by products

Agro-industrial byproducts result from the processing of crops such as oilseeds, sugar cane, sisal, citrus, pineapple and bananas, or the slaughter and processing of livestock and fish (Preston, 1986). They are rich in protein (oilseeds and meals of animal origin) or sugar (molasses, citrus and pineapple pulps) and occasionally in starch (rejected bananas, cassava peels) and are usually low in fibre. In the Sahelian countries, such as Burkina Faso and Mali, the most important agro-industrial products found are cottonseed and cottonseed cake. The quantities of agro-industrial by-products depend on the availability of the raw material and the capacity of the factory. Their use is low in rural areas due to the localization of the processing factories, which are usually located in urban and peri-urban areas. In consequence, the cost of transportation makes the products often quite expensive. Commercial farmers with purchasing power and availability of their own transport can more easily utilize e.g cottonseed cake. The products are often exported by traders, which make them even less accessible to farmers lacking adequate infrastructure and marketing facilities. Not all agro-industrial by-products produced in the factories are used for livestock. For instance, molasses is sometime used as fertilizer in the sugarcane fields or to maintain the road and for the production of alcohol. The cottonseed is partly used as seeds for cotton production, or processed to extract the edible oil for consumption, providing cottonseed cake.

Role of browse plants in the production systems

Browse refers to leaves and twigs from shrubs and trees available to ruminants as feed and in a broader sense including also flowers and fruits or pods. The notion of browse is a complex issue, as discussed by Le Houerou (1980), depending on plant species, animal species, forage availability and accessibility and the nutritional state of the animals. Wicken (1980) estimated that the flora of tropical Africa contains more than 7000 species of trees or shrubs of which at least 75% are browsed to a greater or lesser extent, and probably about 50% are useful to man. Apart from being browsed, woody plants have always played a significant role in human lives in SSA as demonstrated by their multiple usages. With regard to crop production, farmers in semi-arid West Africa have traditionally spared desired species when establishing their fields by clearing natural vegetation. Species such as *Acacia albida* are valuable because of the ability to improve soil fertility through nitrogen fixation, and also because of the reverse vegetation cycle of this tree, that produces green leaves in the dry season for feeding animals, and they in turn spread manure on the field. In the rainy season the species lose their leaves, resulting in no shading effects on the crop. Other species maintained in the croplands have different socio-economical importance (edible leaves or fruits, ethno-medicinal use or shade) and reduce evaporation from the fields. Overall, the multiple uses of woody plants include soil maintenance and protection against erosion and dune stabilisation (as windbreaks), source of energy (fire wood), construction material and with their shade reduced water loss from the soil and lower temperature. The trees serve as source of income through the sale of leaves, fruits and wood, and ethno medicinal and veterinary uses are common. They are also shown to influence the herbaceous cover in the Sahel, by improving flora diversity and mineral content (Akpo *et al.*, 2003).

Indigenous knowledge on the use of browse species in animal feeding

Local people generally recognize the trees and shrubs which are well appreciated by ruminants, and their nutritive importance (Thapa *et al.*, 1997; Briggs *et al.*, 1999; Thorne *et al.*, 1999; Komwihangilo *et al.*, 2001). The role of browse during periods of drought has been recognized and has attracted attention from scientists. Thus important information was collected at the International Conference of Browse in Africa, dealing with various aspects of browse plants (Le Houerou, 1980).

For the improvement of forage production, the screening of browse plants and evaluation of biomass production has concentrated on improved species such as *Leucaena leucocephala* and *Gliricidia sepium*, for which planting material and information are available from international sources. Hence, some authors have recently focussed on screening indigenous fodder trees and shrubs by involving farmers in the choice of promising species. Indigenous browse species are well adapted to the local environment, are well known by farmers and the planting material can easily be collected in the area. The methods have consisted of interviews with informants on the diversity of browse species and their knowledge of their palatability by livestock (Scones, 1994; Komwihangilo *et al.*, 1995;

Roothaert & Frankel, 2001; Okoli *et al.*, 2003), the ranking of browse quality coupled with chemical analysis (Bayer, 1990; Scoones, 1994) and the preference of selected animals (Mtengeti & Mhelela, 2006). It appears that local farmers can generate richer data, as the area under consideration will not be limited to direct observation in paddocks as in many studies. Over 160 species were recorded by Okoli *et al.* (2003), working with indigenous farmers in south eastern Nigeria, as used for ruminant feeding, and this list exceeded the previous report in the literature from the area. The ranking of fodder quality revealed that the farmers' knowledge of the quality is well correlated with the chemical composition. The knowledge of the palatability in different animal species was also in accordance with the field observations. Hence, farmers' preference of browse species was related to the availability, palatability and drought resistance. According to Niamir (1990) local people also have an intimate knowledge of the characteristics and value of different plants e.g. their value in stimulating milk and meat production, the toxicity, saltiness and medicinal value, the ability to indicate the agricultural potential of soil and the prominent characteristics such as prolific fruiters and fast growth. The studies stressed the advantages of a survey of farmers that are quick, compared to direct observations, and give relatively reliable information on the complexity of browse species. In consequence, these surveys are shown to be fundamental in identifying fodder species for further research and development programmes to improve productivity.

Potential and limitations of the use of browse in ruminant feeding

In free ranging systems, browse species constitute an effective insurance against seasonal feed shortage in the dry season, supplementing the quantity and quality of pasture. Trees and shrubs are perennials allowing the provision of permanent fodder compared to herbaceous species, which decrease rapidly in quantity and quality after the rains. Through their deep root system, trees are able to penetrate further into the soil and therefore continue to grow under dry conditions and/or keep green leaves. The regular availability of forage from trees and shrubs depends on the diversity of species and their phenological variation in time and space (Grouzis & Sicot, 1980). On the other hand, their high feeding quality in terms of protein and content of some minerals such as calcium and phosphorus (Paterson *et al.*, 1998) is well appreciated. Almost all literature on the use of shrub and tree fodders to supplement either natural grasses or crop residues has shown positive responses with respect to the productivity of cattle, sheep and goats (Norton, 1998). Also, stocking rates are shown to increase generally when fodder trees are included in the pastures (Leng, 1997). This author further reported the potential use of browse as bypass protein to increase productivity of ruminants where bypass protein supplements in the form of concentrates such as cottonseed meal have been fed to ruminants, supplementing poor quality forages. This process has been linked to the effect of condensed tannins that are bound to foliage protein, preventing the microbial degradation of leaf protein in the rumen. Then, particles high in protein will move to the lower digestive tract where some of the condensed tannin complex with protein may be hydrolysed, allowing protein to be digested. Condensed tannins under acid or alkaline conditions of the intestines may be split to sugars and organic acids, mostly gallic acid, releasing protein and amino acids that are digested in the lower gut. Anthelmintic proprieties have been reported in many plants that are browsed (Hammond *et al.*, 1997), that by improving the nutritional status of the animals, increase their ability to resist the harmful effects of parasites (Hoste *et al.*, 2006).

The utilisation of browse is limited by the high lignin content and the presence of anti-nutritional factors, which may be toxic to ruminants. Many browse species have chemicals that appear to be produced for the purpose of deterring invasion or consumption of their leaves by microbes, insects and herbivorous animals. The most important cited is tannin, which is shown to decrease the digestibility in browse fodders. Tannins are a group of polyphenol substances with the ability to bind protein in aqueous solution. They are classified into two groups: hydrolysable or condensed tannins, and are considered to have both adverse and beneficial effects depending on their concentration and nature, and also animal species, physiological state of the animal and the composition of the diet (Makkar, 2003). Silanikove *et al.* (1996) concluded that goats have the ability to consume large amounts of tannin rich plants without exhibiting toxic syndromes (due to a detoxifying enzyme in the saliva), which is not the case for other ruminant species. The negative effect of tannin is seen in lowered feed intake, directly due to the astringent properties of tannin rich feed, and indirectly by reducing the digestibility of the feed. Hanley (1992) reported that tannin reduced the digestible crude protein by 44% and digestible organic matter by 14%. However, the level of digestibility reduction varied depending on the level and the activities of tannin (Ebong, 1995). A level of tannin below 5% seems to be tolerable for ruminant animals.

While tannins are the best known of the anti-nutritional factors of browse, there is a long list of secondary compounds: cyanide, nitrate, fluoroacetate, cyanogenic glucosides, saponins, oxalates, mimosine and various sterols (Leng, 1997). However, the toxic compounds seem to become of significance nutritionally only when the plant constitutes a high proportion of the diet. Hence, the effects of high protein forage could override the effect of the toxic compounds when used as supplement in the diets.

Goat nutrition and performance

The goat (*Capra hircus*) is shown to have been one of the first animals to be domesticated by humans, about 7000 BC in South West Asia (Peacock, 1996) then spreading into all the tropical zones and most temperate areas. The world goat population is estimated at 790 M and most (96%) are found in developing countries (FAO, 2006) where they are of great importance. Goats are usually kept by poor people (often women in some areas) to whom they provide useful products and services. Goat milk is highly nutritious and has a similar nutritional profile to human milk (Peacock, 1996). Goats are highly prolific, producing twins or triplets (most tropical breeds) allowing owners to build flocks quickly. The goat is often used as a first step towards livestock ownership, as with a large flock part can be sold and replaced by sheep or cattle. Many other attributes of goats are reported, including small size and low price, which is ideal for slaughter at any celebration, and to sell when cash is needed. They are easy to manage by children and can survive in harsh conditions (low availability of vegetation in the arid areas, feed rich in fibre and low in nitrogen, lack of water and heat stress). All these attributes lead to the connotation that the goat is "a poor man's cow" (Mahatma Gandi, great Indian Leader) quotation taken up by Peacock (1996) who qualified it as "a poor person's bank".

With regard to the feeding behaviour, the goat is a natural browser, feeding by preference on tree leaves, flowers, fruits/pods and even the woody stem of trees. Their small mouth and mobile upper lip and tongue enable them to pick small leaves between thorns, flowers, fruits and others plants parts, thus choosing only the most nutritious available feed. They are very active, moving quickly between and around trees, and can walk long distances in search of food to satisfy their nutrient requirements. Goats are shown to eat preferentially at heights between 20 and 120 cm above ground and can stand on their hind legs or even climb trees to reach the best forage. They are known to feed on a wide variety of forages, and the choice is influenced by the diversity of feeds available. This attitude seems to be related to the need to maintain the rumen environment within a certain physiological and microbiological range (Morand-Fehr, 2005). However, they seem to not thrive well when kept on a single type of feed for any length of time (Devendra & McLeroy, 1982). The feeding strategies of goats, reported by Luginbuhl & Poore (1998), consist of selecting grasses when the protein content and the digestibility are high, but switching to browse when their nutritive value may be higher. However, where browse is not available, goats can feed on grasses and crop residues such as cereal straws, but tend to prefer less coarse grasses (Devendra & McLeroy, 1982).

Luginbuhl & Poore (1998) noted that goats are not able to digest cell walls as well as cattle because the feed stays in their rumen for a shorter period of time. On the other hand, Morand-Fehr (2005) reported similar retention time of feed particles in the whole digestive tract of sheep and goats eating the same quantity of good quality forage, but the retention time of goats receiving poor quality forage was longer. Hence sheep and goats have similar patterns of digestion of moderate to high quality forages, but goats are better in digesting forages rich in cell walls and poor in nitrogen. This seems to be related to their ability to recycle urea nitrogen (Silanikove, 2000). In addition, goats are efficient in the use of water and have a low rate of water turnover per unit of body weight (Devendra & McLeroy, 1982). The adaptation of goats to water shortage in hot environments in the tropics has been explained by low water turnover and the ability to resist desiccation (they do not sweat, and lose less water in faeces and urine).

The DM intake of goats, indicating the capacity to utilise feed voluntarily, depends on the breed (meat or milk) and the environment. Thus in the tropics, intake of 4 to 5% of live weight has been reported for dairy goats and 3% for meat goats (Devendra & McLeroy, 1982). The growth rate and mature weight of goats vary widely in different parts of the world, due to differences in breeds and level of nutritional management. However, Luginbuhl & Poore (1998) noted that the goat has lower rate of weight gain and do not fatten like cattle and sheep; thus to achieve maximum potential, goats need high quality feed and require optimum balance of many different nutrients.

Summary of materials and methods

Location of the study area

The study was undertaken in the Sahelian area of Burkina Faso. The field studies (Paper I and II) were done at the village of Tongomayel, located in the province of Soum (13°44′ to 14°50′ N and 0°32′ to 2°07′ W), while the animal experiments (Paper III and IV) were conducted in the research station of Katchari in the Regional Centre of Environmental and Agronomic Research (CRREA) in the North of Burkina Faso. The station is located between 13º55’ and 14º05’ N and 0º and 0º10’ W, and is about 12 km from Dori, the main city in the province of Seno. Both sites (Fig. 1) are situated in the north Sahelian agro-climatic zone (Fontes & Guinko, 1995), characterized by a short rainy season, from June to September, with rainfall varying from 300 mm to 600 mm, and followed by a long dry season. The dry season is characterized by the dry wind called Harmattan, which blows from the North-East to the South-west, with a cool and dry period (November to February) and a hot period (March to May), during which the maximum temperature reaches 45º C in April. The mean rainfall of the last 10 years recorded for the weather station of Djibo is 480 mm.

Fig. 1. Phytogeographycal zones of Burkina Faso (Fontes and Guinko, 1995) and the study site

The vegetation is of the steppe type, with shrubs and trees, and forest galleries are found along riversides and in some parts ligneous species may form more or less penetrable bush (e.g. tiger bush). The most common ligneous species found in the area are: *Acacia nilotica*, *Acacia senegal*, *Balanites aegyptiaca, Boscia senegalensis*, *Commiphora africana*, *Dalbergia melanoxylon*, *Pterocarpus lucens* and *Grewia flavescens*. The grass cover is sparse and dominated by annual grasses such as *Aristida mutabilis*, *Cenchrus biflorus* and *Schoenefeldia gracilis*.

Experimental design (Papers I, II, III and IV)

The layout of the experiments is shown in Fig. 2. A completely randomized design was used in Paper I for the browsing height reached by each animal species, the flora composition and density of browse plants in each pasture type, and number of species identified by different types of farmer. This experimental design was also used in Paper III for voluntary feed intake and the digestibility of nutrients, and in Paper IV for feed intake, weight gain, carcass components and parasite egg counts.

A factorial design with two factors (animal species, season) was applied in Paper I for the study of grazing behaviour and browse species preference, in Paper II (pasture type, height class) for the density of browse species per height class and in Paper III (browse species, accessibility to animal) for the chemical composition of browse species studied. A factorial design with three factors (browse species, height class, period) was used in Paper II for edible biomass production.

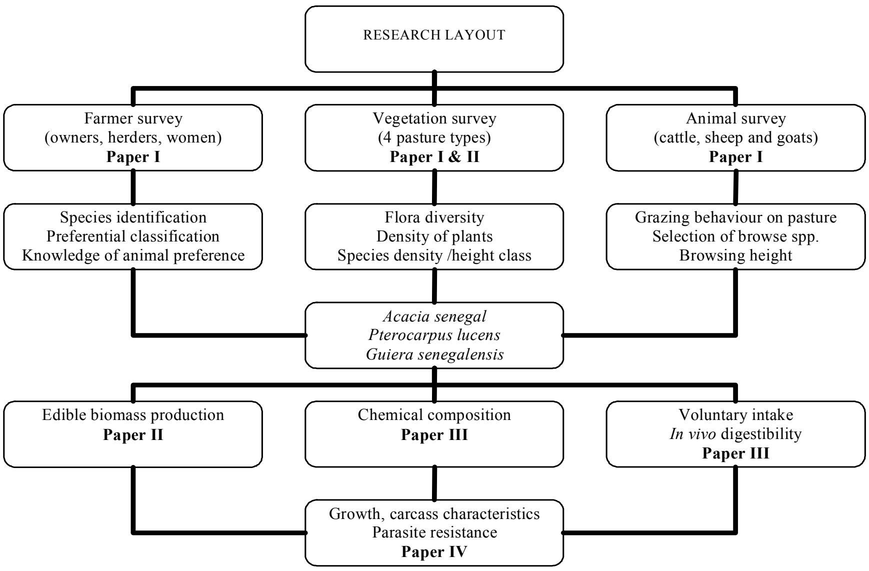

Fig. 2. Research layout

Experimental procedures

Animal behaviour, browsing height and indigenous knowledge of browse species (Paper I)

A sample of 70 farmers (herders, livestock owners and women) was selected randomly and interviewed for identification of the browse species which were represented in their area. A classification was made for the 10 most important species, according to their preference, with respect to the production and the quality of the browse species. The knowledge of browse preference by cattle, sheep and goats was recorded, as well as other utilisation of browse species and the behaviour of the plants under exploitation (species well adapted and species threatened).

The grazing behaviour and browse species preference of animals were studied by following a herd of cattle and flocks of sheep and goats on pasture during three seasons: rainy season, June–September, post rainy season, October–January, and dry season, February–May. For each animal species two mature lactating females were randomly selected on each observation day and followed on pasture during three consecutive whole days per month; their activities, grazing, browsing (fresh leaves, dried fallen leaves, flower, fruits/pods), walking without feeding, ruminating, drinking, resting and other activities, were recorded by one observer per animal every 15 min. When browsing, the species selected were recorded and the height reached by each animal species was identified and measured using a tape meter.

Vegetation inventory and browse biomass production

Different pasture types in the study area were identified after a photointerpretation of available aerial photographs of the zone from 1981 (Appendix A). Five pasture types were distinguished comprising cultivated areas (not investigated), shrubby steppe, sparse woody steppe, lowland pasture (valleys of temporary rivers and flooded basins) and tiger bush. A woody flora inventory was made in three random locations of 1 ha in each pasture type to determine the density of plants and number of species on pasture. All individual trees and shrubs for all species found were counted according to their height and were divided into five classes: [<1m], [1 – 3m], [3 – 5m], [5 – 7m] and [>7m] (Papers I and II).

In Paper II, *Acacia senegal* (L.) Willd, *Guiera senegalensis* J.F. Gmel and *Pterocarpus lucens* Lepr. Ex Guill & Perrott, three species commonly browsed in the study area as identified in Paper I, were investigated. Each species was selected on the pasture type where it is abundant: *A. senegal* was selected in sparse woody steppe, *G. senegalensis* in lowland pasture and *P. lucens* in tiger bush. The phenological phases were assessed using four individual plants per height class, giving 16 individuals of *A. senegal*, 16 of *G. senegalensis* and 20 of *P. lucens,* since no trees were found in the highest class of the first two species. The phenology of all the individuals selected was determined by scoring of the development of leaf, flower and fruit every second week, from June 2003 to March 2004.

Total and accessible edible biomass production was evaluated in different sets of plants from the same species, at the optimum stage of vegetation in September, during two consecutive years, 2004 and 2005. Sixteen individuals of *A. senegal* and *G. senegalensis* and 20 of *P. lucens* from different height classes (as described previously) were protected from browsing in the dry season by wire enclosure. The edible biomass accessible to sheep (0.87 m), to cattle (1.47 m) and to goats (1.65 m) as determined in Paper I, was harvested manually (leaves, fruits and small branches less than 1 cm diameter) up to the mean height reached by the different animal species, starting from the lower height. The edible biomass out of reach of animals was also evaluated by cutting leafy branches and harvesting the browse components to determine total edible biomass. The edible biomass collected was weighed and air dried and samples were taken for dry matter (DM) determination. Before harvesting, the dendrometric parameters, trunk diameter, diameter of the crown and total height of each individual, were measured to determine their correlations with the browse production. The potential browse production in the pastures, with regards to the species studied, was estimated by multiplying the edible biomass production per species by their relative proportion (number of plants/ha and according to height class) in the pasture.

Nutritive value of browse species and growth performance of goats

Chemical composition of edible biomass and experimental feeds

In Paper 3 the chemical composition of edible biomass collected from the three browse species (Paper II) was determined according to the accessibility to animal species. The samples from the same height class (4 individuals) were pooled according to the part accessible to different animal species and also the inaccessible part, for which samples of fruits/pods were also included. For plants <1 m, which were accessible to all animal species, three samples per browse species were collected. In total, 15 samples of *A. senegal* and *G. senegalensis* and 17 of *P. lucens* were analysed.

For the experimental feeds, the leaves were collected in the area in August-September by farmers and sun dried. The dried pods of both species were collected from the trees in January. All forages were stored in polystyrene bags. The hay of *Schoenefeldia gracilis*, an annual grass dominant in the area, was harvested at the end of the rainy season, during September-October from natural pasture around the station, air-dried and stored in the shade. The millet bran was purchased from the farmers, and cottonseed cake produced by the cotton processing factory, was bought from local traders.

Samples of feeds offered and refused were taken on a weekly basis for the voluntary intake trial and pooled per month for the growth experiment. For the digestibility experiment, samples for each animal were mixed for the week of measurement.

Animals and management

The voluntary feed intake of the leaves of *A. senegal, G. senegalensis* and *P. lucens,* and the pods of *A. senegal* and *P. lucens* was determined using mature goats of the Sahel type, with a mean weight and SD of 23.3 (3.8) kg. The pods were fed alone, while the leaves were fed with low amounts (maximum 30% of DM intake) of hay of *Schoenefeldia gracilis*, since the leaves should not be fed alone due to possible anti-nutritional substances. Six treatments, consisting of the five types of forage (3 foliages and 2 pods) and one control group receiving only hay were allocated randomly to six groups of 8 animals in each group. The experiment started with an adaptation period of two weeks, followed by a measurement period of voluntary intake for one week.

The leaves and the pods of *A. senegal* and *P. lucens* were further used in the digestibility trial, conducted with 5 animals randomly selected in each group with the same feed as in the intake trial. The hay was added to the leaves at a level of about 20% (based on observations in the intake trial) and was also fed as a single diet, to allow the estimation of the digestibility of the leaves by difference. The goats were randomly allocated to the digestibility cages and adapted to the cages for one week, followed by one week of measurements. The animals wore faeces collection bags to prevent losses of faeces, then faeces were removed every morning, mixed on a weekly basis and representative samples, as well as feed samples, were taken for chemical analysis.

In Paper IV, the effect of feeding leaves and pods of *Pterocarpus lucens*, and the pods of *Acacia senegal*, on growth performance was evaluated using growing male goats of the Sahelian type, 10 to 12 months old and weighing 15.6 (SD=2.0) kg. Thirty-two animals were allocated randomly to four treatments consisting of the three browse forages and one positive control. The control group was fed cottonseed cake as a protein source at a level of 200 g/day. All groups were supplemented with 200 g millet bran per day. The hay was fed at a level of 200 g/day for the groups given browse fodders, while the control group had *ad libitum* access to hay. They were adapted for 15 days to the feeds and house conditions before the measurements started, and the experiment lasted 10 weeks.

When feeding *ad libitum* (intake trial in Paper III and Paper IV), the animals were offered 4% of body weight (BW) to begin with, and then the amount offered was increased to 130% of the amount consumed the previous day. In the digestibility trial, the amount of feed offered was the same for all the animals in the groups (750 g of feed /day). In all trials the feeds were offered 2 times a day, at 8 h in the morning and at 17 h in the afternoon, and the refusals were removed and weighed each time. The voluntary feed intake was determined by difference between the feeds offered and the refusals.

The experimental animals (Papers III and IV) were vaccinated against PPR and pasteurellosis and were given a prophylactic treatment against gastrointestinal parasites using albendazole or oxfendazole tablets before the commencement of the experiment. The animals had free access to water and a mineral block (63% NaCl, 9% Ca, 11% P, 1.26% Mg, 1% Fe, 0.15% Cu, 0.12% Mn, 0.05% I, 0.01% Co) and were weighed at the beginning and the end of the experiment (Paper III) or every two weeks (Paper IV). They were kept in a sheep house and were tied inside the pens to allow individual feeding and watering (Paper III - intake trial and Paper IV).

The recording of gastrointestinal parasites (Paper IV) was made by recording faecal egg counts of all animals on four occasions during the experiment: 15 days after deworming and every fourth week and at the end of the experiment. A modified technique of the McMaster (MAFF, 1986) method was used to identify eggs of nematodes, cestodes and oocystes of coccidia.

At the end of the growth experiment, 5 animals in each group were selected randomly, fasted overnight and slaughtered for determination of carcass weight, dressing percentage, primal cuts and organ weight.

Chemical analysis

The samples of biomass and feeds used in the experiments (leaves and pods of *A. senegal* and *P. lucens*, leaves of *G. senegalensis*, hay of *S. gracilis*, millet bran and cottonseed cake) were ground in a Wiley mill through a 1mm screen and were analysed for DM, CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and ash. DM, CP, ADF and ash were analysed according to the standard methods of AOAC (1990). NDF and ADL were determined by the methods of Van Soest *et al.* (1991).

Statistical analysis

The data from Papers I, III and IV were analysed using the General Linear Model (GLM) procedures of Minitab Programme Version 14 (Minitab, 2002). Means, which showed significant differences at the probability level of $P<0.05$ were compared using Tukey's pairwise comparison procedures. The data for faecal egg count (FEC) (Paper IV) were subjected to logarithm transformation because of large variation in numbers before analysis to approximate normal distribution.

For species classification by farmers, the score obtained for each species was reported. Species not classified were given a value of 0 and the means were calculated using descriptive statistics in the Minitab programme. The preferences of browse species by cattle, sheep and goats were given in percentage, as number of people mentioning this species in percent of the total number of people interviewed.

The data for density per height class and edible biomass production (Paper II), which contained missing data, were analysed using the GLM procedure of SAS software (SAS, 1998) after log transformation. The treatment means which showed significant differences at the probability level of $P<0.05$ were compared using Tukey-Kramers's pairwise comparison procedures. A regression analysis was performed to test the relationship between the dendrometric parameters of trees and the biomass production. Linear regression, polynomial regressions and $\log_{10}$ transformation were tested and the significant regressions showing the highest regression coefficients were retained.

Summary of results

Behaviour of goats, sheep and cattle and their selection of browse species on natural pasture in a Sahelian area (Paper I)

Farmers had good knowledge of the browse species present in the area. A total of 56 species was mentioned and the highest number was mentioned by herders (34 species). The preferential classification showed 8 species (*P. lucens*, *Adansonia digitata*, *A. senegal*, *Grewia bicolor*, *A. seyal*, *Balanites aegyptiaca*, *G. senegalensis* and *Ziziphus mauritiana*) as being the most valuable because of their availability in the area, their nutritive value and the multiple ways of utilisation of these species e.g. edible plants (fruits or leaves), plants used for medicinal and veterinary purposes or as building material. A wide range of species was mentioned as browsed by goats, while only four species were recorded by at least 50% of respondents as being browsed by cattle. Sheep were shown to feed on the same species as cattle, with some thorny species in addition, such as *A. seyal* and *Balanites aegyptiaca*. However, the farmers' knowledge of the preference of browse species by different animal species was relative, as some divergence existed compared to the result from the behaviour study.

The flora inventory of the four pastures showed an important diversity of woody species, and 42 species were recorded from 17 families and 28 genuses. The most important species found were *A. senegal*, *Boscia senegalensis*, *Combretum aculeatum*, *C. micranthum*, *G. senegalensis*, *Grewia flavescens* and *P. lucens*, with different contributions according to pasture type: 91% of *P. lucens* and 84% of *G. flavescens* were found in tiger bush pasture, 81% of *G. senegalensis*, 53% of *C. aculeatum* and 41% of *B. aegyptiaca* in lowland pasture and 67% of *A. senegal* in sparse woody steppe.

The behaviour of the animals followed showed a decline in the feeding activities of all animal species from rainy to dry season, while resting and ruminating activities were increasing at the same time. This decline was more important for cattle (72% to 39%) that relied on herbaceous species for feeding. The grazing time of cattle was similar to that of sheep in all seasons, but significantly different from goats. Sheep and goats made a shift in their feeding activities from grazing to browsing when herbaceous biomass decreased. Cattle browsed (leaves and litter) during all the study period for around 5% of time spent on pasture. Sheep and goats showed a peak in browsing activity in the dry season (28% and 52%, respectively). During the whole observation period, cattle browsed 10 species, with *G. senegalensis* mostly selected with 59%, 54% and 84% of browsing time respectively in rainy, post-rainy and dry season. *G. senegalensis, C. micranthum* and *B. aegyptiaca* were the most important species browsed by sheep among the 18 browse species selected. Goats avoided only 12 species of the total number of species recorded. *A. senegal, B. aegyptiaca* and *P. lucens* were the most preferred. The mean height reached by goats when browsing was higher (1.65 m) than that of cattle (1.47 m) and sheep (0.87 m).

Edible biomass production from some important browse species in the Sahelian zone of West Africa (Paper II)

The woody flora inventory showed a higher number of species (35) in lowland pasture, while shrubby steppe had the lowest (15) number. The density of plants was highest in tiger bush and lowest in shrubby steppe, 1602 and 222 plants/ha, respectively. Most of the woody species found were browsed (more than 80% of species recorded) in all pasture types.

A total of 65 plants/ha of *A. senegal* was recorded in sparse woody steppe, and most of the plants (68%) were smaller than 1 m. *A. senegal* is also represented in tiger bush but rare in lowland pasture. *G. senegalensis* is a species dominant in lowland pasture in the study area and the individuals of height class 2 represented the majority (77%), while individuals taller than 5 m (class 4) were seldom found. In tiger bush pasture, all the classes of height of *P. lucens* were found, and the individual plants <1m height constituted 73% of this species. Overall, *A. senegal* represented 13% of the woody plants in sparse woody steppe, *G. senegalensis* 45% in lowland, and *P. lucens* 22% in tiger bush.

The phenology study showed that all three species started foliation immediately after the first rain in June. *A. senegal* lost leaves earlier than *G. senegalensis* and *P. lucens*. On average, the foliation phase lasted 6 to 7 months for *A. senegal*, 7 to 8 months for *P. lucens* and 8 to 9 months for *G. senegalensis*. *A. senegal* and *P. lucens* flowered before *G. senegalensis*, for which flowers appeared in full foliation phase in September. The fruiting lasted on average 6 to 7 months for all species.

The accessible edible biomass varied according to the animal species, the plant species and the height of the plants. For sheep the accessible biomass decreased significantly from class 1 for all species, while the part available to cattle and goats showed a peak in class 3 of *A. senegal* and *G. senegalensis* and class 4 of *P. lucens*. Goats browsing at higher height had more edible biomass at their disposal. *P. lucens* was the most productive species, with a maximum of total biomass production recorded with individuals taller than 7 m, 26 kg, followed by *A. senegal* (11.6 kg mean of individuals from 5-7 m height). The amount of accessible edible biomass in percent of total edible biomass decreased with increasing plant height for all three species (excepted plants <1 m). *G. senegalensis* showed the highest proportion, with 47.4%, 17.5% and 7.3%, respectively, for class 2, 3 and 4, while the accessible edible biomass of *P. lucens* was less than 5% of total edible biomass in all height classes. For *A. senegal* the corresponding values of edible biomass accessible to goats were 14.3%, 5.3% and 0.5%, respectively.

The accessible edible biomass was weakly correlated with tree parameters. The regression coefficients varied with animal species and plant species from R^2=0.36 to R^2=0.73 with crown diameter, R^2=0.31 to R^2=0.71 with trunk diameter and R^2=0.37 to R^2=0.62 with height. Crown diameter was the best parameter to predict total edible biomass for all three species, R^2=0.96, 0.90, 0.98 for *A. senegal*, *G. senegalensis* and *P. lucens*, respectively, in log transformation of dependent and independent variables.

Edible biomass production in different pastures with regard to the species studied showed 972 kg DM/ha in tiger bush pasture, 525 kg DM/ha in lowland pasture and 225 kg DM/ha in sparse woody steppe. *A. senegal* contributed 142 kg DM/ha, *G. senegalensis* 508.4 kg DM/ha and *P. lucens* 849.2 kg DM/ha, respectively, in sparse woody steppe, lowland and tiger bush pastures.

Nutritive value and voluntary feed intake by goats of three browse fodder species in the Sahelian zone of West Africa (Paper III)

The chemical composition of the biomass varied significantly between the three browse species. *A. senegal* and *P. lucens* had similar DM content, higher than that of *G. senegalensis*. The crude protein (CP) content was 114, 157 and 217 g/kg DM for *G. senegalensis*, *P. lucens* and *A. senegal*, respectively. The concentration of fiber (NDF, ADF, and ADL) was significantly higher in *G. senegalensis* (604, 409 and 240 g/kg DM, respectively), than in the two other species, and the fiber fraction was significantly higher in *P. lucens* than in *A. senegal*. There were no significant differences in chemical composition according to the part accessible to sheep, cattle and goats. However, individual plants <1 m that were accessible to all animals species had slightly higher concentration of CP in *A. senegal* (235 g/kg DM) and in *G. senegalensis* (146 g/kg DM).

For the feeds used in the intake and digestibility experiment, the hay had low CP (31 g/kg DM), and high ADF and NDF contents, while the browse fodders were high in CP (105 to 170 g/kg DM) and in ADL (164 to 234 g/kg DM except the leaves of *A. senegal*) contents.

The voluntary feed intake was higher in animals fed *P. lucens* leaves (864 g) and lower for the *G. senegalensis* diet (397 g). The lowest daily CP intake was observed with the hay offered as a sole feed (17 g). *P. lucens* leaves (129 g) and the *A. senegal* leaves diet (108 g) provided similar CP intakes. The DM intakes in g/kg BW and in g/kg $W^{0.75}$ were similar for the *A. senegal* and *P. lucens* diets, significantly higher than for the *G. senegalensis* and hay diets. *A. senegal* pods were significantly more consumed (1033 g) than *P. lucens* pods (691 g), and the intake of CP from *A. senegal* pods (189 g) was almost double compared to that of *P. lucens* pods (96 g). The DM intake expressed in g/kg BW or g/kg $W^{0.75}$ was significantly higher for the diet with *A. senegal* pods.

The apparent digestibility of CP in the browse leaves diets was 0.63 g and 0.64 for *A. senegal* and *P. lucens* leaves, respectively, higher than for the hay, which showed higher digestibility of NDF (0.73). ADF digestibility was higher for *A. senegal* leaves (0.62) than for *P. lucens* leaves and hay (0.55). *A. senegal* pods had higher digestibility for all nutrients than *P. lucens* pods. The DM digestibility was 0.54 and 0.63 and the CP digestibility 0.64 and 0.73 for *P. lucens* and *A. senegal* pods, respectively.

Growth and carcass characteristics of male Sahelian goats fed leaves or pods of *Pterocarpus lucens* and *Acacia senegal* (Paper IV)

The highest DM intake was observed for goats fed *A. senegal* pods, which provided higher CP to goat. The diet with *P. lucens* leaves was more consumed than the control diet, but similar CP intakes was observed with these diets. Goats fed the *P. lucens* pods diet had the lowest CP intake. The feed intake expressed in percent of BW and per kg $W^{0.75}$ was higher for *A. senegal* pods and *P. lucens* leaves (51 g/kg BW, 106 g/kg $W^{0.75}$ and 49 g/kg BW, 98 g/kg $W^{0.75}$, respectively).

The goats fed *P. lucens* pods showed significantly lower daily weight gain (24 g), while the goats fed the other three diets had similar average daily gain (ADG) (51 g to 56 g). The feed conversion ratio (FCR) was low for the control diet (13.5 kg DM/kg live weight gain (LWG)), comparable to the diets with *A. senegal* and *P. lucens* leaves, but significantly different from the diet with *P. lucens* pods (37.8 kg DM/kg LWG).

Goats fed the three diets (*A. senegal* pods, *P. lucens* leaves and control) showed higher carcass weight, higher dressing percentage and higher weight for the primal cuts. The neck, the ribs and the loin were significantly heavier for animals offered *A. senegal* pods, while the weight of shoulder, rack and leg did not differ according to the diet. In proportion of carcass weight, a difference was observed only for the loin, and animals offered the control diet (8.71%) and *A. senegal* pods (8.37%) had the highest proportion of loin. The weight of empty digestive tract, head and feet, lung-trachea-diaphragm, heart, spleen and kidney were comparable for goats receiving the four diets. The animals offered *P. lucens* pods showed the lowest weight for all the non-carcass components. In proportion of EBW, the head and legs, skin, omental fat and kidney fat varied significantly between diets. The proportion of head and legs was higher in goats fed *P. lucens* pods, while the goats offered the other browse diets had a higher proportion of omental and kidney fat.

The parasite control showed occurrence of oocysts of coccidians in all animals, with similar fluctuation in oocyst count indicating no significant effect of diet on FEC. However the e.p.g values were low at the initial stage for all animals and higher at the end of the experiment.

General discussion

Indigenous knowledge of browse species

Several studies have shown that surveys of farmers generate more important information on the diversity of plants species in their area than field observations (Bayer, 1990; Okoli *et al.*, 2003). Field inventories require methodologies based on the investigation of sampled areas. The data are then collected with some statistically acceptable margin of error. In this study (Paper I), some species cited by farmers were therefore found in the pasture during the behaviour study, but were relatively scarce in the area. These species can, however, be of importance for the respondents. The knowledge of the diversity of species reflected their importance in the life of the farmers. Various uses of browse plants were mentioned and the preferential classification of species took into account these different aspects. For instance, a specie such as *P. lucens*, which has the highest score, was shown as having a high nutritive value and was browsed by all ruminants, but it was also the first species used as building material. The various uses of browse plants as indicators of the preference of farmers was reported by Briggs *et al.* (1999) in the eastern desert of Egypt and Mtengeti & Mhelela (2006) screening the potential indigenous browse species in central semi-arid Tanzania.

The stratification of respondents showed that herders are familiar with a wide range of species compared to livestock owners and women, and this makes them the key informants for this type of investigation. This result was in agreement with that of Komwihangilo *et al.* (2001), who found that most of the male respondents were able to identify 10 to 20 species, while the majority of female respondents identified 5 to 10 species

When comparing the availability of species (density on pasture) with the percentage of farmers mentioning them, it appears that some species that were well known and cited by all respondents were not abundant in the area, and conversely other more abundant species were not cited. *Ziziphus mauritiana* and *Adansonia digitata* were cited by all respondents and are of considerable importance for farmers but were scarce in the area. The leaves of *Z. mauritiana* are well browsed by sheep and goats, and the fruits are edible for humans, and also sold in the local market or processed to extract powder that is sold in the cities. *A. digitata* is well known by Sahelian people for its role in human nutrition and for its cultural importance. All parts of tree are useful: the leaves are shown to have a high content of iron and calcium (Glew *et al.*, 1997) and are an excellent vegetable used fresh or dry in the form of powder, especially in the dry season where it constitutes the main component of the sauce in the diet. The fruits are edible, rich in vitamin C and used in many recipes. The tree also provides fibre from the bark and the wood, that is spongy and high in moisture, can be eaten by cattle when the tree falls down. With regard to the palatability of browse, the findings from the survey with *A. senegal* and *P. lucens* are consistent with the result from the voluntary intake (Paper III), and agree with the observation of Mtengeti & Mhelela (2006) who found that the preference of local goats was close to the ranking of browse by the livestock keepers. However, some divergence was observed concerning the similarity of cattle and sheep for browse species preference. This could be related to the interest in browse shown by sheep in the dry season when herbaceous plants were scarce.

Feeding behaviour of cattle, sheep and goats

Feeding behaviour refers to any action of an animal that is directed toward the procurement of nutrients. The variety of means of procuring feed reflects the diversity of food used and the type of animal (Encyclopaedia Britannica). Cattle, sheep and goats have different feeding behaviour on pasture due to the inherent characteristics of each species. Cattle and sheep are known as grazers, with a feeding preference for the herbaceous cover, while goats are browsers and prefer eating the leaves and fruits/pods of trees and shrubs. The behaviour on pasture will then reflect these preferences, but the availability of feeds and the climatic conditions will also have some influence. The results showed that the activities of the animals varied according to species and season. Overall, the feeding activity occupied a large amount of time of all animals. This result agrees with Schlecht *et al.* (2006), who noted that the three species spent on average about 60% of the daily grazing time feeding across seasons. However, this activity decreased for all animal species from rainy to dry season, in proportion to the decline in fodder availability. A subsequent study on the dynamic of the herbaceous cover showed a disappearance rate of 76 to 83% in January, depending on the type of pasture and the degree of exploitation during the rainy season (Sanon *et al.*, 2005). The decrease in feeding activities of ruminants in the dry season has also been reported by Dicko & Sikena (1992) in the Sahelian zone of Mali, and Ngwa *et al.* (2000) in the Sahelian zone of Cameroon. This demonstrates the variability of feed resources in the area and its effect as a limiting factor in livestock production.

As feed resources decrease, all animals increased the time allocated to resting and ruminating, especially when the temperature was high, reaching 45° in the shade. Hence, temperature affects the total grazing time of animal, especially for sheep and cattle. Sheep not finding any shade were seen searching for shade, with their head under the flank of another sheep. Resting was important for cattle in dry season (about 23% of the time on pasture), probably to avoid heat stress. In this period the animals mostly grazed in the morning from 8.30 to 12.00 and in the evening from 16.00 to 18.00, sometimes until dark and at night for cattle. These two major feeding periods generally observed have been targeted for observations on diet selection by some authors (Guerin *et al.*, 1988). Night grazing is shown to improve the performance of animals in hot dry seasons (Ayantunde *et al.*, 1999). In this study night grazing was not investigated, due to the difficulty of making observations in the dark on open pasture. Walking was an important activity of goats after feeding and confirmed the mobility of goats when searching for feed. This ability allows them to cover large areas and increases their chance of finding preferred species, which influences the diet composition. However, the energy cost of this locomotion represents a substantial part of the energy expenditure of goats on rangeland (Lachica *et al.*, 1996).

The amount of forage available to animals varied according to the season, but is also influenced by the land use patterns. The common practice in the area used by herders and goat keepers consisted of moving cattle and goats from the village in the rainy season and to construct temporary shelters in pastures apart from the cultivated areas. This practice reduces crop damage and allows animals to maximize the use of the abundant forage resources available in this period, as they can be more selective. After the crops have been harvested in the post-rainy season, crop residues constituted the main component of diet, especially for cattle and sheep. Management is particularly important during the late dry season, when the herders have to direct the animals to areas with residual forages, and to shake trees or tap on branches to make fruits/pods fall down and be available to the animals. Schlecht *et al.* (2006) found that forage mass encountered along the itineraries of the animals was higher than the average amount of forage available in the area.

The decrease in both quality and quantity of feed affects the body condition of all animals, but the extent depend on the ability of each animal species to cope with this situation. Goats, with their habits of browsing, were able to collect more nutrients from the environment. They are also shown to adapt much faster than cattle or sheep to seasonal and geographic variations, which has resulted in them being termed as mixed feeding 'opportunists' (Lu, 1988). The lack of any significant difference in grazing time between cattle and sheep confirms their characteristic as grazers. However, sheep showed interest in browsing especially on fallen leaves and pods when the herbaceous cover became scarce, hence they are intermediate grazers as also reported elsewhere (Guerin *et al.*, 1988; Dicko & Sikena, 1992; Ngwa *et al.*, 2000). Cattle were browsing less (4% of the time) in the post rainy season, when most time was spent on crop residues, then it increased to 6.6% in the dry season. The time spent browsing in the dry season was somewhat lower than reported by Ickowicz & Mbaye (2001), who noted a high percentage of browse in cattle diets (29%) in the late dry season when other feed resources decreased, and the lowest proportion in December when crop residues were available. This difference could be explained by the low availability of preferred browse plants in the grazing itinerary of the animals.

Feed selection involves two interrelated mechanisms, that are the learning process, allowing the animal to select nutritious diets and avoid toxins, and the heritable aspects, as natural selection favours animals that are good foragers (Launchbough *et al.*, 1999). Hence, the success of grazing and browsing is based on how well the animals find, consume and assimilate nutritional resources. Many authors have reported the role of post-ingestive effects on feed selection (Squires, 1975; Baumont *et al.*, 2000; Duncan and Young, 2002). Provenza *et al.* (1992) highlighted affective and cognitive systems through which animals learn about feeds. The affective system seems to integrate the taste of food with post-ingestive feedback. In the cognitive system, animals use odour and sight to select or avoid feed, depending on post-ingestive feedback.

Goats are shown to be more tolerant of bitter taste of plants than cattle and sheep and this may have set goats apart from sheep and cattle in feed competition, particularly in maximizing total grazing capacity in some areas and in biological control of weeds (Lu, 1988). They are shown to have a well developed sense of smell and a new food is investigated by sniffing it. In addition goats have particular characteristics, such as the well-developed use of lips and tongue, allowing them to harvest forages from the shortest grasses and forbs to the thorniest shrubs, and the ability to stand on the hind legs, and even climb trees when the branch structures permit it, thus maximizing the available tree stratum within a given area. A mean browsing height of 1.65 m was recorded, with a maximum of 2.10 m in this study, against on average 1.47 m for cattle and 0.87 m for sheep. The preference of high level feeding related to eye-level feeding is shown to be beneficial for the reduction of the risk of infection by parasite eggs found on the surface vegetation (Lu, 1988). The most important sense involved in forage preference in sheep has been shown to be taste, with sweet and sour plants being preferred and bitter plants being more generally rejected (Krueger *et al.*, 1974). For cattle, the sense of touch seems to be more important in determining which herbage is rejected or preferred. In addition, the prehension act of cattle, which consists of using their tongues to pull forage into their mouths before biting it off, makes them less able to consume short forage plants and disfavours them in the presence of good quality forages that are rare and difficult to pick (Dumont, 1996).

The above descriptions allow understanding of the selection of feed, especially of browse plants by different animal species. Across all seasons cattle browsed 10 species, with *G. senegalensis* more frequently selected (green and dry leaves). This species, from the Combretaceae family, was abundant in the lowland pasture and available for a longer time, as the plant produces new leaves after cutting even in the dry season and herders know how to exploit this fact. Guerin *et al.* (1988) noted that cattle tend to prefer plants from the Combretaceae family. This is probably due to the size of the leaves and/or lack of thorns. The increase in browsing time of sheep was related to the increase in the number of species browsed, in relation with the availability of pods of some species such as *Bauhinia rufescens* or young leaves of *Balanites aegyptiaca*. The latter species contributed substantially to the diet of all animals in the dry season, due to its early foliation and flowering, which occur in the dry season, then attract the animals (Akpo, 1997). For goats, almost all browse plants in the area were eaten to different degrees, confirming the habit of a varied diet as stressed by Haenlein *et al.* (1992).

Availability of browse fodder

Availability in space

The relative density of browse plants associated with flora diversity in different pasture types reflects the availability of browse in the area. The inventory of woody flora showed a difference in woody flora diversity according to pasture type. These differences could be explained by varied ecological conditions such as edaphic factors, gradient of humidity, and soil depth. However, human activities could also have some influence, and the physiognomy of shrubby steppe could be the result of cultivation and selective cutting of trees, hence the specific poverty of woody flora and low density of plants. The density observed in sparse woody steppe was higher than the overall density (298 plants/ha) obtained by Couteron & Kokou (1997) in the semi-arid savanna of Burkina Faso. Higher woody density was observed in tiger bush (1602 plants/ha). This vegetation type has a specific characteristic marked by the dominance of woody plants and a pattern of alternating bare soil strips, acting as impluvium with linear and dense thickets following the contours, and perpendicular to the direction of the gentle slope (Hiernaux & Gerard, 1999). The alternating patterns seem to arise from the interplay of hydrological, ecological, and erosional phenomena. However, the concentration of woody plants created favourable conditions by a combination of plant litter, root macropores, and increased surface roughness, and hence inflitration into the soil around the base of these plants is enhanced. The total density obtained is high compared to the mean value (901 plants/ha) recorded by Hiernaux & Gerard (1999) in tiger bush on Macina sites in Mali, but low compared to the 1721 plants/ha reported by the same authors in the thicket part. The flora diversity reported by these authors (8 to 9 sp) was far below the value in the present study (25 sp).

With regard to the height stratification, individuals of <1m were dominant for the three species studied and overall woody plants in general. The number of plant decrease as the height increase, which can be described as normal regeneration status of woody plants settlement (Poorter *et al.*, 1996). The importance of individuals in height class 1 to 3 m of *G. senegalensis* can be explained by the inherent characteristic of the species that is a shrub seldom exceeding 5 m, but also the frequent cut to which it is subjected to, and/or may indicate actual low regeneration of species. The good regeneration of *P. lucens* is in agreement with the finding of Couteron *et al.* (1992), but is in contrast with the theory about the regression of the species in the Sahel zone, as stressed by some authors (Bortoli, 1983). The topography and relatively dry condition of the site may be the cause. Smaller individuals are frequently browsed by animals and could not express their growth potential well, hence most individuals were stunted, making their chance to avoid browsing hypothetical. Other species affected by this phenomenon are *Balanites aegyptiaca, A. senegal* and *Maerua crassifolia*, in agreement with the observations made by Zoungrana (1991) in the north Sahelian zone. Couteron *et al.* (1992) also found that almost all *P. lucens* of <50 cm (93%) were subjected to mutilation. However, this was not shown to induce mortality in the short perspective, but determined the loss of apical dominance and delayed growth.

Availability in time

Phenology is the study of the times of recurring natural phenomena. The word is derived from the Greek Phainomai - to appear, come into view, and indicates that phenology has been principally concerned with the dates of first occurrence of natural events in their annual cycle (Free Encyclopedia). According to le Floc'h (1969) plant phenology refers to the study of the relations between the morphological and physiological periodicities of the plants and those of active ecological variables, especially climate. Thus the timing of flushing and shedding of the leaves, the flowering and the fruiting are considered, and give an insight into the availability of forage from trees and shrubs during the different seasons. However, the phenology of plants is variable, depending primarily on the intrinsic factors of the species and the climatic conditions of the area (Poupon, 1979; Piot *et al.*, 1980; Grouzis & Sicot, 1980).

The species studied flushed as soon as the rainy season started, but the shedding of the leaves was shorter for *A. senegal* than for *P. lucens* and *G. senegalensis*, and allowed them to be classified into two groups: deciduous and semi-deciduous species. Deciduous species lose their leaves, while semi-deciduous species have the ability to use water reservoirs in deep layers or close to a river system and a strategy to reduce water loss in the dry season by the scleromorphic feature of their leaves (de Bie *et al.*, 1998). Borchert (1994) stated that the seasonal variations in tree water status are the principal determinant of both phenology and distribution of tree species in tropical dry forest. Tree water status is determined by the availability of subsoil water and a variety of biotic factors, such as structure and life span of leaves, time of leaf shedding, wood density and capacity for stem water storage, and depth and density of the root systems.

The availability of subsoil moisture is shown to vary widely depending on the site, and determines the degree of dessication observed in trees with low stem water storage. *A. senegal* was selected in sparse woody steppe, a site with loamy sands soil and apparently well drained, while *G. senegalensis* was selected in lowland with gley loamy sandy soil and *P. lucens* in tiger bush with mostly loamy thin soil. The characteristics of these sites could influence the difference in phenology among the three species. If different sites had been considered for each species, one could have had an insight into site effect. The species were, however, selected in the site where they were dominant, which could indicate the area of predilection i.e. the favourable ecological niche. For *A. Senegal*, which showed early shedding of leaves, the root system could be the cause, as noted by Gaafar *et al.* (2006), who showed that the concentration of lateral and fine roots of *A. senegal* was maximal in the topsoil (0-75 cm), even if the trees was also able to partially utilized water from below 75 cm soil depth, especially during the dry season when the water in the topsoil was depleted. *G. senegalensis* has been shown to have deep root system which is extensive enabling the plant to access soil water several meters away both horizontally and vertically (Breman & Kessler, 1995; Seghieri & Simier, 2002). In addition, Seghieri *et al.* (2005) reported *G. senegalensis* to be tolerant to drought stress, due to its ability to open stomata at low water potential. This combination of strategies in *G. senegalensis* has been shown to increase the period of photosynthetic activity during the dry season and could contribute to the maintenance of this shrub as a dominant species in the Sahelian landscape (Seghieri *et al.*, 2005). Similar explanation with regard to root system could be valid for *P. lucens*. In tiger bush, where it was selected, established trees and shrubs have been shown to exploit soil moisture reserves laterally or by sending roots to deeper, wetter soils.

The phenology of *A. senegal* was somewhat different from that reported by Ickowicz *et al.* (2005) and Hiernaux *et al.* (1994). The difference can be explained by different site conditions and/or rainfall, which determine soil water availability, or maybe the relative air humidity as revealed by Do *et al.* (2005), who noted that interannual variation of canopy phenology is mainly tuned to atmospheric conditions. Indeed some sporadic leaf flush was observed in March 2005, a period not considered in the present study, and can be explained by this phenomenon, as no rain had fallen during this period. Such behaviour is shown to maximize the duration of high photosynthetic activity below a threshold of evaporative demand. This phenological variable in browse plants is fundamental in Sahelian rangeland, as it determines the availability of browse fodder to animals in all season.

Browse production and accessibility to animals

Studies on browse production and browse accessible to animals are scarce in the Sahel area, limiting the comparison of the results with other data, especially for the species investigated. The evaluation of browse production is a complex task, especially for indigenous species in natural rangelands, marked by the diversity of species and the great heterogeneity in plant size. The present study focused on height stratification of the plants in order to assess the variability of production within species and the effect on accessibility to different animal species. The results showed significant variations in edible biomass production, depending on species related to the physiological characteristics of the plants. *P. lucens*, a small tree in general from 3 m up 15 m in the study area, was the most productive, while *G. senegalensis,* mostly a shrub of 2 to 4 m, showed lower total edible biomass production. The total biomass production of *A. senegal* individuals in height class 1 to 3 m (1423 g), is comparable the value of 1800 g obtained by Lamers *et al.* (1994) 5 years after planting. Lower values compared to the results of this study were obtained by Bille (1980) for the adult plants of the three species in the Sahelian zone of Senegal, Mali and Burkina Faso.

The accessible biomass varied according to the height of the plants in relation to the morphological characteristics, such crown shape and the structure of the branches. The density and size of the leaves and their distribution on the branches could also have considerable importance. Expressed in percentage of total edible biomass, the accessible production decreased for all species when the height class increased. Similar observations have been made by other authors (Walker, 1980; Ickowicz & Mbaye, 2001; Kalen & Bergquist, 2004). *G. senegalensis*, with its shorter height, showed a higher amount of biomass accessible at 1.65 m, varying from 7 to 47%, while the corresponding rates were 0.5 to 14% for *A. senegal* and less than 5% for *P. lucens* (all sizes taken into account). This variability in accessible production with height of plants outlines the importance of height stratification in estimating browse accessibility and suggests that the broad estimation of accessible browse production of 25% by Breman & de Ridder (1991) and 20% by Pellew (1980) could be an overestimation.

The potential of browse production with regard to species studied was high in tiger bush pasture and low in sparse woody steppe, while lowland was intermediate. The high productivity of tiger bush in terms of browse production was reported also by Hiernaux & Gerard (1999), who noted 689 to 2094 kg DM /ha, depending on the site. The results of the present study concern only three species which represented 29% of the browse plants in this pasture type, fall in the range obtained by these authors. This confirms the important role of tiger bush in dry season browsing. The value in lowland is high compared to the value (150 g/ha) reported by Piot *et al.* (1980) in the North Sahelian zone of Burkina Faso. The high variation in browse production in different pasture types is in agreement with the observation of Abule *et al.* (2007) in different rangeland sites in the middle Awash valley of Ethiopia (196 to 3311 kg/ha).

The constraints in browse biomass evaluation related to the time cost and tediousness of methods used has lead to the development of allometric relations for indirect estimation of the production. Most of the studies on the regression of biomass production of browse in the Sahel (Poupon, 1976; Cisse, 1980; Bille, 1980) reported the trunk diameter (or circumference) as the best predictor of edible biomass production, and is also easily measurable. The height is sometimes referred to, but rarely the crown. Cisse (1980) found a good correlation between the foliage biomass and the crown area of *P. lucens* (0.97, compared to 0.96 for trunk circumference and height). Bille (1980) expressed the logarithm of the edible biomass linearly as a function of the logarithm of stem circumference and proposed a mean equation (log edible biomass = 21og (diameter) + 1), that could constituted an acceptable approximation in the Sahel zone. This equation is close to the one obtained with *G. senegalensis* and trunk diameter, but different from *A. senegal* and *P. lucens*. In this study single species models were computed and can be applied within the range of the study limit, i.e. with the same site condition of these species, plants exempted from lopping and protected from current year browsing. Crown diameter appeared to be the best parameter to predict edible biomass production. Many other authors have stressed the reliability of crown measurements in estimating edible biomass production (Hughes *et al.*, 1987; Paton *et al.*, 2002; Northup *et al.*, 2005). The crown displays the leaves, which capture the radiant energy for photosynthesis, which provides for the renewal of the leaves. Thus, crown surface area is a useful index of growth and it is shown to be strongly correlated with the growth of the tree (Brack, 1999). This parameter can be also estimated through aerial photographs of appropriate scale, and complemented with field observations to identify different species. Moreover, the measurement of the crown is easy in the Sahelian area, where trees are generally sparse and the crowns seldom jointed. In this study no good correlations were found between tree parameters and accessible biomass. Such equations could have been interesting for direct estimation in the field. However, the knowledge of the accessible percentage makes this estimation possible taking into account different height classes of trees.

Chemical composition of browse

Proteins constitute a principal component of the animal body and are continuously needed in the feed for repair and synthetic processes, hence they are vital for animal maintenance, growth, and production (NAP, 1981). For this purpose the CP content of feed has been given special attention in feed evaluation. The high CP content of browse species is well documented and is one of the main distinctive characteristic of browse compared to mature grasses. Norton (1998) reported a range of CP contents from 12 to 30% for tropical tree legumes, and le Houerou (1980) found a mean of 12.5% in West African browses, with about 17% for legume species. Generally, the CP content in browse has been shown to be above the minimum level required for microbial activities in the rumen (8% CP according to Norton, 1998). The species in the Leguminosae family have a higher protein content compared to other species, although species in the Capparidaceae family have on average 25% more protein than legumes (Le Houerou, 1980). Le Houerou (1980) also noted that all browse species are able in all their phenological stages to meet the energy requirements of livestock at maintenance level and often well above, and considered West African browse to be excellent fodder, with very few exceptions. The species used in the present study have CP content within the range mentioned by these authors. *A. senegal* and *P. lucens* being legume trees have higher CP content than *G. senegalensis.* A similar level of CP in *A. senegal* leaves was also found by Rittner & Reed (1992). The difference in CP content between species can be explained by inherent characteristics of each species related to the ability to extract and accumulate nutrients from soil and/or to fix atmospheric nitrogen, which is the case of legumes plants. The other factors causing variation in the chemical composition of browse forages include soil type (location), the plant part (leaf, stem, pod), age of leaf and season. With regard to the location, some authors have reported that browse plants in the arid (Sahelian) zone are higher in N compared to plants in the humid zone (Rittner & Reed, 1992). Younger leaves are richer in N than mature leaves, which contain more N than the litter. The fruits are shown to have a N content between young and old leaves, and vary little with stage of maturity (Breman & Kessler, 1995). The leaves of *A. senegal* and *P. lucens* had somewhat higher CP content than the pods. Comparing pods of *A. senegal* with pods from other *Acacia* species, the CP content was higher than the value for *A. nilotica* (13.5%) and lower than for *A. tortilis* (20.5%) obtained by Sawe *et al.* (1998). *A. albida* pods also had lower CP content (11.4%) according to Fall *et al.* (1997).

With regard to the cell wall content, Rittner & Reed (1992) noted similar means in NDF and lignin content across different ecological zones, 40.1% and 11.7% in the Sahelian zone, 45.7% and 10.5% in the sub-humid zone and 43.6% and 9.3% in the humid zone, respectively. Fall (1993) found a range of 31 to 57% of NDF and 19 to 43% ADF. The values in the present study fall within the range obtained by these authors. NDF and ADF content in *G. senegalensis* is similar to the value found by Fall (1993). This species also had a high lignin content. Lignin is a component of the cell wall, and deposited as part of the cell wall-thickening process (Boudet, 1998). It is also reported to be important in limiting water loss by reducing the permeability of the cell wall, and in impeding disease organisms, all attributes that are desirable from the perspective of plant function and survival, but limit the nutritional value of the plant for herbivores (Moore & Jung, 2001). Lignin is in general higher in browse than in herbaceous plants. The content varies according to species, age and the plant parts. Positive correlations are reported between content of lignin and soluble or insoluble proanthocyanidins (Rittner & Reed, 1992). Reed (1986) also found a negative correlation between the content of NDF and soluble phenolics, while the correlation with insoluble proanthocyanidins was positive. The content of both soluble and condensed tannins could not be evaluated in this study. However, the relation between fibre and these anti-nutritive compounds could give an idea about their probable level in the species studied.

Browse plants have also been shown to develop defensive systems (physical or chemical) that deter utilization by ruminants. The physical defence is related to the development of spines and thorns that are more defensive in juvenile trees and growing parts of the plants. Brooks & Owen-Smith (1994) noted longer and more closely spaced thorns on branches of *A. nilotica* and smaller leaves in juvenile than adult plants, while Cooper & Owen-Smith (1986) reported fewer spines in many plants as they grow out of reach of browsers. The same phenomenon was found in *A. senegal*, as the younger individuals showed smaller leaves and densed thorns, making browsing difficult. The chemical defence refers to the concentration of phenolic compounds that could be high in plants exposed to browsing. Ernst *et al.* (1991) found that the concentration of phenolic substances in various *Acacia* and *Dichrostachys* species was high in young leaves, immature fruits and seeds and low in mature leaves and pods. Although not significant, there was a relatively high lignin content in smaller individuals of *G. senegalensis* in the present study, which could be seen as a defensive trait. The chemical composition did not differ within plants due to browsing height, which is in contrast with the findings of Nordengren *et al.* (2003), who related the improvement in quality and quantity of forage to the height of the tree.

Digestibility of browse species

Studies on the digestibility of browse fodders are very important as they allow the estimation of nutrients really available for animal nutrition. The *in vivo* technique is the classical and direct method for estimating feed digestion by animals. However, due to difficulties in its application, indirect methods are frequently used. Most of the studies on digestibility of browse fodders used the *in vitro* technique, which provides a comparative estimate of DMD and can be used to rank the quality of the feed. However, the significance of the method is limited as it does not take into account the intake of forage by the animal. The *in sacco* method has the advantage of measuring the rate of digestion of different feed components (protein and starch) through nylon bags suspended in the rumen, and can also be used to rank feeds. The *in sacco* method is known to usually overestimate *in vivo* digestibility (Gutteridge & Shelton, 1998). In the present study the *in vivo* method was applied using goats, owing to their preference for browse forages. The comparison of the results with other data is uncertain due to different experimental conditions: the method used, animal species used, and the level of browse fodder in the diet. The leaves were used with a fix amount of hay at a minimum level, since it was anticipated that leaves could not be fed alone due to possible anti-nutritive factors, while the pods were fed as a single feed. The factors involved in the variation in digestibility among browse fodders include the concentration of N, cell wall content, especially lignin, and tannins. A low level of CP (less than 80 g/kg DM) is shown to depress digestibility, as it is not sufficient to meet the needs of the rumen bacteria (Norton, 1998). On the other hand, low NDF content (20 to 35%) has been shown to result in high digestibility, while lignification of the plant cell wall decreases the digestibility of plant material in the rumen. Many studies (Buxton & Redfearn, 1997; Moore & Jung, 2001) have reported a negative correlation between lignin concentration and cell wall digestibility by its action as a physical barrier to microbial enzymes. Negative correlations between tannin and protein or DM digestibility have also been studied (Balogun *et al.*, 1998; McSweeney *et al.*, 1999). Hence information on the NDF, ADF, lignin and tannin content of tree foliage is essential for the assessment of their digestibility.

A wide range of variation in digestibility is reported in tropical browse species. Breman & Kessler (1995) showed a mean OMD of 0.53 in Sahelian and Sudanian zones of West Africa. Le Houerou (1980) reported a mean DCP of 510 g/kg for West African browses, with 760 g/kg for legumes. Fall (1991) reported large variations in DMD, ranging from 0.26 to 0.88 between species and plant parts. In the present study OMD (0.56 to 0.66 g/kg) and CPD (0.64 to 0.73 g/kg DM) were high compared to the mean values reported by these authors. The digestibility values were somewhat higher for the pods than the leaves (except CPD of the leaves of *P. lucens*). Fall (1991) also found the pods of some *Acacia* species more digestible than the leaves (*A. albida* and *A. tortilis*).

Voluntary feed intake

Voluntary feed intake is very important as it determines the amount of nutrients that can be released for animal maintenance and production. The feed intake is strongly related to the rate of degradation of DM in the rumen. A number of theories are reported behind feed intake regulation in ruminants, including physical constraints, metabolic constraints, the efficiency of oxygen utilization, and the water content of feed.

Many studies have reported limitation of intake due to physical constraints related to the distention of the rumen resulting from restricted flow of digesta through the gastrointestinal tract (Jung & Allen, 1995; Allen, 1996; Beauchemin, 1996). Fibre is recognized as a required dietary ingredient for ruminants and is necessary for normal rumen function. Through microbial degradation and synthesis, dietary fibre supplies energy to support animal maintenance and production. NDF corresponds to the coarse insoluble fibre that is adequate for promoting rumen function and is better related to intake and gastrointestinal fill (Van Soest *et al.*, 1991). However increased dietary NDF is shown to decrease DM intake linearly in growing goats (Luginbuhl *et al.*, 1998). Many other factors, including particle size, chewing frequency and effectiveness, particle fragility, indigestible fraction, rate of fermentation of the potentially digestible NDF, and characteristics of reticular contractions are also involved.

The metabolic constraints refer to physiologically determined intake according to Katelaars & Tolkamp (1992) and depend on the nutrient requirements of the animal. This theory assumes that the animal consumes feeds to realize a genetically determined maximum capacity for growth and milk production. The expression of this genetic capacity requires the presence of feed with high nutritive value (high digestibility and adequate content of protein, mineral and vitamins), adequate environmental conditions and health status of animals. Feed intake has also been shown to depend on the tolerance of the animal for a certain rumen fill, and this tolerance generally increases with an increase in the nutrient requirements of the animal. Feeds of low nutritive value restrict the intake of DM and hence the intake of nutrients due to slow degradation of feed in the rumen, which in turn slows down the rate at which the animal can ingest new feed. Later on these authors developed a new theory based on the efficiency of oxygen utilization, and suggested that feed is consumed to optimize yield per unit of oxygen consumed (Ketelaars & Tolkamp, 1996).

Fisher (2002) proposed an integrated approach to understand ruminant feed intake regulation, in which a number of feedback regulators, such as distention and protein and energy in the context of their interacting regulatory effects should be considered. The ruminant central nervous system has been shown to integrate distention or fill feedback with chemostatic feedback in regulating intake. With regard to energy and protein, the dietary balance is particularly important and constraints to intake are serious when protein is limiting, because of metabolic limitations in processing energy. Lu & Potchoiba (1990) showed a curvilinear decrease in DM intake as dietary ME density increased, while it increased linearly with increased dietary CP. With regard to browse forages, the presence of tannins has been shown to affect voluntary intake, and Cooper & Owen-Smith (1985) noted a threshold of 5% condensed tannins, over which the plants were rejected during the wet season.

The different mechanisms involved in determining feed intake allow understanding the differences observed in intake of the browse fodders studied. Concerning the foliages (Paper III), low intake of *G. senegalensis* can be explained by the high NDF and lignin content, while for the hay, low CP content could be the limiting factor for intake. The intake of CP and DM from *P. lucens* leaves was somewhat higher than from *A. senegal* leaves, probably due to a better balance between energy and protein as more OM was consumed from the *P. lucens* leaves diet. The small size of the leaves of *A. senegal*, mostly small leaflets around 5 mm long, could have influenced intake, insofar as goats are shown to be extremely sensitive to diets poor in fibre and rich in concentrate or forage characterized by small particle size, which decreases the rumen pH, resulting in a fall in intake (Morand-Fehr, 2005). For the two pods, the low intake of *P. lucens* pods can be explained by the low nutritive value compared to *A. senegal* pods. Considering the intake of foliages and pods, more *A. senegal* pods (1033 g/kg DM) were consumed, followed by the *P. lucens* leaves diet (864 g/kg DM), then *P. lucens* pods (691 g/kg DM), *A. senegal* leaves diet (675 g/kg DM) and *G. senegalensis* diet (397 g/kg DM). The explanation regarding CP and fibre content could be valid for the difference in intake observed in Paper IV. Apart from *G. senegalensis*, the result indicates that the forages studied could constitute the main component of goat diets and would be well consumed. The animals increased in weights, especially with *A. senegal* leaves and pods and *P. lucens* leaves, which could indicate efficient utilization of these fodders. The intakes expressed in g/kg BW and g/kg $W^{0.75}$ were high compared to the estimation of Devendra & McLeroy (1982) for tropical goat breeds.

Growth and carcass characteristics of Sahelian goats

In spite of the adaptation to harsh environments and poor quality feeds, goats require for optimum growth, an efficient utilization of nutrients that supply adequate energy and protein. Knowledge of nutrient requirements is therefore important for the estimation of genetic potential of the animals. It is well documented that the nutrient requirement depends on body size and growth rate or production potential of animals, environmental conditions (temperature, humidity, …) and the quality of the feed (Sahlu *et al.*, 2004; Mandal *et al.*, 2005). The Sahelian goats, also known as the West African long-legged goats, are well adapted in the semi-arid zones. In Burkina Faso, they are kept for milk and meat production. The type is characterized by large size, with a height at withers of 70 to 85 cm and a mature weight of 30 to 40 kg for male and 27 kg for female (Wilson, 1991). This author reported some productivity characteristics, although no information on nutrient requirements of this breed is available to our knowledge. References were then made from nutrient requirements of local goats based on Langston University Goat Research Extension (Langston University, 2000). The nutrient requirements of the goats considered in this study may be different from the local ones referred by Langston University, due to genetic differences and different climatic conditions.

The weight gain by all goats was lower than expected, as nutrient intakes from all diets were higher in protein (94 to 145 g) than the estimated requirements (74.3 g).
The difference can be explained either by the inadequacy of the requirement estimates for other breeds, or the low genetic potential of Sahelian goats marked by low capacity for growth or low efficiency of nutrient utilization. The ADG varied from 24 to 56 g/day, and the diet with *P. lucens* pods resulted in the lowest performance, suggesting a low efficiency in utilization of this forage type. When used as a sole feed in the voluntary intake trial (Paper III), the animals fed *P. lucens* pods lost weight. The gain observed (Paper IV) could then have been due to the supply of millet bran, an energetic source, which could enhance protein utilization of this forage. There is a close relation between energy and protein intake and growth of animal (Mtenga & Kitaly, 1990; Lu & Potchoiba, 1990; Chowdhury & Orskov, 1997). Protein is the most limiting factor for growth, and increase in protein intake leads to increased ADG. However, protein synthesis is an energy demanding process, as microbial proteins in the rumen require energy for their activities, hence the presence of digestible carbohydrates is needed. The relation between energy and protein for growth was well demonstrated by Lu & Potchoiba (1990), who found an increase in ADG with increased CP intake in Alpine goats and Nubian goats, while similar energetic efficiency for weight gain (Mcal ME intake/g of gain) was found between low-energy and high-energy diets. They suggested that the effect of dietary energy density on energy utilization for gain to be attributed to differences in gut fill and composition of gain (higher energy diet resulted in greater fat deposition in tissue), while the effect of dietary energy density on utilization of protein for gain could be attributed to the energy to protein ratio. The effect of dietary protein level on protein utilization for gain could be explained by an excess of CP and loss of ammonia N in the urine. The weight gains were somewhat lower compared to the results of Sawe *et al.* (1998) supplementing goats (57 to 68 g/day) with tree leaves and pods in Kenya. Similar results to the present study were obtained by Mtenga & Kitaly (1990) with indigenous goats in Tanzania. The significantly higher CP intake from *A. senegal* pods did not result in significantly higher gain compared to *P. lucens* leaves and the control diet containing CSC. One could therefore expect an excess of CP and loss of ammonia N, probably due to rapid passage rate through the gastrointestinal tract.

However, the high intake of CP observed from all diets could be relative, since browse forages are known to contain antinutritional factors that limit the efficient utilization of nutrients. The animals fed *A. senegal* pods and *P. lucens* leaves gained more weight in the voluntary intake trial (Paper III), on average 68 g/day and 84 g/day, respectively, compared to the growth experiment in Paper IV (56 and 55 g/day, respectively). Feed consumption per BW for these animals was also somewhat lower, 4.6 and 3.7 g/kg, against 5.1 and 4.9 g/kg, respectively. The period in the voluntary intake trial may, however, have been too short to give a good estimate of growth.

The feed conversion ratio was low for the control diet containing CSC, but the availability of this feed in the rural areas is low and the cost is high. Hence the leaves of *P. lucens* and pods of *A. senegal* could be an alternative because of the high availability in the area where the foliage can be collected and stored for stall-feeding. The aim of this study was to compare different types of browse forages in terms of digestive utilization and their effect on animal performance. They were then used *ad libitum*, hence the economic feasibility of this technique was not considered. The similar performance obtained for the CSC diet and *A. senegal* pods and *P. lucens* leaves diets suggested that they can be used to replace the concentrate feed. However, *ad libitum* feeding of the browse forages should be limited if the high CP content of browse fodders is to be exploited, and it will require large amount of forages to store. Since *P. lucens* leaves are sold in the local market this could limit the availability. The use of these browse species as a supplement should be evaluated, and the levels that allow optimum growth at lower cost be assessed.

The slaughter data showed that the goats with high nutrient intake and high ADG had somewhat higher empty body weight, higher dressing percentages and higher weights for all carcass components. When EBW increases, the weights of all constituents have been shown to increase, but at differing rates (Mc Donald *et al.*, 1995). Fat is deposited at an increasing rate and lean body components at decreasing rates. This can explain why these animals deposited more fat, and indicated that they had sufficient nutrients available. Many authors (Kadim *et al.*, 2003; Mahgoub *et al.*, 2004) have reported that fat is a late maturing tissue. In general, goat meat contain less fat than lamb meat, as fat is deposited mostly around organs in goats, whereas lambs contain more intramuscular fat (Jansen & van den Burg, 2004). The meat of an adult buck has a strong smell that is appreciated or not, depending on cultural habits. In Burkina Faso goats are well exploited for meat and the percentage slaughtered was 32%, compared to 26% for sheep and 12% for cattle (FAO, 2006).

Effect of feeding browse on parasite infestation in Sahelian goats

Goats are more susceptible to internal parasites than sheep and cattle because of their feeding behaviour, that is browsing, which means consuming vegetation above the height at which infective parasite larvae exist. They are then less exposed to parasites, hence their low natural tolerance (Peacock, 1996). The main internal parasites in small ruminants in general are nematodes, cestodes, trematodes and protozoa (coccidian). The three first types, referred to as helminthes, are the most important and responsible for economic losses in small ruminants by decreasing the productivity of the animals (Knox *et al.*, 2006). The animals may host a low number of parasites while grazing, and this has been shown to have little impact. However, as the number increases, the infested animals reduce weight gain and decrease appetite, and clinical signs (weight loss, diarrhea, anemia, or sub-mandibular oedema) occur with heavy worm burdens (Sissay, 2007). The effect of gastro-intestinal parasites depends on the age of the animals (younger animals are more susceptible) and their nutritional status. The infection is shown to increase nutrient requirements, in order to replace the losses of endogenous protein (leak of plasma protein and increased muco-protein production) into the alimentary tract (Liu *et al.*, 2005).

The development of drug resistance to gastro-intestinal parasites in small ruminants is widely reported and has stimulated the use of anthelmintic plants in traditional medicine (Hammond *et al.*, 1997). Besides anthelmintic plants, browse species in general have been shown to have an effect on GI parasites. The mode of action of these forages seems to be two fold, improvement of the nutritional status of animals and direct effects on parasites through the tannin content. Condensed tannin is reported to have a biological effect on the control of gastro-intestinal parasites directly through possible tannin-nematode interactions, which reduce nematode viability (Nguyen *et al.*, 2005). Supplementary feeding, especially of protein has been shown to increase animal resistance to gastro-intestinal parasites (Knox *et al.*, 2006; Louvandini *et al.*, 2006). Browse forages could play a significant role due to high CP content, but also through tannin at adequate levels (2 to 4% according to Barry, 1985) which bind to protein preventing microbial degradation in the rumen, and increasing protein availability in the small intestine.

In this study the goats were dewormed before the experiment to avoid the interaction of nutrition and parasite infestation. There were no helminths detected during the course of the study, suggesting the efficiency of the drug used and/or absence of drug resistance, as small ruminants in the area are less subjected to preventive treatment. Conversely oocysts of coccidian were constantly present in fluctuating numbers. High occurrence of coccidiosis is reported by many authors in tropical Africa (Vercruysse, 1982; Chhabra & Pandey, 1991; Woji *et al.*, 1994). The infection is mostly chronic and clinical syndromes seem to occur only in young animals, which can be heavily infected. The disease is manifested by diarrhea with more or less blood and mucus, and intestinal lesions at necropsy (Harper & Penzhorn, 1999). The number of oocysts can be quite high, and Harper and Penzhorn (1999) found 13000 to 61000 e.p.g. in young goats and 5500 to 7042 e.p.g. in adult goats in different sites in South Africa. Multiple infections are common (Chhabra & Pandey, 1991; Woji *et al.*, 1994; Kusiluka *et al.*, 1996) with species of different pathogenic effects. The present study did not investigate the prevalence of oocyst species, which could give an idea of the possible overt effect. No effect of the browse forages used was detected on the number of oocysts. All the goats in the experiment were in good condition, and therefore one could suggest an improvement in their nutritional status that could help them to resist parasite occurrence.

Main conclusions

- Farmers have relatively good knowledge of the main browse species preferred by the different ruminant species. Farmers' preference for browse species was based not only on the feeding objective, but the multiple utilisation of browse species was also taken into account in their choice, such as for human consumption and material for construction.

- The feeding activities of cattle, sheep and goats declined from the rainy season to the dry season, in relation to the decrease in forage available. This decline was more important for cattle (72% to 38%) that relied on herbaceous vegetation for feeding, while sheep made a shift in the feeding activities from grazing to browsing in the dry season. Goats preferred browsing in all seasons and most of the woody plants in the area were edible to them, while cattle selected 10 browse species and sheep 20 species during the observation period.

- The availability of browse biomass and its distribution in time, in terms of edible biomass was good from June to February, and consisted of various fodder components (green leaves, dry leaves and pods). *A. senegal* showed a shorter period of fodder availability than *P. lucens* and *G. senegalensis*.

- The most important part of the edible biomass of the trees is not directly accessible to animals. Overall edible biomass accessible to animals varied according to species and the height of the trees. Less than 5% of edible biomass from *P. lucens* trees (> 1m) was accessible compared to 0.5 to 14.3% for *A. senegal* and 7.3 to 47.3% for *G. senegalensis.*

- The relationships found between the biomass production and different tree parameters demonstrated the possibility of estimating browse biomass production in pasture. The models developed are species-specific and for extrapolation the heterogeneous distribution of plant height should be considered as well as the degree of accessibility. Thus the models could be applied to similar agro-ecological zones.

- Based on the protein content, *A. senegal* leaves and pods, and *P. lucens* leaves are suitable as supplements to poor quality diets. However, *G. senegalensis,* with the lowest crude protein and highest fiber and lignin content, had low intake characteristics and this resulted in weight loss during the experimental period. Feeding pods of *P. lucens* also resulted in weight loss.

- *senegal* leaves and pods and *P. lucens* leaves had good intake characteristics and showed high nutrient digestibility. They could be used as alternative low cost sources of protein in livestock feeding.

- *senegal* pods and *P. lucens* leaves showed good intake characteristics for goats under stall-feeding conditions, allowing them to achieve similar or somewhat better performance than goats offered cottonseed cake. These browse forages are locally available and could be used to improve nutrition and strengthen resistance against gastrointestinal parasites. Pods from *P. lucens* resulted in lower performance, but can be fed with small amounts of millet bran, that is also available to farmers, for maintenance of goats during the dry season.

Implications

In the Sahelian area of Burkina Faso, domestic ruminants exploit various resources as feeds, including herbaceous species, crop residues and browse species. Cattle, sheep and goats used the same rangelands, with different grazing behaviour, which varied more or less according to season depending on forage availability. The preference of cattle and sheep for grazing, especially in the rainy season, suggests that they could exert great pressure on the herbaceous cover when grazing together in the same area, resulting in degradation of this resource, while cattle and goats grazing together could be advantageous. The common practice in the area consists of mixed flocks of sheep and goats from different owners (having a few animals) under the control of a hired herder. In the late dry season some competition for browse forages could occur between the two species. Under natural conditions goats are not great destroyers of vegetation, as is often stated, because they cover a large area, grazing and browsing selectively. Herders' practices are damaging as they cut down branches, which prevents the flock from dispersing and goats from feeding far away.

The grazing behaviour study showed a decrease in feeding activities related to the decline in forage availability and demonstrated a critical period for foraging and maintenance of animals. In consequence, feeding conserved forages, such as crop residues (mainly cereal straws and some legume haulms), hay collected from natural pasture and to a lesser extent concentrate feeds constituted an essential rescue strategy for animals that do not undergo transhumance. Fodder conservation concerns mainly herbaceous plants, and is promoted by the ministry in charge of livestock production, but the collection and conservation of browse fodder, especially fruits or pods, can be recommended in the period of feed shortage.

Farmers are aware of the importance of browse species for animal feed and for their livelihood, as revealed by the multiple usages. Hence a sustainable management of this resource is of paramount importance, and requires a dialogue between different users and their involvement in the regeneration of the well-appreciated species. High stocking density and common grazing prevailing in the area are hardly compatible with open plantations. Promotion of fodder banks that involve maximum number of small farmers can improve feed availability. In addition plantation of browse trees in alley farming should be encouraged. Agreement between different development projects acting in the area in soil restoration, tree plantation and animal production is necessary for the choice of species. *A. senegal* is already promoted by the government for gum production. The sale of *P. lucens* leaves generates income, and with other uses the species can be easily adopted by farmers for plantation. The multipurpose characteristics of these species make them especially valuable.

Edible biomass production from the species studied is quite substantial, especially for *P. lucens*. However the most important part is not directly accessible to animal, and varies according to animal species and the height of the trees, hence these factors should be considered when dealing with browse forage accessibility to ruminants. The herders' normal practice consists of cutting or lopping branches which allows short term provision of fodder, but this practice is prejudicial to long term production and also for the survival of the tree if not managed appropriately. It is preferable that animals be left to browse the plants of 3-5 m height for *A. senegal* and *G. senegalensis*, and class 4 (5–7 m) for *P. lucens*, as these plants recorded the highest accessible production and this practice could be used as a range management tool. Then, an appropriate pruning for individuals in the higher classes could be suggested. On the other hand, the inaccessible part will be at a given time available, when it has dried and fallen to the ground, especially the pods that are well consumed by animals.

Edible biomass production can be predicted from crown diameter and the accessible biomass is estimated by applying the accessible rate, depending on the height of the tree. The extension of this study to more species is necessary for better assessment of total browse potential on rangeland.

The leaves of *P. lucens* and pods of *A. senegal* can be used by small farmers for growing and fattening animals. These forages are of good nutritive value and give acceptable weight gains in stall feeding. They provide sufficient nutrients (protein and energy) to goats, resulting in similar performance for growth and carcass characteristics as for goats fed cottonseed cake. The leaves of *P. lucens* can be harvested in the rainy season, dried and stored, while the pods of *A. senegal* can be collected in the early dry season and stored. The nutritional importance of *P. lucens* leaves is well known by farmers in the area and many women are involved in selling the leaves for stall-fed animals in the city, at an estimated price of 0.1 USD per kg DM. Some farmers collected *A. senegal* pods to supplement animals left around the homestead for diverse reasons: reproductive males especially bucks, as they are shown disturb the feeding activities of the female, and sick animals. *A. senegal* leaves have good nutritive value, but the collection of sufficient quantity is difficult because of the thorns and the small size of the leaves, and may be also more destructive for the plants. Hence this forage can not be recommended for stall feeding. *P. lucens* pods have relatively good palatability, but the digestibility is low, indicating inefficient use of nutrients. However, it can be used in combination with millet bran to ensure the maintenance of goats in the dry season. Low palatability of *G. senegalensis* in stall feeding suggested that this forage is browsed on pasture because of its availability when preferred forages are lacking, but also the ability of animals to select various forages. This species and others such as *Combretum micranthum,* are also known for medicinal uses.

Future research

- Further studies should be conducted on the spatial and temporal variation in browse production, including a proper evaluation of production of fruits from various browse species. A regression model for edible biomass production should be developed for other important browse species, and the validity of models developed should be tested in similar agro-ecological zones.

- Studies should be undertaken to establish the optimum level of incorporating *A. senegal* pods and *P. lucens* leaves in the diet for long-term feeding and to evaluate the cost/benefit of this supplementation.

- An evaluation of the tannin content of *P. lucens* pods should be conducted and the methods to improve the digestive utilization of this forage, such as use of polyethylene glycol, clay or charcoal, should be investigated.

- Increased fodder production through planting appreciated local and improved browse species and their integration in the production systems should be tested. Seed germination and plant growth characteristics of selected local species (including *A. senegal* and *P. lucens*) should be studied, followed by production in seedbeds and the setting up of seed-banks for sustainable provision of seeds to the farmers.

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Acknowledgement

The studies presented in this thesis have been conducted within the framework of a collaborative program for research, training and capacity building in Burkina Faso, financed by the Swedish International Development Agency (SIDA), Department for Research Cooperation (SAREC). I am grateful to SIDA-SAREC for the financial support, which made this work possible, and to my home institution INERA/CNRST for allowing me to accomplish the PhD program and for support during the course of the study.

This thesis is the result of many contributions from different persons and institutions that I am please to acknowledge here.

Words are lacking to express my deepest gratitude to my main supervisor Prof Inger Ledin for continuous guidance and excellent help whenever needed. Your visits, emails and calls to Burkina, when I was struggling with the field work and with other related problems, were of extreme importance, and gave me confidence and inspiration. Your critical comments and peer reading of the manuscripts contributed greatly to the improvement of the content. I learned from you the way of methodically and meticulously writing scientific papers. Thank to Prof Stig, your husband, for encouragement and sharing time with us.

I'm grateful to Prof Brian Ogle for always being available to read and correct the English language of my papers and the thesis. I appreciated well the parties in your house with other students, and thanks to your wife Britta for delicious meals.

My sincere gratitude to Prof Chantal Zoungrana, my local supervisor, and the person responsible for Agro-pastoralism group, for her guidance and the support in various ways during the course of the study.

Special thanks are due to the Professors and lecturers of the Department of Animal Nutrition and Management and to those from the courses I attended for sharing their knowledge. I got useful help from Prof Lennart Norell, for statistical analysis of my data on biomass production, using the SAS programme. Thank you very much.

The actual and former head of my department at INERA, Dr Hamidou Tamboura and Dr Tinrmegson Ouedraogo provided me valuable support during the course of this thesis. It is a pleasure for me to express here my great regards. I am indebted to Dr Sibiri Jean Zoundi for giving me useful comments on the feeding experiment, and for his constant encouragement, and Dr Moumini Savadogo for his assistance in the inventory of the vegetation. Dr Kanwé (head of the programme of cattle production/INERA) and all the colleagues and friends at the research Station of Farako-ba are acknowledged for their support.

The project for livestock development in the Soum province (PDES) at Djibo, especially the former coordinator of the project, Desiré Somé, is gratefully acknowledged, for providing me accommodation and other facilities during the field study, and for encouraging me.

The field study has benefited from active collaboration of many farmers in Tongomayel village, to which I am indebted: the local chief, M. Dicko helped to convince farmers and herders to adhere the work as if it was their own. Many thanks to all farmers who took part in the survey, and to livestock-owners and herders who allowed me to study the behaviour of their animal: Haïssama, Mikaelou, Sambal, Yero, Amadou, and Salou. It was not easy for me, nor for some of you who were not so much involved in herding, to follow cattle, sheep and especially goats all the day, especially in the dry season when the temperature was so high and the dry and warm wind blowing. "Fofo sanné".

The contribution of undergraduate students was essential for some data collection: Fousseni, Severin, Paul and Gustave. Thank you for work well done. Colleagues at the research station of Katchari helped a lot, especially Seydou, Zono and Yaya, who took care of part of the experimental work when I was in Sweden; many thanks, and also to all the herders at the research station.

It is a pleasure to gratefully acknowledge the Family Hagberg, Minata, Sten and the children, for various invitations and dinners, which made us to feel like at home. I appreciated your hospitality, and the talks and fun we had were really relaxing. My sincere gratitude to Inger Bertilisson and her friend Frederica at administration of SLU (Uppsala), for helping us discover the countryside in Sweden. I enjoyed the walks in the forest, riding a horse, and fishing. Tack so mycket.

My friends and colleagues from home, Salifou, Salimata, Sita, Catherine, Vinsoun and Alice, who with their company, helped me to cope with the study environment, far away from home. Salifou, my fellow student for nice times of fun, and also difficult moments during the course of the program.

The stay in Sweden for this PhD programme has been an opportunity to meet students from various origins and cultures. It was nice to meet all the friends and colleagues from Vietnam, Laos, Cambodia, and Nicaragua: Kim Dong, Van, Minh, Borin, Nadir, Vanthong, Oudom, Kerya, Lampheuy, Len, Thuy, Hong, Giang, Tram, Thang, Thieu, Vo Lam and Brian. Thanks for the friendly atmosphere and exchange of experiences.

I would like to express my heartily felt thanks to my beloved family and friends for their valuable support and encouragement. Thank you for fondness and for believing in me.

Lastly, my sincere gratitude to all of whom in one way or another contributed to the completion of this study.

Résumé

L`importance de quelques espèces ligneuses fourragères sahéliennes comme aliments pour caprins

Les espèces fourragères ligneuses contribuent substantiellement à la disponibilité alimentaire du bétail dans la zone Sahélienne du Burkina Faso. Cette étude avait pour but d'identifier les espèces les plus appréciées et les plus utilisées dans la zone d'étude, évaluer leur potentiel de production fourragère ainsi que leur valeur nutritive, puis tester leur utilisation en production animale intensive.

Le comportement des bovins, ovins et caprins a été suivi aux pâturages de la saison pluvieuse à la saison sèche. Parallèlement une enquête a été conduite auprès des producteurs pour estimer les connaissances locales sur les fourrages ligneux et leur utilisation par les ruminants. *Acacia senegal*, *Guiera senegalensis* et *Pterocarpus lucens*, trois espèces qui se sont avérées bien utilisées, ont été étudiées à travers un suivi des phases phénologique et une évaluation de la production de biomasse fourragère, total et directement accessible aux ovins (0.87 m), caprins (1.65m) ou bovins (1.47 m). La production de biomasse a été également estimée en utilisant des paramètres dendrométrique. La valeur nutritive et la consommation volontaire des ces fourrages ont été évaluées chez les caprins de même que leur effet sur la croissance, les caractéristiques de carcasse et la résistance aux parasites gastro-intestinaux.

Les résultats ont montré des variations de comportement alimentaire de toutes les trois espèces animales en fonction des disponibilités fourragères herbacées et ligneuses. Les activités alimentaires diminuaient de la saison pluvieuse à la saison sèche, tandis que le temps consacré au repos et à la rumination augmentait. Les bovins ont brouté pendant toute la période de l'étude environ 5% du temps passé au pâturage. Les ovins et les caprins ont observé un changement dans leurs activités alimentaires, en passant de la pâture des herbacées au broutage des ligneux (28% et 52% du temps au pâturage, respectivement, pour les ovins et les caprins). La classification préférentielle des fourrages ligneux par les producteurs répondait à des critères de disponibilité, de valeur nutritive, et de plusieurs autres utilisations dont ils font l'objet (pharmacopée, ethno-vétérinaire, bois d'œuvre). *A. senegal*, *G. senegalensis* et *P. lucens* ont commencé la phase de feuillaison dès l'arrivée des premières pluies, mais la chute des feuilles a été plus précoce chez *A. senegal*. *P. lucens* a montré une production de biomasse fourragère totale plus élevée. Cependant, la proportion de biomasse accessible aux animaux a été plus élevée chez *G. senegalensis*. Les chèvres broutant plus haut, ont eu plus de biomasse à leur disposition. Le diamètre de houppier a permis de bien estimer la production de biomasse des trois espèces fourragères avec des coefficients (R^2) de 0.90, 0.96 et 0.98 pour *G. senegalensis*, *A. senegal* et *P. lucens* respectivement.

L'évaluation de la valeur nutritive de ces fourrages a montré une variation significative dans la composition chimique et dans la digestibilité des éléments nutritifs. Les teneurs en protéines brutes (CP) étaient de 114, 157 et 217 g/kg de matière sèche (MS) et celles en NDF (Neutral Detergent Fibre) 604, 534 et 412 g/kg de MS pour G. senegalensis, P.*lucens* et *A. senegal* respectivement. Les feuilles de *P. lucens* et d'*A. senegal* ont eu des digestibilités semblables pour les protéines, tandis que les gousses d'*A. senegal* ont eu une digestibilité élevée de tous les nutriments.

Le régime à base des feuilles de *P. lucens* a été le plus consommée (864 g) et celui à base de *G. senegalensis* (397 g) le moins consommé. Les gousses d'*A. senegal* ont été plus consommées que des gousses de *P. lucens*. Les chèvres alimentées avec les gousses d'*A. senegal* ont montré un taux de croissance plus élevé (56 g/day) et les chèvres recevant les gousses de *P. lucens* ont eu le plus faible gain (24 g/day). Le poids carcasse, le taux d'habillage et le poids des coupes principales ont été plus élevés chez les chèvres alimentées avec les gousses d'*A. senegal*, les feuilles de *P. lucens* et le régime témoin.

En conclusion, les gousses d´*A. senegal* et les feuilles de *P. lucens* peuvent être recommandés comme suppléments aux fourrages pauvres

Mots clés : *Acacia senegal*, Bovin, Caprin, characteristiques de carcasses, comportement alimentaire, Composition chimique, Connaissances indigènes, Consommation alimentaire, Digestibilité, Fourrage ligneux, *Guiera senegalensis*, Ovin, Phénologie, Production de biomasse fourragère, *Pterocarpus lucens*, Resistance parasitaire, Taux de croissance

Appendix A. Landuse in the Tongomayel area