The role of ligneous vegetation for livestock nutrition in the sub-Sahelian and Sudanian zones of West Africa: Potential effects of climate change

The role of ligneous vegetation for livestock nutrition in the sub-Sahelian and Sudanian zones of West Africa: Potential effects of climate change

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Dedication

To

The memory of my dad Soumaila

My mum Bancé Zenabo

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Summary

The role of ligneous vegetation for livestock nutrition in the Southern Sahelian and Sudanian zones of West Africa: Potential effects of climate change

Climate change and variability in sub-Saharan West Africa is expected to have negative consequences for crop and livestock farming due to the strong dependence of these sectors on rainfall and natural resources, and the low adaptive capacity of crops farmers, agro-pastoralist and pastoralists in the region. The objective of this PhD research was to investigate the anticipated impacts of expected future climate change and variability on nutrition and grazing management of livestock in the prevailing extensive agro-pastoral and pastoral systems of the Sahelian and Sudanian zones of Burkina Faso. To achieve this, three studies were undertaken in selected village territories (100 km² each) in the southern Sahelian (Taffogo), northern Sudanian (Nobere, Safane) and southern Sudanian (Sokouraba) zone of the country during 2009 and 2010. The choice of two villages in the northern Sudanian zone was guided by the dichotomy between intense agricultural land use and high population density near Safane, and lower agricultural land use in the tampon zone between the village of Nobere and the National Park Kaboré Tambi of Pô.

Using global positioning and geographical information systems tools, the spatio-temporal variation in the use of grazing areas by cattle, sheep and goats, and in their foraging behaviour in the four villages was assessed by monitoring three herds each per species during a one-year cycle (Chapter 2). Maximum itinerary lengths (km/d) were observed in the hot dry season (March-May); they were longer for sheep (18.8) and cattle (17.4) than for goats (10.5, $p<0.05$). Daily total grazing time spent on pasture ranged from 6 - 11 h with cattle staying longer on pasture than small ruminants ($p<0.05$). Feeding time accounted for 52% - 72% of daily time on pasture, irrespective of species. Herds spent longer time on pasture and walked farther distances in the southern Sahelian than the two Sudanian zones ($p<0.01$), while daily feeding time was longer in the southern Sudanian than in the other two zones ($p>0.05$). Proportional time spent resting decreased from the rainy (June - October) to the cool (November - February) and hot dry season ($p<0.05$), while in parallel the proportion of walking time increased. Feeding time of all species was to a significantly high proportion spent on wooded land (tree crown cover 5-10%, or shrub cover >10%) in the southern Sahelian zone, and on forest land (tree crown cover >10%) in the two Sudanian zones, irrespective of season. It is concluded that with the expansion of cropland in the whole region, remaining islands of wooded land, including also fields fallowed for three or more years with their considerable shrub cover, are particularly valuable pasturing areas for ruminant stock.

Measures must be taken that counteract the shrinking of wooded land and forests across the whole region, including also active protection and (re)establishment of drought-tolerant fodder trees.

Observation of the selection behaviour of the above herds of cattle and small ruminant as far as browse species were concerned, and interviews with 75 of Fulani livestock keepers on use of browse as feed by their ruminant stock and as remedies for animal disease treatment was undertaken (Chapter 3) in order to evaluate the consequence of climate change for the contribution of browse to livestock nutrition and animal health in the extensive grazing-based livestock systems. The results indicated that grazing cattle and small ruminants do make considerable use of browse species on pasture across the studied agro-ecological zones. Goats spent more time ($p<0.01$) feeding on browse species than sheep and cattle, which spent a low to moderate proportion of their feeding time on browsing in any of the study sites. As far as the agro-ecological zones were concerned, the contribution of browse species to livestock nutrition was more important in the southern Sahelian and northern Sudanian zone than the southern Sudanian zone, and this contribution is higher during the cold and hot dry season than during the rainy season. A total of 75 browse species were selected on pasture year around, whereby cattle strongly preferred *Afzelia africana, Pterocarpus erinaceus* and *Piliostigma* sp., while sheep and goats primarily fed on *Balanites aegyptiaca, Ziziphus mauritiana* and *Acacia* sp. Crude protein concentration (in DM) of pods or fruits of the most important browse species selected by goats, sheep and cattle ranged from 7% to 13% for pods, and from 10% to 18% for foliage. The concentration of digestible organic matter of preferred browse species mostly ranged from 40% to 60%, and the concentrations of total phenols, condensed tannins and acid detergent lignin were low. Linear regression analyses showed that browse preference on pasture is strongly related to its contents (% of DM) of CP, ADF, NDF and OM digestibility. Interviewed livestock keepers reported that browse species are increasingly use by their grazing animals, while for animal health care use of tree- and shrub-based remedies decreased over the last two decades. It is concluded that due to climate change with expected negative impact on the productivity of the herbaceous layer of communal pastures browse fodder will gain in importance for animal nutrition. Therefore re-establishment and dissemination of locally adapted browse species preferred by ruminants is needed to increase the nutritional situation of ruminant stock in the region and contribute to species diversity and soil fertility restoration in degraded pasture areas.

In Chapter 4 a combination of household surveys and participatory research approaches was used in the four villages, and additionally in the village of Zogoré (southern Sahelian zone) and of Karangasso Vigué (northern Sudanian zone) to investigate pastoralists' (n= 76) and agro-pastoralists' (n= 83) perception of climate change, and their adaptation strategies in crop and livestock production at farm level. Across the three agro-ecological zones, the majority of the interviewees perceived an increase in maximum day temperatures and decrease of total annual rainfall over the last two decades. Perceptions of change in climate patterns were in line with meteorological data for increased temperatures while for total rainfall farmers' views contrasted the rainfall records which showed a slight increase of precipitation. According to all interviewees climate change and variability have negative impacts on their crop and animal husbandry, and most of them already adopted some coping and adaptation strategies at farm level to secure their livelihoods and reduce negative impacts on their farming system. Although these strategies are valuable and can help crop and livestock farmers to cope with the recurrent droughts and climate variability, they are not effective against expected extreme climate events. Governmental and non-governmental organisations should develop effective policies and strategies at local, regional and national level to support farmers in their endeavours to cope with climate change phenomena; measures should be site-specific and take into account farmers' experiences and strategies already in place.

Zusammenfassung

Aufgrund der starken Abhängigkeit von Niederschlägen und natürlichen Ressourcen gelten Ackerbau und Viehzucht im subsaharischen westlichen Afrika als besonders anfällig für klimatischen Wandel. Verstärkt wird dies durch das geringe Anpassungsvermögen der lokalen Bauern und Viehzüchter an die neuen Umstände. Das Ziel der vorliegenden Arbeit war daher die Untersuchung der zu erwartenden Einflüsse zukünftiger Klimaveränderungen auf die Tierernährung und Weidenutzung in der südlichen Sahelzone und der nördlichen und südlichen Sudanzone in Burkina Faso. Um dies zu erreichen, wurden von 2009 bis 2010 drei Studien durchgeführt; dafür ausgewählt wurden die Dörfer und Dorfgebiete (100 km²) von Taffogo (südliche Sahelzone), Nobere und Safane (nördliche Sudanzone) und Sokouraba (südliche Sudanzone). Die Wahl von zwei Dörfern in der nördlichen Sudanzone war begründet durch die Dichotomie zwischen intensiver landwirtschaftlicher Nutzung und hoher Bevölkerungsdichte in Safane und geringer ackerbaulicher Nutzungsintensität in der Pufferzone zwischen dem Dorf Nobere und dem Nationalpark Pô.

Unter Verwendung globaler Navigations- (GPS) sowie Geoinformationssysteme (GIS) wurden räumliche und zeitliche Veränderungen in der Weidenutzung sowie im Fressverhalten von Rindern, Schafen und Ziegen in den vier Dörfern untersucht. Hierzu wurden pro Dorf jeweils drei Herden der genannten Haustierarten über einen Zeitraum von einem Jahr beobachtet (Kapitel 2). Die längsten Weidewege (km/Tag) waren während der heißen Trockenzeit (März – Mai) festzustellen. Schafe (18,8) und Rinder (17,4) legten dabei signifikant größere Distanzen zurück als Ziegen (10,5; $p<0,05$). Die tägliche Weidedauer lag zwischen sechs und elf Stunden und war bei den Rindern länger als bei den kleinen Wiederkäuern ($p<0,05$). Artunabhängig wurden 52–72% des Weidetages mit der Aufnahme von Futter verbracht. In der südlichen Sahelzone verbrachten die Herden mehr Zeit pro Tag auf den Weideflächen und legten zudem größere Distanzen zurück als in den beiden sudanischen Zonen ($p<0,01$); die effektive Fresszeit war dagegen in der südlichen Sudanzone am längsten ($p<0,05$). Eine proportionale Abnahme von Ruhephasen war während der Regenzeit (Juni - Oktober) im Vergleich zur kühlen (November - Februar) sowie heißen Trockenzeit zu beobachten ($p<0,05$), während gleichzeitig der proportionale Anteil der Marschzeit zunahm. Unabhängig von der Jahreszeit erfolgte die Futteraufnahme in der südlichen Sahelzone bei allen drei Arten signifikant häufiger in bewaldeten Bereichen (Baumdeckung 5-10% oder Strauchdeckung >10%), während sie sich in den beiden sudanischen Zonen vornehmlich auf Waldflächen (Baumdeckung >10%) konzentrierte. Daraus lässt sich ableiten, dass bei gleichzeitiger Ausdehnung von landwirtschaftlich genutzten Flächen verbleibende Waldinseln und baumreiche Bereiche, einschließlich älterer (und damit buschbestandener) Brachflächen wertvolle Weidegründe für die lokalen Wiederkäuerherden darstellen. Es sollten daher

Maßnahmen ergriffen werden, um dem Rückgang solch bewaldeter Bereiche entgegenzuwirken und gleichzeitig den Schutz sowie die (Wieder-)Anpflanzung dürretoleranter Futterbäume aktiv zu fördern.

In einer weiteren Studie (Kapitel 3) wurde die Futterselektion der genannten Herden weidender Rinder und kleiner Wiederkäuer untersucht, und 75 Tierhalter zum Weideverhalten ihrer Tiere sowie zur Behandlung von Tierkrankheiten mit traditionellen pflanzlichen Medikamenten befragt. Ziel war es, die Auswirkungen des Klimawandels auf die Ernährung und Gesundheit der Nutztiere zu erfassen. Über alle drei untersuchten agro-ökologischen Zonen hinweg zeigen die Ergebnisse eine bevorzugte Nutzung holziger Futterpflanzen durch die drei Tierarten. Der Anteil der auf Selektion solcher Pflanzen verwendeten Zeit an der Gesamfreßzeit war dabei bei Ziegen signifikant höher als bei Schafen und Rindern ($p<0{,}01$). Die Bedeutung holziger Arten für die Tierernährung war in der südlichen Sahelzone sowie in der nördlichen Sudanzone ausgeprägter als in der südlichen Sudanzone, und in der kühlen und heißen Trockenzeit jeweils höher als während der Regenzeit. Lediglich Ziegen wiesen eine ganzjährlich gleich bleibende Präferenz für holzige Futterpflanzen auf. Insgesamt 75 holzige Arten wurden von den Tieren im Laufe eines Jahres gefressen. Dabei zeigten Rinder eine starke Präferenz für *Afzelia africana, Pterocarpus erinaceus* und *Piliostigma* sp., während Schafe und Ziegen vorrangig *Balanites aegyptiaca, Ziziphus mauritiana* and *Acacia* sp. selektierten. Der Rohproteingehalt (in der Trockenmasse) von Früchten und Blättern der bedeutendsten Futterpflanzen reichte von 7% bis 13% bei Hülsen sowie 10% bis 18% bei Blättern. Der Anteil an verdaulicher organischer Substanz variierte bei diesen Arten zumeist zwischen 40% und 60%, während die Konzentration an Gesamtphenolen, kondensierten Tanninen und Lignin (ADL) gering war. Die Ergebnisse der Befragungen von Viehhaltern wiesen auf eine zunehmende Bedeutung holziger Futterpflanzen für die Ernährung der weidenden Wiederkäuer hin, während ihr Einsatz als Medizinalpflanzen für Tiere in den letzten zwei Jahrzehnten zunehmend an Bedeutung verlor. Somit stellen holzige Arten qualitativ und quantitativ auch weiterhin eine wichtige Futtergrundlage für die pastoralen und agro-pastoralen Viehbestände in Burkina Faso dar, und werden in ihrer Bedeutung noch zunehmen, wenn die Produktivität der Krautschicht kommunaler Weideflächen infolge klimatischer Veränderungen und anthropogenen Druck weiter sinkt. Um die Vorzüge holziger Futterpflanzen zu nutzen, sollten solche Arten, insbesondere mit guter lokaler Adaptation, in den agro-pastoralen Systemen erhalten und (wieder) verbreitet werden. Neben einer Verbesserung der Ernährungssituation der lokalen Herden würde dies gleichzeitig die Artenvielfalt sowie die Bodenfruchtbarkeit auf degradierten Weideflächen erhöhen.

Mithilfe von Haushaltsbefragungen von 76 Ackerbauern und 83 Viehhaltern in den genannten vier Dörfern sowie im Dorf Zogoré (südliche Sahelzone) und Karangasso Vigué (nördliche

Sudanzone) und weiteren partizipativen Methoden wurde die Wahrnehmung von Phänomenen des Klimawandels durch die örtliche Bevölkerung sowie deren Anpassungsstrategien analysiert (Kapitel 4). Die Mehrzahl der befragten Personen berichtete von steigenden Temperaturen und abnehmenden Regenmengen innerhalb der letzten zwei Jahrzehnte. Die Wahrnehmung des Temperaturanstiegs entspricht dabei den Ergebnissen der regional erhobenen Klimadaten durch den meteorologischen Dienst Burkina Fasos, während der Eindruck von rückläufigen Niederschlagsmengen im Widerspruch zu den vorliegenden meteorologischen Daten steht, welche einen leichter Anstieg der Niederschlagsmenge in der Region verzeichnen. Laut Aussage aller befragten Bauern haben Klimaveränderungen negative Auswirkungen auf den Ernteertrag sowie die Viehhaltung. Die meisten Bauern haben daher bereits Anpassungsstrategien entwickelt, um diese negativen Folgen abzumildern. Obwohl die meisten dieser Gegenmaßnahmen wirkungsvolle Strategien gegen wiederkehrende Dürren und klimatische Veränderungen darstellen, sind sie weitgehend unwirksam im Kampf gegen zu erwartende extreme Klimaereignisse. Daher sollte es Ziel staatlicher und nichtstaatlicher Organisationen sein, effektive politische Instrumente und praktische Maßnahmen auf lokaler, regionaler, und nationaler Ebene zu entwickeln, die die Folgen des Klimawandels für die landwirtschaftliche Bevölkerung abmildern und damit gleichzeitig ihren Fortbestand sichern. Solche Anpassungsprogramme sollten standortbezogen sein und die bisherigen Erfahrungen der lokalen Bevölkerung im Umgang mit klimatischer Variabilität und mit klimatischen Veränderungen berücksichtigen.

Chapter 1

General introduction, study objective and research hypotheses

1.1. Livestock farming system in West Africa: potential and constraints

In West African Sahelian countries, agriculture and livestock husbandry are important economic sectors given their multiple roles for food security, employment and their contribution to the Gross Domestic Product (GDP). Pure crop cultivation systems, mixed crop-livestock systems and pastoral livestock systems are the major forms of farming. The total number of domestic animals is estimated at about 60 million and 160 million cattle and small ruminants, respectively, which contribute about 20 to 30% of the agricultural GDP of the Sahelian countries (CILSS, 2010). Particularly in Burkina Faso, livestock keeping contributes about 15% to the national GDP and involve, in one way or the other, more than 90% of the rural population. The country’s livestock population is estimated at 7.9, 7.5 and 11.3 million head of cattle, sheep and goats, respectively, whereby 70% of the cattle are managed by transhumant Fulani groups (MRA, 2005). The dominant livestock husbandry systems in the Sahelian and Sudanian zone of West Africa countries are transhumant pastoralism, and predominantly sedentary, sometimes also semi-transhumant agro-pastoralism. The latter is characterized by a more or less intensive integration of crop and livestock farming, and is mostly characterised by small size of the cattle and small ruminant herds (Blench, 2001). Transhumant pastoralism*,* on the other hand, is defined as “a system of animal production characterised by seasonal and cyclical migration of varying degrees between complementary ecological areas and supervised by few people, with most of the group remaining sedentary” (Blench, 2001). Transhumant pastoralism involves 70% to 90% of the cattle and 30% to 40% of the goats and sheep in the Sahelian zone, supplying about 65% and 40% of cattle and small ruminant meat in West Africa (OCDE/SWAC, 2009). The seasonal mobility of ruminant herds, main characteristic of mobile systems, is adapted to marginal, unbalanced and changeable environments such as the Sahelian zone (Standford, 1983). Micro-mobility as well as long-distance transhumance are ways of adapting to a harsh environment and the spatio-temporal variability of forage resources, and has since centuries allowed pastoralists and agro-pastoralists to use the complementary natural pastoral resources of the Sahelian and Sudanian zones (Thebaud and Batterbury, 2001, Adriansen and Nielsen, 2002, Brook, 2006; McGahey, 2011). Recent studies proved that pastoralism, for ecological, social and economic reasons seems to be adapted to arid and semi-arid regions of West Africa (Fratkin and Mearns, 2003; Hatfield and Davies, 2006; OECD/SWAC, 2008; Mortimore, 2010). Pastoralism and agro-pastoralism have allowed the local population groups to cope with recurrent droughts and high climate variability in the region, whereby agro-pastoralism is considered as adaptation strategy to climate variability and change (CILSS, 2009). However, the transhumant pastoralism formerly practiced in the Sahelian zone has been threatened by the severe droughts of the years 1973/74 and 1984 which caused changes in the pastoral management system due to changes in land use, vegetation changes and socio-economic transformation (Nori et al., 2008; Basset and Turner, 2007). Nowadays, the transhumant pastoralism is in transition to “semi-transhumance” or agro-pastoralism with the sedentarisation of former pastoralists, who now also rely on cereal cropping for household purposes. Pastoralist groups have moved from the Sahelian zone to settle in the Sudanian zone where water and forage resources are still abundant: pastoralists from Burkina Faso, Mali and Niger have been gradually settling down in northern Ghana, Benin and Ivory Coast since the severe droughts of the 1970s and 1980s (Tonah, 2003; Bassett and Turner, 2007). The increasing livestock densities in the Sudanian zones of West Africa, in addition to cropland expansion and agricultural intensification, increase the pressure on the yet relatively abundant natural resources – soil, water, and vegetation.

1.2. The role of ligneous fodder resources for ruminant husbandry in semi-arid and sub-humid West Africa

In the Sahelian and Sudanian zone of West Africa, primary fodder resources for ruminants are natural forages such grasses and dicotyledonous herbaceous species, ligneous plants and crop residues (Teferedegne, 2000). A ligneous fodder plant, so-called “browse”, comprises the tender shoots, twigs and leaves of shrubs and trees, and their fruits and pods (Devendra, 1996). Browse plants provide valuable fodder that, particularly in the dry season, supplements the senescent herbaceous vegetation and cereal residues of poor digestibility and low nutritive value. Numerous studies have addressed the value of browse for livestock nutrition, such as an increased metabolizable energy intake, nitrogen intake and feed use efficiency, and thus an improved reproductive and productive performance of the animals (Le Houerou, 1980a; Fall Touré et al., 1998; Abdulrazak et al., 2000; Sangaré et al., 2003; Bwire et al., 2004; Yayneshet et al., 2009). Browse availability is especially important for grazing livestock systems, where it enables survival of sheep, goats, cattle and camels during dry periods and drought years (Le Houerou, 1980b; Thomas and Sumberg, 1995; Devendra, 1996), and herders generally have a good knowledge on the occurrence, palatability and availability of browse (Bellefontaine et al., 2002; Gautier et al., 2005). Apart from direct grazing of browse plants and their organs, different techniques are practiced by herders to make browse material available to livestock. Pruning, which consists in “eliminating dead or small branches and the suckers that tend to weaken the tree”, is often practiced by herders (Teferedegne, 2000). This technique aims to obtain a maximum amount of forage and also has a positive effect on tree growth and leaf production if properly practiced (LEAD, 1999). Leaves and pods are also harvested by agro-pastoralists and serve as feed supplement for sedentary animals during the dry season (Sanon, 2005).

For the Sahelian zone of Burkina Faso, Sanon et al. (2007a) reported that browse represented 43 - 52%, 5 - 28% and 4 - 7% of the daily diet of grazing goats, sheep and cattle. The contribution of browse to the daily diet of small ruminants may be greater than of herbaceous forage in certain areas and during dry seasons: in Botswana goats spent 50% and 80% of their daily feeding time on browse fodder in the wet and the dry season (Ommple et al., 2004). The use of browse for livestock nutrition has also been promoted through the implementation of shrub- and tree-based fodder banks in agro-forestry and silvo-pastoral systems (Kessler and Breman, 1991; Ayuk, 1997). Those systems have several benefits: firstly, environmental improvement by increasing soil fertility and productivity; secondly, increased water infiltration and erosion control; and thirdly improvement of animal production through the provision of quality livestock feed (Le Houerou, 2006). The most promising multipurpose species used in these systems are *Gliricidia sepium* and *Leucena leucocephala* as exotic species*, Acacia senegal, Faidherbia albida, Prosopis africana, Pterocarpus erinaceus* and *Afzelia africana* as native adapted species (Dowela et al., 1997*).* The nutritive value of browse plants has also been widely investigated – while leaves with metabolizable energy (ME) content between 3 and 5 MJ ME kg^{-1} DM can ensure the maintenance of sheep but do not allow for production, maintenance and production of goats may be provided by a pure browse diet (Devendra, 1996; Table 1.1). However, the potential use of browse as ruminant feed is often limited by the presence of anti-nutritional factors that affect nutrient availability, palatability and intake of the respective plant or plant part (D'Mello, 1992; Balogun, et al., 1998; Aganga and Tshwenyane, 2003). Those factors are mostly non-protein amino acids (mimosine and indospecine), glucosides (cyanogens and saponins) and polyphenolic compounds such as tannins and lignin. In semi-arid and sub-humid West Africa, browse fodder is especially important as feed for livestock in dry season and drought periods, when grasses and herbages lack, both quantity and quality (Thomson et al., 1987). As indicated by Yayneshet et al. (2009), during the rainy season grass species contained crude protein levels close to the critical level suggested for maintenance, but in general, ruminants cannot satisfy their maintenance needs on dry grass alone over the whole dry season. In particular, they would suffer from mineral deficiency, but they also depend on browse to saturate their needs of protein, phosphorus, calcium and vitamin A (Le Houerou, 1980b). Although, browse nutrient contents and digestibility also decrease in the course of dry season, fresh or dry browse leaves available at that period of the year, have nutrient contents adequate to sustain smallholder livestock production systems (Yayneshet et al., 2009). Browse thus plays a very important role for livestock nutrition in semi-arid and sub-humid West Africa; it provides an ideal and necessary complement for the diets of goats, sheep and cattle especially during the long dry season and droughts periods (Le Houerou, 1980a). Many species are selected on pasture by ruminants according to their preference, palatability, occurrence, abundance and nutritive value (Ngwa et al., 2000). Among the most important livestock reared in West Africa, goats' intake consists to a very large part of browse due to their feed preferences for a very diverse diet. This was affirmed by the high number of different species goats consumed in preference trials (Ngwa et al., 2002). In the respective feeding trials, *Acacia senegal, A. nilotica, Dichrostachys cinerea* and *Pterocarpus lucens* showed to be high quality protein supplements (Rubanza et al. 2006). Sheep and cattle also consume browse, especially in the dry season when grass and herbage is scarce (Bwire et al., 2004; Sangaré et al., 2003). For both, *Guiera senegalensis* played a major role in preference and feeding trials. Additionally, *Acacia albida, A. tortilis, Dichrostachys cinerea* and *Ziziphus mauritania* induced high weight gains (Fall-Touré, 1997; Bwire et al., 2003; Yayneshet et al., 2008). Pods and fruits are especially valuable for supplement feeding, and leguminous browse is of particular importance for the diets. Concerning browse species above biomass production, of 16 Sahelian and Sudanian browse species such *Acacia senegal*, *A. dudgeoni, A. macrostachya, Afzelia africana, Daniellia oliveri, Ficus sycomorus* subsp. *Gnaphalocarpa, Pterocarpus erinaceus, Guiera senegalensis, Pterocarpus lucens, Balanites aegyptiaca Piliostigma thonningii, Anogeissus leiocarpa, Combretum glutinosum, C. micrantum, C. nigricans* and *Detarium microcarpum* above ground biomass production can be estimated by species-specific allometric equations using dendrometric parameters (Sanon et al., 2007b; Bognounou et al., 2008; Sawadogo et al., 2010) as well as a combination of allometric equations and satellite imagery approaches (Savadogo and Elfving, 2007). The existence of generalized or species-specific allometric equations for the prediction of tree biomass production is of increasing interest in the actual context of climate change for carbon sequestration studies but could also be used for determining edible foliage and twig biomass in livestock nutrition investigations. For Sub Saharan African forests, about 850 available allometric equations and 125 related references were reviewed by Henry et al. (2011) and incorporated into an open-access database on the Carboafrica website (www.carboafrica.net).

1.3. Anticipated climate change in West Africa

1.3.1. Consequences for farming systems in semi-arid and sub-humid zones

Climate projections for West Africa are consistent when it comes to predicting and forecasting temperature changes, but projections of future rainfall patterns and overall amounts are contrasting. According to IPCC (2007), the average rise in temperature between 1980/99 and 2008/99 is expected to be between 3°C and 4°C for the whole African continent with the highest increase in West Africa (+4°C). According to the vulnerability and adaptation analyses by MECV (2007), temperature projections based on the climate model of the Meteorological Research Institute (MRI) of the Japanese Meteorological Agency (JMA) indicated that in Burkina Faso average daily temperatures will increase by about 0.8°C in 2025 and 1.7°C in

2050 as compared to year 1990, whereby the increase may be doubled due to seasonal variation. At the same time, the average annual rainfall will be reduced by 3.4% in 2025 and by 7.3% in 2050, with very strong inter-annual and seasonal variability. Local farmers have also observed an increase in maximum daily temperatures and a decrease in rainfall over the last decade in the Sahelian region (Metz et al., 2009). Although there is still a fair amount of uncertainty in rainfall-related climate projections for West Africa (Brook, 2006; OCDE/SWAC, 2009), changes will occur and increasing climate variability will have negative impacts on cereal production, land use, water resources and food security (Mendelsohn, 2009). As far as the regional grazing-based livestock systems are concerned, the anticipated changes will very likely lead to a decreasing animal productivity and will threaten the provision of a wide range of livestock products (MRA, 2005; Nardone et al., 2010) due to an expected drastic reduction of pasture biomass production and of the possibilities for watering the major livestock species, namely cattle, sheep and goats (Seo and Mendelsohn, 2006). The grazing and rainfed mixed systems will be threatened most by the negative effects of climatic change (Nardone et al., 2010; Crane et al., 2011); nevertheless the integrated crop-livestock systems are presumably more resilient than the specialised pastoralist systems (Seo, 2010). In order to mitigate or reduce the increased vulnerability of their production systems and thus their livelihoods, crop and livestock farmers in the region respond to climate change and variability by various adaptation strategies (Nyong et al., 2007). Studies reported an adoption of a wide range of small-scale adaptation and coping strategies by local farmers to secure their farming activities and incomes (Barbier et al., 2010; Ouedraogo et al., 2010, Metz et al., 2009, 2011). At the national level, most of the Sahelian and Sudanian countries in West Africa have adopted national programmes to mitigate the negative impacts of climate change (Kandji et al., 2006). How effective these are in reaching the local crop and livestock farmers and sustaining their livelihoods remains to be investigated.

1.3.2. System vulnerability and adaptive capacity

There have been many attempts to define vulnerability in relation to climate change (Adger et al., 2005; Brooks et al., 2005; Barry and Wandel, 2006; Traerup, 2010) and each definition depends on the purpose of the study. According to the IPCC (2007), vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. It is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptation capacity (IPCC, 2001). Vulnerability has also been defined as ”the propensity of human and ecological systems to suffer harm and their ability to respond to stresses imposed as a result of climate change effects” (Adger et al., 2007). Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007, p. 869). In sub-Sahara Africa, the Sahelian countries are considered to be more vulnerable than others because of the intrinsically high climate variability in the region and the low local adaptive capacity (Sarr, 2010).

1.3.3. Farmers' coping measures and adaptation strategies

In the literature on adaptation to climate change, the term 'coping' is sometimes used as a synonym for adaptation (Fankhauser et al., 1999). But the two concepts are differently used in many cases. Dinar et al. (2008) defined coping strategies as those that have evolved over time through people's long experience in dealing with the known and understood natural variation that they expect in seasons, combined with their specific responses to the season as it unfolds. The same author defined adaptation strategies as long term strategies that are needed for people to respond to a new set of evolving biophysical, social and economic conditions that they have not experienced before. This definition of adaptation is consistent with IPCC (2007) that defined adaptation as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, in order to moderate harm or exploit beneficial opportunities. Adaptation can be anticipatory (i.e. proactive) or reactive (Frankhauser et al., 1999; IPCC, 2007). Anticipatory adaptation takes place before impacts of climate change have been actually observed, whereas reactive adaptation occurs after the impacts have been observed. Both anticipatory and reactive adaptations may further be differentiated as either public or private. While public adaptation is normally initiated, implemented or facilitated by governmental institutions, the private one is initiated and implemented by individuals, households, or communities.

1. 4. Study objective, research hypotheses, and thesis outline

Against the background of increasing climate variability and anticipated negative effects of climate change in the Sahelian and Sudanian zones of West Africa, this PhD research project aimed to investigate the importance of the ligneous vegetation for the nutrition of domestic ruminants in the semi-arid and sub-humid zones of Burkina Faso, and determine current and possible future impacts of climate change and variability on livestock grazing management as this provides the basis for livestock production.

Therefore, it departed from the following hypotheses:

1. The impacts of climate change on the agro-silvo-pastoral production systems of Burkina Faso can be studied along a transect representing a false timeline and ranging from the semi-arid sub-Sahelian zone (already more strongly affected by climate variability) to the more humid northern and southern Sudanian zones (most probably affected by increasing climate variability in the near future).
2. Browse fodder will play an important role for ruminant nutrition in these systems as climate variability increases and probabilities and patterns of precipitation change.
3. Although agro-pastoralist and pastoralists perceive the impacts of climate change on their cropping and livestock activities, their adaptation strategies are of very limited effectiveness.

To achieve the main objective, participatory rural appraisal tools including focus group discussions and household interviews (chapter 4) were combined with repeated herd monitoring of feeding behaviour (chapter 3) and itinerary tracking using global positioning and geographical information systems tools (chapter 2) across three agro-ecological zones of Burkina Faso (Figure 1.1). This allowed in chapter 2 an assessment of the possible impacts of climate change on ruminants' general grazing itineraries and specifically the selection of grazing areas, and in chapter 3 the determination of the probable consequences of climate change for the contribution of browse to ruminant nutrition and health care across the three agro-ecological zones. Chapter 4 evaluates the perception of pastoralists and agro-pastoralists on climate change and its possible impact on livestock management, as well as their respective adaptation and coping strategies. Results and insights gained in the previous chapters are discussed comprehensively in chapter 5, and implications with respect to projected climatic and environmental changes in the Sahelian and Sudanian region of Burkina Faso and neighbouring countries are discussed.

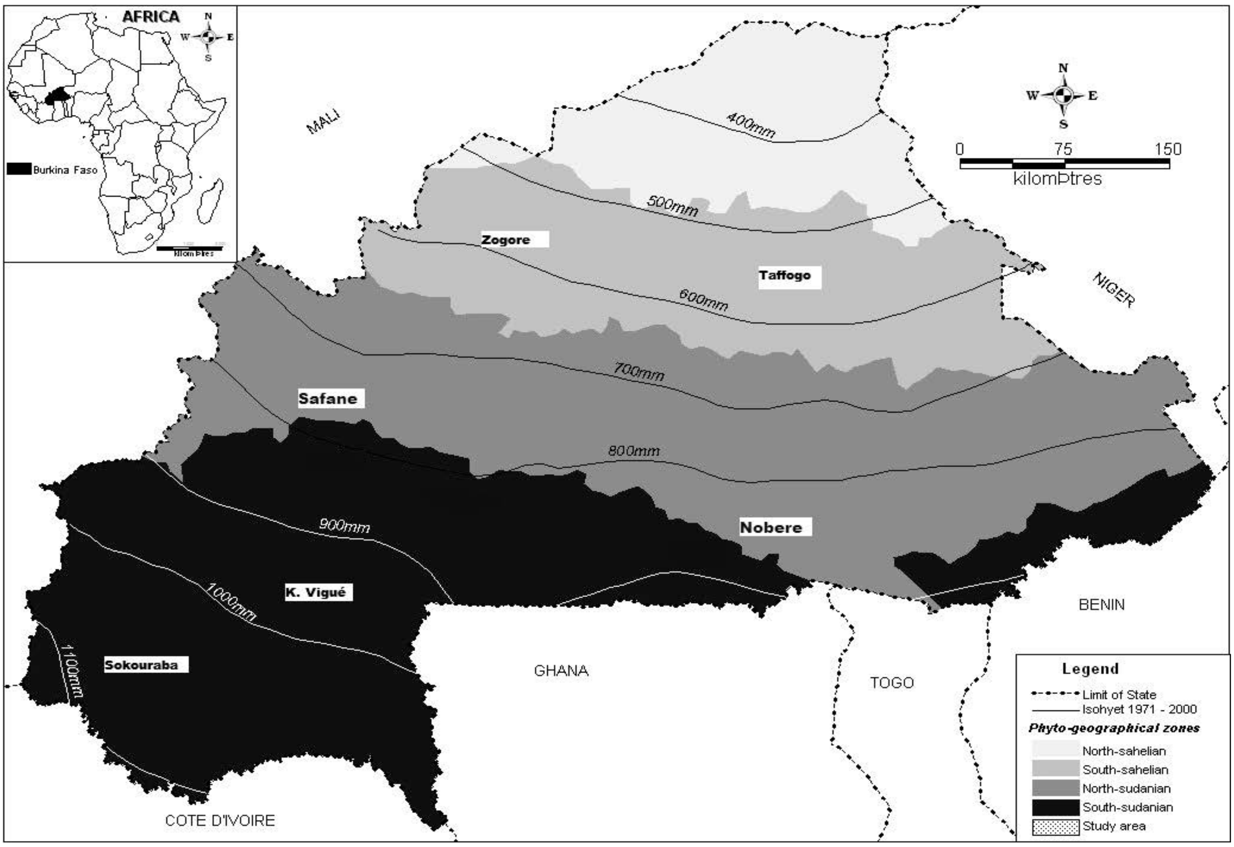

Figure 1.1: Agro ecological (phyto-geographical) zones of Burkina Faso with isohyets and location of the six study sites (Readapted April 2007 by CTIG/INERA/Burkina Faso after Fontes and Guinko 1995 and Direction of the National Meteorology).

Table 1.1: Feeding value of dry grass and browse during the dry season (Le Houerou, 1980b)

Feed	NE (MJ/kg DM)	Digestible Protein (g/kg DM)	P (g/kg DM)	Ca (g/kg DM)
Dry grass/ straw	2.6- 3.4	-	-	1.5- 3.0
Browse	1.7- 3.0	56- 300	1.5- 2.5	2.5- 20
Maintenance needs	3.0	50	1.3	2.5

Note: NE (Net energy), DM (dry Matter), P (Phosphorus), Ca Calcium).

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Chapter 2

Spatio-temporal variation in use of grazing areas and foraging behaviour of cattle and small ruminants across three agro-ecological zones of Burkina Faso

Spatio-temporal variation in use of grazing areas and foraging behaviour of cattle and small ruminants across three agro-ecological zones of Burkina Faso

Abstract

We investigated the spatio-temporal variation in the use of grazing areas and foraging time of ruminants in the southern Sahelian, northern and southern Sudanian zone of Burkina Faso by monitoring three herds each of cattle, goats and sheep in four village territories during a one-year cycle. Grazing routes were tracked using a Global Positioning System; coordinates logged at 10 s intervals were overlaid on maps from where time allocated to different land cover types and dominant animal activities there were derived. Maximum itinerary lengths (km/d) were observed in the hot dry season; they were longer for sheep (18.8) and cattle (17.4) than for goats (10.5, $p<0.05$). Daily time on pasture ranged from 6 - 11 h and was longer for cattle and sheep than for goats ($p<0.05$). Proportional time spent resting decreased from the rainy to the cool and hot dry season ($p<0.05$), while in parallel proportional walking time increased. Feeding accounted for 52% – 72% of daily time on pasture for cattle, sheep and goats ($p>0.05$), while time spent walking was higher for cattle and sheep than for goats ($p<0.01$). Feeding time of all species was to a significant proportion spent on wooded and forest land in all zones, irrespective of season. This indicates that under the ongoing cropland expansion, remaining islands of wooded land are particularly valuable pasturing areas for ruminant stock. Measures are needed that counteract the shrinking of forests and wooded land across the whole region, including active protection and (re)establishment of drought-tolerant fodder trees.

Keywords: Agro-pastoral system, global positioning system, ruminants, Sahelian zone, Sudanian zone, West Africa.

2.1. Introduction

Mobility is key for livestock production in the agro-pastoral systems of West Africa. Population growth and increased climatic risk of crop failure lead to cropland expansion which affects herd mobility and access to forage resources to varying degrees across agro-ecological zones. In the Sahelian region, several studies have investigated livestock grazing behaviour and feed selection on pasture to understand its implications for livestock nutrition and production (Provenza, 1996; Decruyenaere et al., 2009; Goetsch et al., 2010) and the interaction between livestock and the environment (Ayantunde et al., 1999; Baumont et al., 2000; Nianogo et al., 2004). Some of theses studies also focused on the role played by grazing animals for nutrient cycling and its spatio-temporal aspects in the Sahelian and Sudanian agro-ecosystems (Ickowicz et al., 1999; Schlecht et al., 2004). Methodological approaches used in livestock grazing studies are often herd monitoring based on direct observation of grazing behaviour, or herder interviews (Petit and Diallo, 2001; Turner and Hiernaux, 2002; Vall and Diallo, 2009). Recently, an increased use of Global Positioning Systems (GPS) and Geospatial Information Systems (GIS) can be observed (Turner et al., 2001; Barbari et al., 2006; Schlecht et al., 2009; Anderson, 2010). In Burkina Faso studies on grazing behaviour focused on cattle herds (Petit, 2000; Botoni, 2003) and were mostly limited to one agro-ecological zone, either the Sahelian zone (Sanon et al., 2007) or the Sudanian zone (Ouédraogo-Koné et al., 2006). Although these studies have provided important results on the foraging behaviour of freely grazing and herded animals, and contributed to the acknowledgement of the importance of herd mobility for the sustainability of the regional agro-pastoral and pastoral livestock husbandry systems (Diarra et al., 1995; Cesar and Zoumana, 1999; Botoni, 2003), comparative analyses of the spatio-temporal arrangements of livestock grazing and foraging behaviour across the major agro-pastoral zones of West Africa are lacking. Yet, the recurrent droughts in the 1970s and 1980s, the overall decline in rainfall since the past 20 years (Yoshioka et al., 2007; MECV, 2007; Sarr, 2010) and population growth have profoundly altered land use patterns and intensities, livestock numbers, species composition of national herds and livestock management (Turner et al., 2005; Dicko et al., 2006; Pare et al., 2008; Mougin et al., 2009). These changes, together with a reduced herd mobility due to reduced availability and accessibility of forage and water resources and rural labor scarcity (Thebaud and Batterbury, 2001; Tiffen, 2006; Ouedraogo et al., 2010; Hoffman and Vogel, 2008), increasingly challenge adequate nutrition of extensively managed ruminant stock in the agro-pastoral zones of West Africa – not only in the late dry and early rainy season, where this has always been problematic, but also in the other periods of the year (Ayantunde et al., 2008). Since most climate change scenarios predict an increased variability and overall modification of rainfall regimes in the Sahelian and Sudanian zones of West Africa (IPCC, 2007; Ruti et al., 2011; Wang and Alo, 2012) we aimed at analyzing, across the three major ago-pastoral zones of Burkina Faso, the spatial distribution of grazing ruminants, so as to identify land cover types that serve as major grazing areas in different zones and at different times of the year. This should enable us to evaluate the likely consequences of land cover change and increasing rainfall variability and scarcity, on the nutritional situation of the majority of the national ruminant stock of West African countries such as Burkina Faso, Mali, and Niger, which contribute 35%, 28% and 30% to the respective country's agricultural GDP (CILSS, 2010).

2.2. Materials and methods

2.2.1. Study location

For this study four different village territories across three agro-ecological zones of Burkina Faso were selected, following a north-south transect. The village of Taffogo represented the sub-Sahelian zone, Nobere and Safane the northern Sudanian zone and Sokouraba the southern Sudanian zone. As for the northern Sudanian zone, Safane is characterised by intense agricultural land use and high population density, while Nobere is located near the National Park Kaboré Tambi of Pô, where Fulani livestock keepers settle and a communal grazing area was established as tampon zone between the village territory and the park by the "Projet d'Appui à la Gestion Participative des Ressources Naturelles" (PAGREN) in 2001. The sub-Sahelian zone, approximately located between latitudes 15°N and 14°N, is characterised by an annual precipitation of 300 - 600 mm which falls from June to September. Moving southwards, rainfall increases to 600 - 900 mm in the northern Sudanian zone (14°00'N to 11°30'N) and to more than 1000 mm in the southern Sudanian zone (11°30'N to 9°00'N), while the length of the rainy season increases to 5 – 6 months (May/June to October/November).

2.2.2. Data collection

2.2.2.1. Livestock herd tracking and observation of grazing behaviour

The grazing behaviour and daily grazing itineraries of cattle, sheep and goats was assessed using lighter-sized trackstick GPS[1] devices. In each village one representative herd of cattle, sheep and goats, mainly of pastoralist families, were selected (3 herds per village, identified during a baseline survey). With the exception of the sheep herds in Taffogo and Safane during the hot dry season, all herds were surveyed by a herder year-round. Within each herd of cattle, sheep and goats, one representative female animal was equipped with the GPS, which was fixed to the animal's horn. The GPS was switched on when the herd set out for pasture in the morning (between 7 – 9 a.m.) and when the herd returned from pasture in the evening (around 6 - 7 p.m.) the raw data file was downloaded and saved on a laptop. At intervals of 10 seconds the GPS recorded the date, time, altitude, longitude, latitude and ambient temperature. Each herd was monitored during three consecutive days, once each during the rainy (June - September 2009), cool dry (October 2009 - January 2010) and hot dry season (February - May 2010). A total of 108 itineraries were thus recorded (3 animal species, 4 study sites, 3 seasons, 3 days of observation per season and herd).

2.2.2.2. GPS data processing and land use mapping

The 108 GPS raw data files were firstly processed in Microsoft® Excel™, where the horizontal distance (D_H) covered between two subsequent positions (x_1/y_1; x_2/y_2) was calculated according to equation [1], whereby d_1 equals 107,800 m per longitudinal degree and d_2 equals 110,400 m per latitudinal degree at the study locations. The vertical distance (D_V) covered was derived from the difference in altitude between position 1 (z_1) and position 2 (z_2; $DV= z_2 - z_1$), and the total distance covered between the two positions, D_T, was then calculated according to equation [2]. The distances covered between individual points were then summed up to daily distances walked, and likewise the total time on pasture, that is the time elapsed between morning departure and evening return to the corral or homestead, was derived from the GPS records. The speed of position change (v) was calculated dividing distance D_T by the time elapsed between two successive position loggings. In a second step the data on speed of position change was averaged per minute. Using the criteria established by Schlecht et al. (2004) and Moreau et al. (2009), these average values of speed of movement then served to deduce the animals' behaviour on pasture, namely resting or very slow motion feeding (<0.12 m/s), feeding including walking between feeding stations (0.12 - <0.62 m/s) and directional movements (that is walking; $\geq$0.62 m/s). The activities were then expressed as proportion of the daily time spent on pasture; the latter calculations were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

$$D_H = \sqrt{(x_2 - x_1)^2 d_1 + (y_2 - y_1)^2 d_2} \qquad \text{[Eq. 1]}$$

$$D_T = \sqrt{(D_H)^2 + (D_V)^2} \qquad \text{[Eq. 2]}$$

For each study site, a land cover map was elaborated for a 10 km x 10 km area per village (with the village being close to the central point of the quadrate). The following land cover classes (FAO, 2010) were distinguished: (1) *forest*, (2) *other wooded land*, (3*) other land*, or

(4) *other land with tree cover*, which is a sub-category of "*other land*" (Fischer et al., 2011). The shape files of the 108 itineraries were overlaid on the land cover map of the respective territory, and the time spent and distances crossed per land cover type were extracted using Arc GIS 9.2. By coupling this information with the derived behaviour classification, the relative allocation of different activities to different land cover types was calculated as well.

2.3 Statistical analyses

The statistical analyses of GPS/GIS derived information were performed using the general linear models (GLM) procedure of SPSS v.19 (SPSS Inc. Chicago, USA). Characteristics of grazing itineraries (total duration and distance, proportion of time devoted to different land use types), animal behavior (proportion of time spent resting, feeding and walking, and proportion of resting, feeding and walking time spent on different land cover types) were compared between animal species (n=3), seasons (n=3) and locations (n=4). While cattle and goat data sets were normally distributed, this was not the case for the sheep data. Yet, we refrained from normalizing that data, therefore reported p-values are indicative only. Post-hoc comparison of means was performed using the Tukey test.

2.3. Results

2.3.1. Characteristics of daily grazing itineraries

Total duration and length of the daily grazing itineraries of cattle ranged from 8 to 11 hours and from 7.5 to 17.4 km per day, respectively (Table 2.2). Across seasons, cattle herds stayed longer on pasture in Nobere (9.2 h) and Taffogo (9.6 h) than in Safane (8.1 h) and Sokouraba (8.5 h); ($p<0.05$), (Table 2.2). Maximum distance travelled by cattle herds was higher in Nobere (13.4 km) than at the others locations ($p<0.01$), irrespective of season. At Safane and Taffogo, daily distance covered were both shorter during the cool dry season than during the rainy and hot dry season ($p<0.05$).

Across seasons, Safane and Taffogo were the locations where goats stayed longer on pasture (9.0 and 9.5 h/d, respectively) and travelled longer distances (8.7 and 8.9 km/d, respectively) than in Nobere and Sokouraba ($p<0.01$). Except for Nobere, the shortest distances travelled by goats were observed in the cool dry season (Table 2.3). The highest values for duration and length were recorded during the hot dry season in all zones, except for Sokouraba where longest values were obtained in the cool dry season.

The duration and length of sheep grazing itineraries ranged from 7.1 to 11.3 h/d and from 8.8 to 18.8 km/d, respectively (Table 2.4). The highest values for duration and length were recorded during the hot dry season in all zones, except for Sokouraba where longest itineraries (length and duration) were observed in the cool dry season. Across seasons maximum distance travelled per day and time spent on pasture by sheep were recorded in Safane (13.2 km/d and 8.7 h/d) and Taffogo (14.7 km/d and 10 h/d).

Among the three animal species cattle spent more time ($p<0.05$) on pasture than goats and sheep. They covered similar distances per day as sheep ($p>0.05$) but longer distances than goats ($p<0.01$) across village territories and seasons.

Table 2.1: Area (km^2) occupied by four major land cover types accounting for the presence/absence of ligneous vegetation in the four mapped village territories located in three different agro-ecological zones of Burkina Faso.

FAO (2010) land cover class	Argo-ecological zone			
	Southern Sahelian:	Northern Sudanian:		Southern Sudanian:
	Taffogo	Nobere	Safane	Sokouraba
Clouds and missing data	2.4	20.1	2.7	71.3
Other land	75.3	26.6	31.4	3.1
Other land with tree cover	1.4	0.1	14.1	14.4
Other wooded land	13.8	35.9	9.1	0.0
Forest	7.1	15.3	42.8	9.4
Total area mapped (km^2)	100.0	97.9	100.0	98.2

2.3.2. Daily behaviour at pasture

The proportion of time spent feeding by cattle was high in the rainy season (65 - 72%) but significantly decreased in the cool and hot dry season for Nobere, Safane and Sokouraba. Resting time for cattle was higher for the southern Sahelian site of Taffogo (15%) and the northern Sudanian sites of Nobere (14%) and Safane (23%) as compared to Sokouraba (10%, $p<0.01$), irrespective of season. The proportion of time spent walking was also highest at the two northern Sudanian sites in the hot dry season, while for the southern Sahelian site and the southern Sudanian ones it was higher during the cool dry season than during rainy and hot dry season. No significant differences were observed for time spent walking by cattle ($p>0.05$).

Proportional time spent feeding, walking or resting, respectively, by sheep (Table 2.4) was not significantly different between locations ($p>0.05$).

For goats, proportional feeding time was higher (p<0.01) at the northern and southern Sudanian sites of Safane (65.4%), Nobere (65.3%) and Sokouraba (67%), than at the southern Sahelian zone of Taffogo (55.6%). The highest proportion of time spent feeding was observed in the cool dry season at Taffogo and Nobere (Table 2.3). The proportion of time spent resting by goats was highest during the hot dry season, except for Safane - however, all differences between seasons were insignificant (Table 2.3). Walking time was highest in Safane in the rainy season (18%, p<0.01) compared to the others sites.

When comparing animal species, cattle and sheep spent a higher proportion of time walking (p<0.05) than goats, while goats spent a higher proportion of time resting than the other two species, irrespective of location (p<0.01). On the other hand, no significant differences were found in the proportion of time spent feeding between cattle, sheep and goats across locations and seasons.

Table 2.2: Characteristics of the daily grazing itinerary and foraging behavior of cattle across three agro-ecological zones of Burkina Faso

Zone (Village)	Season	Tracks (n)	Itinerary characteristics		Daily time spent on grazing activities (%)		
			Duration (h/d)	Length (km/d)	Resting	Feeding	Walking
Southern	Rainy	3	9.0	12.6	10.2	72.2	17.6
Sudanian	Cool dry	3	8.6	13.3	9.0	59.4	31.6
(Sokouraba)	Hot dry	3	8.4	10.9	10.5	68.5	21.0
Northern	Rainy	3	8.3	8.5	19.8	65.4	14.8
Sudanian	Cool dry	3	9.3	14.3	16.0	55.0	29.0
(Nobere)	Hot dry	3	10.0	17.4	9.6	59.3	31.1
Northern	Rainy	3	9.1	10.8	17.7	69.7	12.6
Sudanian	Cool dry	3	8.0	7.5	33.2	52.3	14.5
(Safane)	Hot dry	3	7.4	12.3	21.0	44.0	35.0
Southern	Rainy	3	9.8	12.8	18.0	59.3	22.7
Sahelian	Cool dry	3	8.1	8.0	11.3	63.7	25.0
(Taffogo)	Hot dry	3	11.1	12.4	15.1	61.9	23.0
SEM			*0.44*	*1.27*	*4.61*	*3.20*	*4.05*
Variable		*df*			*p≤*		
Village		2	0.01	0.03	0.01	0.01	0.65
Season		3	0.08	0.03	0.62	0.01	0.01
Village x season		6	0.01	0.01	0.26	0.01	0.02

SEM= Standard error of the mean.

Table 2.3: Characteristics of the daily grazing itinerary and foraging behavior of goats across three agro-ecological zones of Burkina Faso

Zone (Village)	Season	Tracks (n)	Itinerary characteristics		Daily time spent on grazing activities (%)		
			Duration (h/d)	Length (km/d)	Resting	Feeding	Walking
Southern	Rainy	3	8.2	5.3	30.8	66.8	2.4
Sudanian	Cool dry	3	8.1	4.5	31.0	65.9	3.1
(Sokouraba)	Hot dry	3	7.5	4.8	27.7	70.3	2.0
Northern	Rainy	3	6.0	5.8	29.8	58.9	11.3
Sudanian	Cool dry	3	7.5	7.7	19.7	71.0	9.3
(Nobere)	Hot dry	3	8.0	6.1	27.5	66.5	6.0
Northern	Rainy	3	9.1	10.8	20.1	61.9	18.0
Sudanian	Cool dry	3	9.2	6.5	30.9	64.5	4.6
(Safane)	Hot dry	3	8.9	8.7	20.0	69.6	10.4
Southern	Rainy	3	9.2	10.0	27.2	54.6	18.2
Sahelian	Cool dry	3	8.1	6.4	36.0	52.1	11.9
(Taffogo)	Hot dry	3	11.4	10.5	28.8	60.2	11.0
SEM			*0.32*	*0.65*	*2.21*	*2.39*	*1.16*
Variable		*df*			*p≤*		
Village		2	0.01	0.01	0.01	0.01	0.01
Season		3	0.01	0.01	0.11	0.01	0.01
Village x season		6	0.01	0.01	0.01	0.08	0.01

SEM= Standard error of the mean.

2.3.3. Spatio-temporal orientation of grazing itineraries

The feeding and resting behaviour of cattle, goats and sheep on pasture concentrated on distinct pasture areas in each village territory (Appendix 2.1). Similarly, the orientation and choice of specific land cover types for grazing changed across seasons, for any single livestock herd. Moreover, cattle, goat and sheep herds from the same village grazed along different pathways, with daily itineraries starting and ending at their specific night resting place (Appendix 2.1). The proportion of daily time on pasture allocated to different land cover types varied widely according to season, animal species and village territory (Figure 2.1), the latter being partly a result of different proportions of the four distinguished land cover classes in each village territory (Table 2.1).

At the northern Sudanian site of Nobere, cattle always spent a significant proportion of their daily time on pasture on *other wooded land,* irrespective of season ($p<0.05$). At the same site, goat and sheep herds allocated most of their daily time on pasture to *other land*, while the proportion of time allocated to *forest* and *other land with tree cover* was similar to that of cattle across seasons (26-30%). At the northern Sudanian site of Safane, cattle and small ruminants spent a high proportion of daily pasturing time on *forest* and *other land with tree cover* (Figure 2.1), but across species there was a marked influence of season on daily time allocated to the different land cover types (Figure 2.1). At the southern Sudanian site of Sokouraba, cattle spent most time in *forest*, while sheep and goats allocated a similar proportion of their daily time on pasture to *other land*, *forest* and *other wooded land* (Figure 2.1). At the southern Sahelian site of Taffogo, daily time on pasture of cattle, sheep and goats was preferentially spent on *other wooded land* with no significant difference between species in the proportion of daily feeding time spent on this land cover type ($p>0.05$).

In parallel to the variations in the proportion of daily time on pasture allocated to different land cover types, the daily proportion of feeding time spent on different land cover types also varied across seasons, locations and animal species. In Nobere feeding time allocated by cattle to the four land cover types was more or less similar (Figure 2.2a) with no significant difference between seasons. In Safane, the proportion of feeding time allocated to *forest* was higher during the rainy season than during the cool and hot dry season ($p<0.05$), whereas cattle spent a higher share of feeding time on *other wooded land* during the latter two seasons. At Sokouraba, cattle feeding time allocated to *forest* was also higher than the time share allocated to the other land cover types ($p<0.05$) throughout the year. At Taffogo, feeding time of cattle was mainly allocated to *other wooded land* with no significant difference between seasons. Concerning small ruminants, the share of feeding time allocated to the different land cover types varied less between seasons than in cattle (Figures 2.2 b, c). Nevertheless, goats in Safane spent the highest proportion of feeding time on *land with tree cover* during the cool and hot dry season, and preferentially grazed on this land cover type throughout the year in Taffogo. In Sokouraba, goats and sheep spent a high proportion of feeding time on *other land* in the cool and hot dry season, whereas in the rainy season this time share was similar to that allocated to *forest,* which was also the case in Safane.

Table 2.4: Characteristics of the daily grazing itinerary and foraging behavior of sheep across three agro-ecological zones of Burkina Faso

Zone (Village)	Season	Tracks (n)	Itinerary characteristics		Daily time spent on grazing activities (%)		
			Duration (h/d)	Length (km/d)	Resting	Feeding	Walking
Southern	Rainy	3	8.1	8.8	21.2	65.8	13.0
Sudanian	Cool dry	3	7.4	13.1	4.7	62.7	32.6
(Sokouraba)	Hot dry	3	6.7	7.3	18.0	69.7	12.3
Northern	Rainy	3	7.1	9.7	15.0	66.1	18.9
Sudanian	Cool dry	3	7.6	12.0	13.0	58.7	28.3
(Nobere)	Hot dry	3	10.2	11.9	19.2	52.8	28.0
Northern	Rainy	3	9.1	11.6	14.6	68.1	17.3
Sudanian	Cool dry	3	8.1	11.1	17.7	62.1	20.2
(Safane)	Hot dry	3	9.0	16.8	7.2	43.2	49.6
Southern	Rainy	3	9.1	9.5	19.1	69.1	11.8
Sahelian	Cool dry	3	10.2	15.8	13.1	57.9	29.0
(Taffogo)	Hot dry	3	11.3	18.8	11.6	53.7	34.7
SEM			*0.32*	*0.65*	*2.21*	*2.39*	*1.16*
Variable		*df*			*P≤*		
Village		2	0.01	0.01	0.76	0.24	0.18
Season		3	0.15	0.01	0.05	<0.01	<0.01
Village x season		6	0.01	0.01	0.01	0.18	<0.01

SEM= Standard error of the mean.

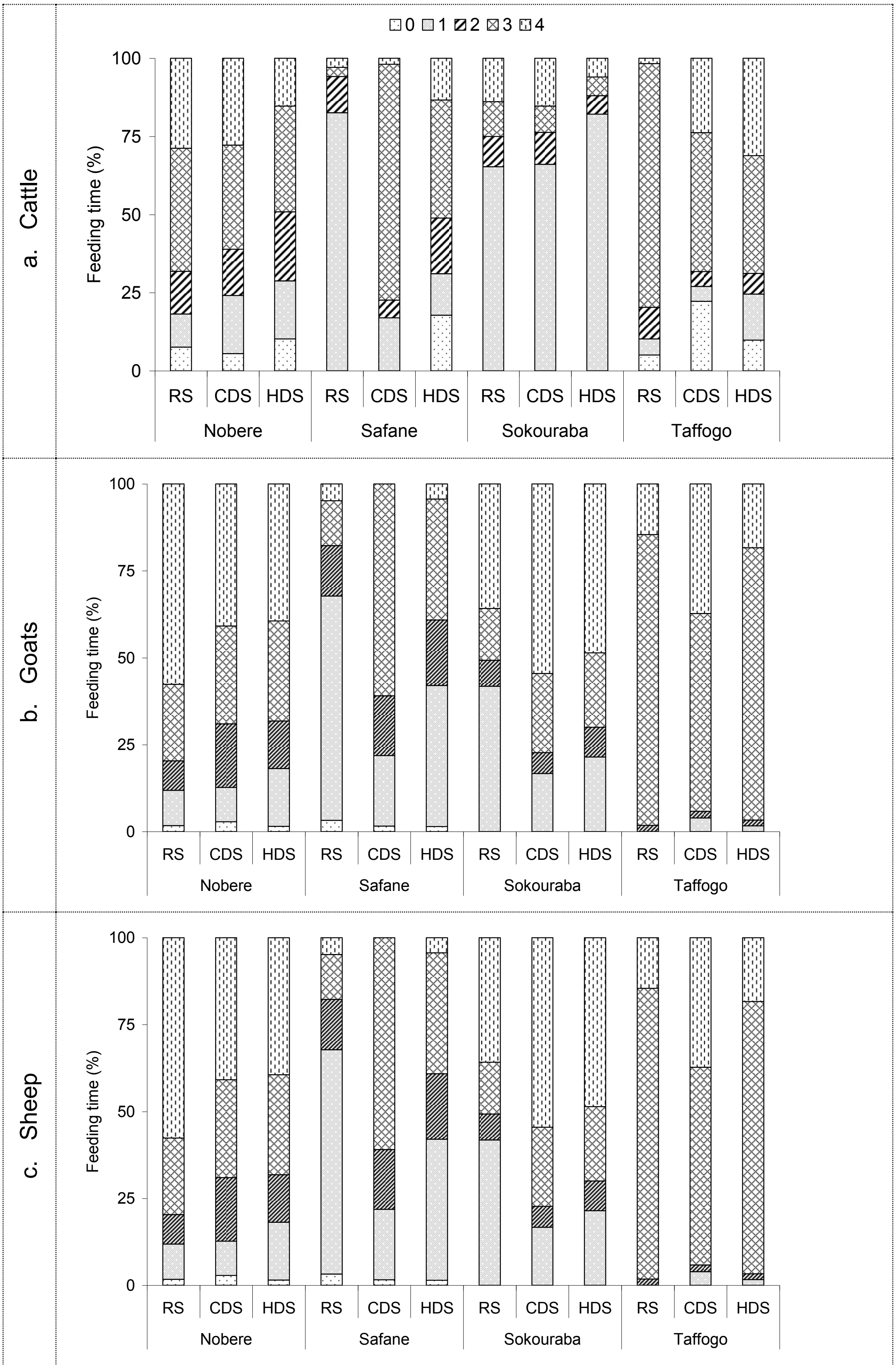

Figure 2.1: Proportion (%) of the daily feeding time allocated to different land cover types by grazing cattle (a), goats (b) and sheep (c) in four village territories of Burkina Faso during the rainy (RS), cool dry (CDS) and hot dry (HDS) season.

Legend: 0= missing data, 1= forest; 2= other land with tree cover, 3= other wooded land, 4= other land

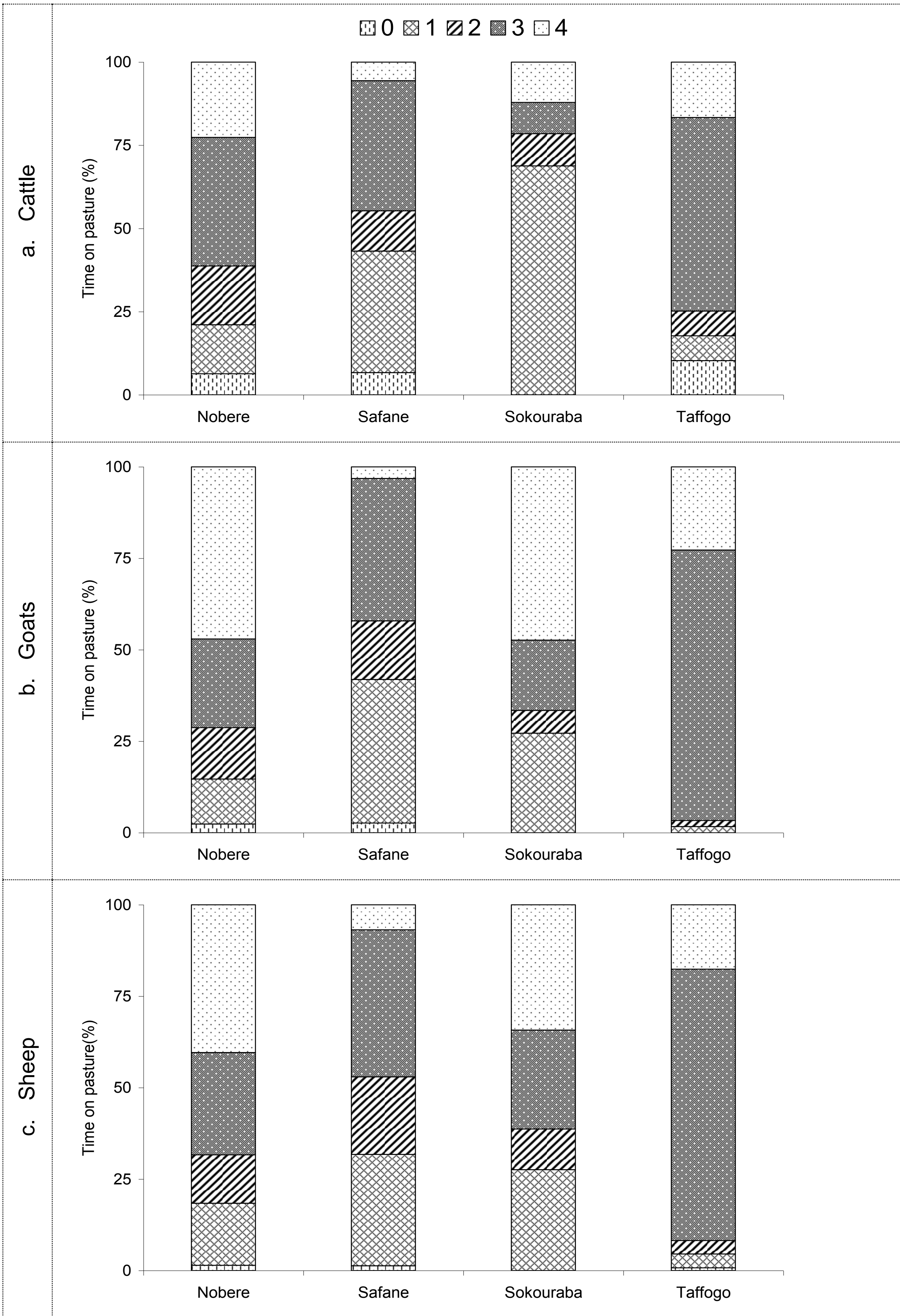

Figure 2.2: Proportion (%) of the daily time on pasture allocated to different land cover types by cattle (a), goats (b) and sheep (c) in four village territories of Burkina Faso a year cycle.

Legend: 0= missing data, 1= forest; 2= other land with tree cover, 3= other wooded land, 4= other land

2.4. Discussion

The spatio-temporal variations in livestock grazing itineraries and foraging behaviour observed in this study were a response of grazing animals and herders to the spatio-temporal availability and accessibility of forage resources (water, grasses and browses species) across the different agro-ecological zones (Schlecht et al., 2006; McCarthy, 2007; Butt, 2010), although differences reported in foraging behaviour between livestock species are to a certain extent also due to physiological and anatomical differences, since, for example, cattle require more forage than small ruminants (Prache et al., 1998). Across the different land cover types, the available herbaceous biomass is diminishing from the rainy season to the hot dry season, and from the southern Sudanian zone to the southern Sahelian zone, independent of annual variations in biomass yield and pasture accessibility (FAO, 2006). Herders as well as grazing animals themselves respond to these circumstances by increasing the length of the daily grazing itinerary and by staying longer on pasture to compensate the lower forage intake per unit of time and per unit of land visited (Ayantunde et al., 2001, 2008). Through the increased time spent walking, cattle and sheep (herders), during the hot dry season, tried to compensate for the lack of forage by visiting remoter pasture areas. The large proportion of feeding time of goats during the cool and hot dry season was due to their increased use of browse species that were still offering green leaves, flowers and fruits during these periods (Sanon et al., 2007), but are more time-consuming to feed on than the herbaceous layer (Chapter 3). The similarity in foraging behaviour, time spent on pasture and distances travelled between cattle and sheep migth be explained by the co-grazing system practiced in Burkina Faso, which is beneficial in terms of the complementary use of forage resources along grazing routes and also the efficient use of labor for herding; the latter is more and more getting rare due to the migration of young herders (Turner and Hiernaux, 2008). Our study also revealed a decreased distance travelled per day and an increased time spent feeding by all livestock along the north to south transect, with the highest feeding time values recorded at the southern Sudanian site of Sokouraba where biomass is most abundant (Fournier, 1994, Yanra, 2004). The proportion of time spent feeding of 52% - 70% of daily time on pasture across species, locations and seasons compare well to previous results (60% - 65%) reported for the Sahelian zone of Western Niger (Ayantunde et al., 2000; Schlecht et al., 2003). For cattle in the Sahelian zone of Burkina Faso, Sanon et al. (2007) reported a value of 72% for the rainy season, and lower ones (54% and 38%) for the cool and hot dry season. Similar observations were made by Koné-Ouedraogo et al. (2006) for cattle, sheep and goats in the southern Sudanian zone. As shown in Appendix 2.1, season and location had a marked effect on daily feeding time allocated to a certain land cover type. A large proportion of feeding time was shared between *forest* and *other wooded land* across all zones, indicating that in the studied region remaining stands of ligneous vegetation such as older fallows, tiger bush or forests represent most valuable grazing areas. However, livestock access to these areas was restricted by interspersed agricultural land (*other land)* at the southern Sahelian site of Taffogo and the northern Sudanian site of Safane. At the northern Sudanian site of Nobere where the grazing itineraries entered, or even focussed, on the national park, feeding time allocated to different land cover types was well balanced across seasons, and for the southern Sudanian site of Sokouraba the large proportion of feeding time allocated to *forest* is explained by the fact that this land cover type accounted for 85% of the mapped village territory. The accessibility of pasture areas by grazing animals during the rainy season seemed to drive the choice of grazing itineraries by herders. During this period forage availability is not a limiting factor to animal production, neither is the quality of the herbage grazed on pasture (Ayantunde et al., 2008). However, crop fields can fragment pasture areas and restrict their accessibility by livestock (Turner and Hiernaux, 2002); therefore herders are obliged to herd their animals far from these cultivated areas - leading to longer itineraries and longer grazing days - or else focus grazing on *forest* and *other wooded land*. In interviews (Chapter 3), herders acknowledged that across the year they respond to declining forage availability and accessibility by staying longer on pasture, and that their ruminants increasingly rely on browse forages. An increase in transhumance practices and/or herd splitting systems (Moritz, 2010) as well as a shift of livestock raising to southwards regions in West Africa (Basset and Turner, 2007) are other strategies adopted by local livestock keepers to respond to the present, seasonal or year-round, difficulties in livestock nutrition and grazing management. The current results indicate that action should be taken to facilitate livestock access to pasturing areas such fallows, forests and other wooded land. (Community-based) forest management should include measures aiming at controlling grazing pressure exerted in forests and on other wooded land; within this a wide dispersion of livestock faeces could contribute to regeneration of certain ligneous species, thus preserving and increasing biological diversity (Matera et al., 2010). Good pasture management systems, in addition to various local practices such fallow systems, soil and water conservation technologies, and protection of trees in cultivated lands that are already adopted by farmers, will furthermore sustain soil fertility, vegetation cover, and carbon sequestration (Vagen et al., 2005; Perez et al., 2007). According to Perez et al. (2007), modest improvements of natural ressource management in African pastoralist systems may yield gains of 0.5 t C/ha/year, which translate to a monetary value of 50$/year and could increase the income of involved households by about 14% if a direct payment was made. Therefore linking these livestock management systems to the international carbon market, though still complex (Perez et al., 2007; Follett and Reed, 2010), could be an option to encourage the adoption of better management practices for pastures with important ligneous cover. Assisting the natural regeneration of local tree species would also be useful to conserve valuable fodder trees and shrubs.

2.5. Conclusions

The GPS/GIS tools used in this study proved useful for a rapid and semi-automated evaluation of the use patterns of (communal) grazing areas and different land cover types by ruminant herds. Our data shows that the expansion of cropland, induced by human population growth and increasing variability of rainfall in the study region, enforces high livestock mobility in the agro-pastoral Sahelian and northern Sudanian zone of West Africa. This situation leads to an increased share of daily feeding time allocated to *wooded land* and *forest* irrespective of season and ruminant species. *Forest* and *other wooded land* including young fallows are thus the most valuable pasturing areas for the numerous pastoralist and agro-pastoralist ruminants in these regions. Policies and practical measures must be established that safeguard these grazing areas, facilitate their accessibility, and encourage an active protection and (re)establishment of drought-tolerant fodder trees.

2.6. References

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Appendix 2.1

Daily grazing itineraries of cattle herds during different seasons and along three agro-ecological zones of Burkina Faso.

Legend:

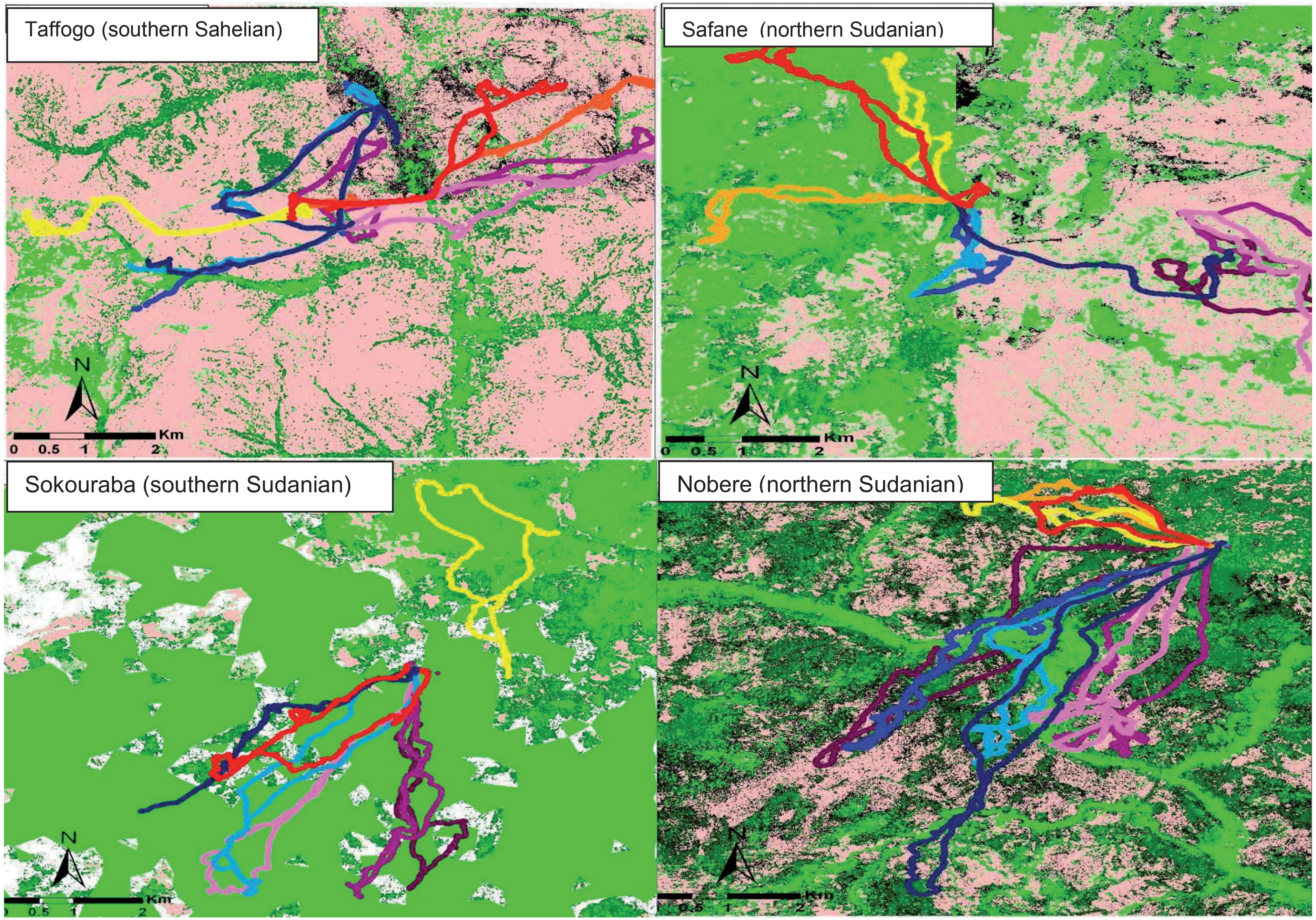
Rainy season : 24/08/2009, 27/08/2009, 31/08/2009

Cold dry season : 20/01/2010, 21/01/2010, 22/01/2010

Hot dry season : 14/05/2010, 15/05/2010, 17/05/2010

Land Use

- Clouds and missing data
- Forest
- Other land with tree cover
- Other wooded land
- Other land



Chapter 3

Consequences of climate change for the contribution of browse to ruminant nutrition and health care across three agro-climatic zones of Burkina Faso

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Consequences of climate change for the contribution of browse to ruminant nutrition and health care across three agro-climatic zones of Burkina Faso

Abstract

We determined the contribution of various ligneous species to the diet of cattle, sheep and goats across three agro-ecological zones of Burkina Faso, and assessed the ethno-veterinary uses of these plants by Fulani livestock keepers. Regular manual observation and GPS-tracking of one cattle, one sheep and one goat herd each in three different villages were used to investigate ruminants' browsing activities on pastures. Additionally, 25 Fulani livestock keepers per village were interviewed on the use of ligneous plants by foraging livestock and for disease treatment, and on changes in browse use over the past two decades. Across the three study sites, 75 woody species from 24 botanical families were identified as being of importance. Cattle strongly preferred *Afzelia africana, Pterocarpus erinaceus* and *Piliostigma* sp., while sheep and goats primarily fed on *Balanites aegyptiaca, Ziziphus mauritiana* and *Acacia* sp. Contribution of browsing to ruminants' daily eating time was highest for goats ($P<0.001$) across all seasons and zones, while for sheep and cattle browse contribution was only important during the hot dry season with no significant differences between agro-ecological zones. Interviewed livestock keepers reported an increased browse use by their animals, while browse species use for traditional animal health care decreased over the past 20 years. The combined influences of anthropogenic pressure and climate change, which affect the survival and regeneration of most preferred trees and shrubs, are threatening livestock keepers' current management practices and need to be counteracted in an adequate way.

Keywords: domestic ruminants; ethno-veterinary practices; forage selection; grazing time; ligneous species.

3.1. Introduction

Nutrition of cattle, sheep and goats in the agro-silvo-pastoral livestock farming systems of the Sahelian and Sudanian regions of West Africa is essentially based on the exploitation of naturally occurring herbaceous and ligneous plant species, and crop residues. Qualitative and quantitative forage shortage, particularly in the dry season, is the major constraint to this farming system (Fernández-Rivera et al., 2005). In this period of the year, fodder trees and shrubs play an important role for ruminant nutrition, providing proteins, minerals, vitamins and energy (Ickowicz and Mbaye, 2001; Ouedraogo-Koné, 2008), thus complementing herbaceous plants of low nutritive value. After the severe droughts of the years 1973-1974 and 1983-1984, much information has been accumulated on the potential of trees and shrubs as sources of feed for the extensive livestock systems in the West African Sahel (Ickowicz et al., 2005; Sanon et al., 2008; Ouedraogo-Koné et al., 2009). However, ligneous plants and plant parts are also used for human nutrition and health care, in ethno-veterinary medicine and for household energy supply (Tamboura et al., 1998; Kristensen and Balslev, 2003). Due to the high spatio-temporal variability of forage availability in Burkina Faso, ruminants' foraging behaviour on common pasture, and particularly their browsing activities, vary widely across seasons (Ouédraogo-Koné et al., 2006; Sanon et al., 2007), ruminant species (Botoni, 2003; Sanon, 2007) and agro-climatic conditions (Hansen et al., 2008), and depend to some extent on herd management (Turner and Hiernaux, 2008). Variations concern time spent browsing in general, browse species selection, qualitative and quantitative intake of browse. Several of the aforementioned independent variables partly interact, such as region and season which determine the botanical composition of the pasture vegetation that is plant occurrence, abundance, accessibility, palatability and nutritive value (Ngwa et al., 2000). Apart from the effects of climate, variation is also determined by land use patterns and anthropogenic pressure. Considering climate, landscape and flora, Wittig et al. (2007) observed a partial Sahelisation of the Sudanian zone of Burkina Faso, and pointed out that changes in landscape characteristics and floristic composition of the vegetation are mainly driven by anthropogenic pressure. Studies in the West African Sudanian and Sahelian regions have also identified recurrent droughts, cropland expansion and grazing pressure as drivers of vegetation degradation and even desertification, leading to the reduction of biomass production and species diversity (Turner, 1999; Wezel and Lykke, 2006; Maranz, 2009; Kaspersen et al., 2011). Recent studies in the Sahelian and Sudanian zones of Burkina Faso reported a noticeable decline of woody vegetation over time (Ariori and Ozer, 2005; Pare et al., 2010; Sop and Oldeland, 2011). Although this should induce changes in the use of browse species by ruminants on pasture, information on the occurrence, extent and consequences of such changes is lacking for the different agro-ecological zones of Burkina Faso and the neighboring Sahelian and Sudanian countries.

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

3.2. Material and methods

3.2.1. Study locations

This study covered the sub-Sahelian, northern and southern Sudanian zone of Burkina Faso, which were represented by the village territories of Tougouri/Taffogo (13°26.56' N, 0°34.17' E), Noberé (11°28.82' N, 1°10.50' W), and Sokouraba (10°50.49' N, 5°09.99' W), respectively, as permanent study locations. The sub-Sahelian zone receives 300 - 600 mm of rain annually during 3 - 4 months; the northern and southern Sudanian zones receive 600 - 800 mm/a and more than 1000 mm/a of rain in about 5 - 6 months. The vegetation in the sub-Sahelian zone is a thornbush savannah with mostly deciduous trees and shrubs, and riparian forests found at riversides. The most common ligneous species are *Balanites aegyptiaca, Acacia seyal, Acacia dudgeoni, Acacia tortillis, Acacia raddiana, Leptadenia hastata, Pterocarpus lucens, Combretum micranthum, Combretum nigricans, Feretia apodanthera, Gardenia sokotensis*, and *Guiera senegalensis* (authorities are given in Appendix 3.1). The herbaceous layer of natural pastures and fallows is mostly patchy with many bare spots. It is dominated by annual grasses such as *Aristida mutabilis* Trin. et Rupr., *Schoenefeldia gracilis* Kunth and *Loudetia togoensis* (Pilg.) C.E. Hubb. The prevailing vegetation types in the Sudanian zone are woodlands and savannas; in the northern zone agroforestry parklands with *Vitelaria paradoxa* or *Faidherbia albida* are found, and the important grass layer is dominated by the *Poaceae* family. The trees in this zone are dominated by the *Combretaceae* family. Noberé has the particularity to border the natural reserve "Parc National Kaboré Tambi" of which one part is located in the southern Sudanian zone. There the grass layer is essentially composed of annual and perennial grass species such as *Pennisetum pedicellatum* Trin., *Andropogon gayanus* Kunth and *Andropogon ascinodis* C.B. Clarke. Ligneous species such as *Afzelia africana, Pterocarpus erinaceus,* and *Khaya senegalensis,* which are rare in the other zones, are found here. In addition important plantations of mango (*Mangifera indica* L.), sweet orange

(*Citrus sinensis* L.) and cashew nut (*Anacardium occidentale* L.) are also found in this area, which is the most humid part of the country.

3.2.2. Monitoring of grazing behaviour on pasture

The grazing activities of cattle, sheep and goats were monitored from June 2009 to May 2010, covering the rainy season (June - September 2009), cool dry season (October 2009 - January 2010) and hot dry season (February - May 2010) in all three locations. In each zone one herd each of cattle, sheep and goats, respectively, was randomly selected from the total of herds of Fulani livestock keepers - mainly transhumant pastoralists – who had been identified during a baseline survey. Cattle were mostly of the Fulani breed (*Bos indicus*) and crossbreds of zebu with humpless *Bos taurus*. Sheep were of Mossi and/or Djallonké breed and goats were mostly of Sahelian type in Tougouri, and of Djallonké dwarf breed in Noberé and Sokouraba. The number of animals per herd ranged from 10 to 60 for goats, 35 to 75 for sheep, and from 50 to more than 100 for cattle. Within each herd of cattle, sheep and goats, one representative female animal was followed by an observer during its daily time on pasture and all its activities were recorded every 5 minutes from the departure in the morning to the pasture areas (between 7 and 9 a.m.) until its return to the night resting place (around 6 or 7 p.m.). The following activities were differentiated: grazing (defined as the consumption of grasses, dicotyledonous herbs and crop residues), browsing (consumption of fresh or dry leaves, flowers, fruits, and pods of trees and shrubs), short-distance movements between feeding stations, larger-scale directional movements, and resting (resting and/or ruminating, including also social activities and idling). However, time spent on the activities walking and resting is not further considered in this chapter.

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

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

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

Daily browsing and grazing time and preference index of browse species:
From the total number of recorded activities during daily time on pasture, the proportion of

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

$$\text{Grazing time (\%)} = \sum_{i=1}^{n} Gj/T \; * 100 \qquad [1]$$

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

$$\text{Feeding time (\%)} = (\sum_{i=1}^{n} Bi + \sum_{i=1}^{n} Gj)\,/\,T \; * 100 \qquad [3]$$

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

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

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

3.2.3. Proximate composition and nutritive value of browse species

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

3.2.4. Ligneous plants use by livestock keepers

From February to May 2009, focus group discussions on the use of ligneous plants by livestock keepers were held in each of the three villages. A total of 15 to 30 persons per village - mainly Fulani herders and livestock owners - were asked on their perception of the use of ligneous plants as fodder by their grazing animals, and on their own application of such plants for animal health treatments. In addition to the group discussions, interviews using structured questionnaires were conducted with 75 individual Fulani livestock keepers (25 per village) from January to May 2010. The questionnaire addressed details on the use of ligneous plants (i) as feed by animals, (ii) for the treatment of animal diseases, and (iii) the perception of the respondents on changes in browse use by livestock and its relation to reported vegetation degradation in Burkina Faso.

3.2.5. Statistical analyses

Differences in the number of browse species selected and their relative contribution to browsing time across seasons and agro-ecological zones, the perception of livestock keepers on the uses of browse for different purposes and respective changes during the past twenty years were analysed using the non-parametric Kruskal-Wallis test. The Chi-square test was used to compare the contribution of browsing time to daily eating time across the three livestock species. A binary logistic regression with a stepwise backwards elimination of predictors was performed to identify the most determinant variables affecting ruminants' browsing activities on pasture. The fit of the final model was assessed by the model Chi-square (Model χ^2) and the goodness-of-fit test of Hosmer and Lemeshow (Archer and Lemeshow, 2006). Well-fitting models show significance ($P \leq 0.05$) on the Model χ^2 and non significance ($P > 0.05$) on the goodness-of-fit test. In addition, a multiple linear regression analysis was performed for the relationship between the proximate constituents of an overall number of 20 browse species and their preference (in %, year-round) by cattle, sheep and goats; hereby, missing data on proximate constituents were completed from Guerin (1994).
All statistical analyses were performed using SPSS 19.1 (SPSS Inc., 2011); significance was declared at the 0.05 level.

3.3. Results

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

A total of 75 ligneous species distributed across 24 families (Appendix 3.1) were browsed by goat, sheep and cattle herds across the three study locations during the monitoring period. The most important ligneous families were Mimosoideae (20%), Combretaceae (12%) and Caesalpiniaceae (10%). The preference for browse species varied according to season, agro-ecological zone and animal species. The total number of browse species selected by goats throughout the year was 20 in the northern Sudanian zone, 14 in the southern Sudanian zone and 9 in the sub-Sahelian zone. Similar to goats and in contrast to cattle, sheep browsed on a large variety of woody species (Table 3.1). However, regardless of animal species and zone, browse species were less frequently selected in the cool dry season than in the rainy and hot dry season. The overlap coefficient for browse species preferred by goats and sheep was 0.46, 0.35 and 0.32 in the northern Sudanian, southern Sudanian and sub-Sahelian zone, respectively. Regardless of season, the proportion of total browsing time spent by goats and sheep, respectively, on their five most preferred browse species was 87% for both species in the sub-Sahelian zone, 87% and 66% in the northern Sudanian zone, and 61% and 52% in the southern Sudanian zone. For cattle in the northern and southern Sudanian zone, respectively, the proportion of total browsing time spent on *Afzelia africana* was 40% and 24%, while the values were 11% and 46% for *Pterocarpus erinaceus,* 21% for *Acacia siberiana* (only present in the northern Sudanian zone) and 11% for *Prosopis africana* (only present in the southern Sudanian zone*).* In the sub-Sahelian zone, browsing time of cattle was exclusively concentrated on *Piliostigma reticulatum* (92%) and *Anogeissus leiocarpa* (8%). The crude protein concentration (in DM) of the pods or fruits of the most important browse species selected by goats, sheep and cattle (Table 3.2) ranged from 7% to 13%, and from 10% to 18% for foliage. The concentration of digestible organic matter of preferred browse species mostly ranged from 40% to 60%, and the concentrations of total phenols, condensed tannins and acid detergent lignin were low. From Pearson correlation analyses, the following correlation coefficients (r) were obtained between preference of a browse species by goats and its CP, DOM, OM, NDF and ADF concentration: $r_{CP} = 0.64$, $P<0.05$; $r_{DOM} = 0.46$, $P<0.05$; $r_{OM} = -0.35$, $P<0.05$; $r_{NDF} = -0.26$, $P>0.05$; $r_{ADF} = -0.33$, $P>0.05$. The multiple linear regression analysis also showed a significant and positive relationship between goats' preference of browse species and their concentrations of CP and NDF, while correlations for the concentrations of DOM and ADF were negative (Table 3.3). No correlations were determined for cattle and sheep.

Table 3.1: Average daily time (min/d) spent foraging on different browse species by small ruminants and cattle, and rank (Rk) of browse species across the different seasons* of a year in three agro-ecological zones of Burkina Faso.

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

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

Table 3.2: Concentrations of crude protein (CP), digestible organic matter (DOM), metabolisable energy (ME), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), total phenols (TP) and condensed tannins (CT) in the dry matter (DM) of samples of fruits (Fr) and foliage (Fl) of browse species selected by domestic ruminants in three agro-ecological zones of Burkina Faso (Means and (SD)).

Browse species, plant part		n	CP (%)		DOM (%)		ME (MJ/kg DM)		NDF (%)		ADF (%)		ADL (%)	TP (g/kg)	CT (g/kg)
Acacia dudgeoni	Fr	2	12.4	(0.00)	47.3	(0.00)	5.8	(0.00)	46.7	(1.00)	31.7	(0.68)	12.9		
Acacia macrostachya	Fr	6	12.9	(4.07)					44.0	(3.46)	31.7	(3.36)	11.1	7.0	0.3
Acacia siberiana	Fr	2	8.5	(0.00)	47.2	(0.00)	6.2	(0.00)	31.7	(1.36)	24.2	(1.00)	10.7		
Cassia siberiana	Fr	6	7.9	(1.09)					33.0	(1.38)	24.4	(1.28)	13.1		
Faidherbia albida	Fr	2	8.3	(0.00)	59.7	(9.40)	8.6	(1.62)	41.6	(0.00)	32.4	(0.09)	9.4		
Piliostigma reticulatum	Fr	6	7.5	(1.36)					32.6	(0.86)	24.4	(0.86)	17.5	7.7	0.4
Piliostigma thonningii	Fr	2	7.2	(0.00)					36.7	(0.07)	26.5	(0.19)	18.4		2.4
Prosopis africana	Fr	2	8.7	(0.00)					32.9	(0.13)	23.4	(0.23)	12.6		
Acacia gourmaensis	Fl	2	12.8	(0.14)	56.9	(0.00)	7.4	(0.00)	35.6	(0.25)	21.9	(0.45)	6.4	1.2	0.3
Acacia macrostachya	Fl	2	14.5	(0.00)					40.6	(3.55)	30.2	(1.73)			7.0
Acacia seyal	Fl	2	15.6	(0.04)	54.4	(3.70)	7.6	(0.92)	20.4	(0.92)	12.8	(0.60)	5.3		0.1
Afzelia africana	Fl	4	18.4	(0.62)	50.9	(3.60)	8.1	(0.73)	43.7	(3.35)	30.5	(2.50)	12.6	0.1	n.d.
Anogeissus leiocarpus	Fl	4	10.5	(0.38)	36.3	(0.00)	4.7	(0.00)	20.3	(3.16)	13.7	(1.40)			
Balanites aegyptiaca	Fl	8	14.2	(3.30)	59.8	(4.20)	7.8	(0.56)	32.4	(4.49)	20.5	(3.61)	15.5	1.0	n.d.
Combretum glutinosum	Fl	4	10.5	(0.40)					36.8	(8.99)	25.6	(5.70)	10.7	7.5	2.5
Combretum micranthum	Fl	2	24.5	(0.00)					21.9	(0.13)	15.3	(0.00)	6.4	8.9	0.4
Faidherbia albida	Fl	6	16.7	(3.73	47.8	(6.10)	6.6	(1.11)	35.5	(2.88)	24.8	(1.97)	11.1	1.3	0.7
Gardenia erubescens	Fl	6	7.8	(0.95)	46.7	(0.00)	6.2	(0.00)	27.8	(6.26)	18.9	(4.56)	10.6		
Piliostigma reticulatum	Fl	4	10.2	(1.32)	40.7	(5.20)	5.9	(0.88)	32.9	(0.71)	22.2	(0.60)			
Pterocarpus erinaceus	Fl	6	15.3	(1.30)	46.2	(8.20)	6.5	(1.28)	50.2	(3.03)	35.5	(4.20)	13.0	0.2	n.d.
Ximenia americana	Fl	2	11.2	(0.00)	37.0	(0.00)	4.9	(0.00)	19.5	(1.69)	14.9	(2.24)	16.1		
Ziziphus mauritiana	Fl	6	13.3	(0.59)	48.6	(4.60)	6.5	(0.85)	34.2	(2.62)	23.4	(2.10)	16.1	3.3	1.2

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

Table 3.4 presents the relative contribution of browsing time to ruminants' daily eating time across seasons and agro-ecological zones. Compared to the southern Sudanian zone, goats spent a significantly higher proportion of their eating time on browsing in the sub-Sahelian and northern Sudanian zones ($P<0.01$). In the two latter zones, browsing contributed significantly more ($P<0.05$) to goats' eating time than grazing of herbaceous forage in all seasons. Nevertheless, the proportion of browsing time was significantly ($P<0.05$) higher in the hot dry season than in the cool dry season and in the rainy season. Across the three zones, sheep and cattle spent a low to moderate proportion of their feeding time on browsing. However, this proportion was significantly ($P<0.05$) higher in the hot dry season than in the cool dry and rainy season. The results of the logistic regression analysis (Table 3.5) indicated that season and agro-ecological zone were the most important factors determining browsing time of goats, sheep and cattle on communal pastures: in the rainy and cool dry season browsing activities of all ruminant species were reduced ($P<0.01$); in the sub-Sahelian and northern Sudanian zones cattle were more likely to browse than in the southern Sudanian zone. The use of browse species by small ruminants was less likely to occur in the northern Sudanian zone as compared to the sub-Sahelian and southern Sudanian zone.

Table 3.3: Multiple linear regression coefficients for the relation between goats' preference (see Eq. 4) for the fruits or leaves of a browse species and the respective concentrations of proximate constituents.

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

OM = organic matter

[#] Sig. and r^2 change: $*P \leq 0.05$; $**P \leq 0.01$

[§] Final equation: Preference (%) = $-17.97 + 5.71CP - 6.21ADF + 3.76NDF - 0.67DOM$

3.3.3. Livestock keepers´ use of woody plants, and perceptions of changes in the recent past

Without significant differences across agro-ecological zones, all Fulani livestock keepers affirmed that goats were the animal species browsing most across all seasons (Table 3.6). According to them, sheep and cattle mostly browse during the cool and hot dry season, with significant differences ($P<0.05$) perceived between seasons for cattle. Overall, a significant proportion of the respondents, ranging from 64% in the southern Sudanian zone to 80% in the sub-Sahelian zone, reported that they used browse species for ethno-veterinary purposes. Across all agro-ecological zones, the most common use of browse species in ethno-veterinary applications was disease treatment (Table 3.6); as detailed in Appendix 3.1, a total of 36 woody species were used to treat 13 of the most frequent animal diseases at the different study locations. Although the majority of interviewed livestock keepers had a good knowledge of woody plant species and of their uses in traditional animal health care, most of them mentioned that they also relied on modern veterinary medicine to prevent and to cure some complicated cases of disease.

Livestock keepers acknowledged to have perceived changes over the past two decades regarding their animals' intake of browse species, and in their own applications of ligneous plants for animal health care purposes (Table 3.7). While they reported an increased intake of browse species by ruminants across the three different zones over the past 20 years, they noticed a significant decrease in their own use of ligneous plants for animal health care, and the disappearance of the use of browse plants to stimulate cows' milk production. According to the respondents, the main driving factors behind those changes were the decline over time of the herbaceous biomass, the negative impacts of drought and desertification, and the expansion of cropping areas. Respondents further identified the development and systematic use of modern veterinary medicine and veterinary services, combined with the decline in the availability of the most commonly used browse species, as main reasons for the observed decrease in the use of woody plants for animal health care purposes.

Table 3.4: The relative contribution of browsing to daily eating time, and the number of browse species selected per day by small ruminants and cattle across three seasons and three agro-ecological zones of Burkina Faso (Means and (SD)).

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

ns non significant.

3.4. Discussion

3.4.1. Browse species selection by cattle and small ruminants

Our results indicate that domestic ruminants make use of a considerable number of browse species across the various agro-ecological zones of Burkina Faso. The highest diversity of browsed species was found in the Sudanian zone, where the vegetation consists of dry and sub-humid tree savannas and forests (Schmidt et al., 2010). In this zone the browsed species are essentially *Combretaceae*, the genus also dominating the zone's ligneous vegetation (Thiombiano et al., 2006). In the semi-arid sub-Sahelian zone, *Acacia* species, *Combretum micranthum* and *Balanites aegyptiaca,* which are the dominant woody species there (Sop et al., 2011), were frequently browsed, especially by goats and sheep. Surprisingly, the browse species preferred by small ruminants in the sub-Sahelian zone were not used by cattle, while goats and sheep had nine preferred browse species in common. In some species, such as

Piliostigma sp. and *Faidherbia albida,* especially the pods were preferred and used by all ruminant species across zones, particularly during the cool and hot dry season, which correspond to their fructification period (Heuzé and Tran, 2011). Our multiple linear regression analysis showed a significant relationship between the proximate constituents of browse species and their preference by goats, indicating that beyond physical browse characteristics the nutritive value affects preference by ruminants on pasture (Beaumont et al., 2000), although the negative – though weak – correlation between preference and organic matter digestibility cannot be explained. The results of the logistic regression analyses underline that on pasture browse preferences by a specific ruminant species are strongly related to the occurrence and phenological stage (and thus nutritive value) of the ligneous plants (Ngwa et al., 2000), factors that vary with environmental conditions (agro-ecological zone and season) but also land uses (Fischer et al., 2011). The heterogeneity of Sahelian and Sudanian pastures (Schmidt et al., 2010) is thus certainly a further explanation of the observed variability in browse preference across agro-ecological zones.

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

Table 3.5: Results of the binary logistic regression on the effects of agro-ecological zone and season on browse use by goats, sheep and cattle on communal pastures in Burkina Faso.

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

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

Table 3.6: Interview-based information on the proportion (%) of pastoralists' confirming the use of browse plants by their grazing animals and their own use of ligneous plants for health care purposes across three agro-ecological zones of Burkina Faso.

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

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

Table 3.7: Pastoralists' perception (% of respondents) of the changes in browse use as forage by their animals and for animal health care purposes during the past 20 years across three agro-ecological zones of Burkina Faso.

Browse use	Use tendency	Sub-Sahelian (n=26)	Northern Sudanian (n=25)	Southern Sudanian (n=25)	Overall (n=76)
By animals*	Increased	82.1	56.0	70.7	69.7
	Decreased	15.4	6.7	24.0	15.4
	No change	2.6	37.3	5.3	14.9
For animal disease prevention	Increased	0	0	0	0
	Decreased	95.5	94.6	100	96.9
	Disappeared	4.5	0	0	1.6
	No change	0	5.6	0	1.6
For animal disease treatment	Increased	0	0	0	0
	Decreased	95.5	91.3	100	95.7
	Disappeared	4.5	0	0	1.4
	No change	0	8.7	0	2.9
For stimulating milk production in cows	Increased	0	0	0	0
	Decreased	0	100	100	66.7
	Disappeared	100	0	0	33.3
	No change	0	0	0	0

* Cattle, sheep and goats

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

Our results from the monitoring of grazing behaviour underlined the important contribution of browsing to ruminants' daily eating time (Cisse et al., 2002; Sanon et al., 2007). Irrespective of season, browse contribution to goat feeding was high in the sub-Sahelian and the northern Sudanian zone, but only moderate in the southern Sudanian zone. Although browsing time of cattle and sheep was significantly lower than of goats, their relative browsing time was higher than the values reported in previous studies conducted in the region. For example, at the Sudanian site of Dossin, Nianogo et al. (2004) found that the average proportion of feeding time spent browsing was 82% for goats and 15% for sheep. Botoni (2003) reported an average rainy season value of 6% for cattle in the southern Sudanian zone, which increased to 10 - 13% in the cool dry season and to 30% in the hot dry season. However, a direct comparison of these figures with those obtained in our study is not possible because of sources of variation such as methods used, observer error, intra- and inter-annual variation of forage availability, and land use changes over time. In the present study, Fulani livestock keepers and herders reported an increased use of browse by ruminants on pasture especially during the dry season when herbaceous forage is scarce. This perceived increase in the duration of ruminant browsing time might be related to the steady decline in primary production and species richness of the herbaceous vegetation during the past 40 years (Gonzalez, 2001; Hiernaux et al., 2009, Paré et al., 2010). Hiernaux et al. (2009) showed that from 1994 to 2006, the overall herbaceous biomass in southern Niger decreased at an annual rate of 5%, which could not be explained by changes in rainfall. Turner and Hiernaux (2008) argued that this decline has probably induced changes in pastoralists' grazing management strategies and in their use of pasture resources. In Burkina Faso, the expansion of cropland reduced pasture availability and access to watering points especially during the rainy season. This might explain the important use of browse species by small ruminants during that period of the year. In the case of sedentary livestock keepers, lack of labor for herding during the rainy season triggered stall-feeding of small ruminants with collected browse foliages at the Sudanian sites of Safané and Sokouraba. During the cool dry season, crop residues are often not accessible any more to pastoralist herds because they are systematically collected by crop farmers who feed their own animals, or are being sold (Powell et al., 2004). In consequence, especially goats grazing harvested fields relied on fresh sprouts or seedlings of ligneous plants re-emerging on cultivated land and fallow. The results of our logistic regressions confirmed these observations, indicating that a decrease in the spatio-temporal availability and accessibility of herbaceous forages (in the cool dry season) increases the odds of the contribution of browse to the diet of grazing ruminants, in particular of cattle and sheep.

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

3.4.3. Implications of climate change on browse use by livestock

As discussed above, the increased use of browse by ruminants on pasture points to a reduced availability and/or accessibility of herbaceous forages including crop residues. Although this situation seems to be more strongly influenced by anthropogenic pressure on land and natural resources in general, than by climate variability and change, these phenomena are of course interrelated and it is very difficult to disentangle them. Irrespective of this, we agree with Nardone et al. (2010) that further climate change might significantly and negatively affect the feeding practices and animal performances in the agro-silvo-pastoral systems of the Sahelian and Sudanian zones which are already facing serious problems such as reduced availability of drinking water for animals, shortage of forage resources, reduced pasture areas and shrinking transhumance routes that reduce transregional livestock mobility.

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

3.5. Conclusions

Our data indicates an increasingly intense use of browse species as forage by pasturing cattle, sheep and goats across three major agro-ecological zones of Burkina Faso. Decreased availability of herbaceous forages including crop residues due to anthropogenic and climatic reasons is the main driver of this development, especially in the sub-Sahelian and the northern Sudanian zones. Therefore, policies should address the protection and valorization of prominent browse species as important and low cost sources of crude protein and energy for ruminant nutrition. Future studies should particularly investigate the potential of integrating *Balanites aegyptiaca, Piliostigma reticulatum* and *P. thonningii* in the local feeding systems. Moreover, species such as *Acacia dudgeoni*, *A. seyal*, and *A. senegal* seem to be promising candidates for agro-forestry systems to secure dry season fodder supply to domestic ruminants in the Sahelian and northern Sudanian zones.

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Appendix 3.1: List of browse plants used by grazing animals on pasture and by herders for the treatment of animal diseases in Burkina Faso.

Browse family and species	Season[1]	Zone[2]	Animal species	Browsed organ	Disease treated[3]
ANACARDIACEAE (6)					
Anacardium occidentale L.	HDS	S-SUD	Sheep	Fruit	
Lannea acida A. Rich.	RS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, fruit	
Lannea microcarpa Engl. & K. Kraus	CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, fruit	
Manguifera indica L.	CDS, HDS	N-SUD	Cattle	Leaves, fruit	
Ozoroa insignis Del.	HDS	S-SUD	Sheep, goat	Leaves	
*Sclerocaria birrea (*A. Rich.) Hochst	RS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, fruit	FMD
ANNONACEAE (1)					
Anona senegalensis Pers.	RS	N-SUD	Goat	Leaves	Snake bites
APOCYNACEAE (3)					
Baissia multifolia A. DC.	CDS	N-SUD	Cattle	Leaves	
*Saba senegalensis (*A. DC.) Pichon	CDS, HDS	N-SUD	Sheep, goat	Leaves	
Saba comorensis (Boj. ex DC.) Pichon	CDS	S-SUD	Cattle	Fruit	
ASCLEPIADACEAE (2)					
*Caloptropis procera (*Ait.) Ait. f.	RS	S-SAH	Goat	Leaves	
Leptadenia hastata (Pers.) Decne.	RS, CDS, HDS	S-SAH	Goat, sheep, cattle	Leaves	Placental retention
BALANITACEAE (1)					
Balanites aegyptiaca (L.) Del.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, fruit	FMD, eye infections, anthrax
BIGNONIACEAE (1)					
Stereospermum kunthianum Cham.	CDS, HDS	N-SUD	Cattle	Leaves	
BOMBACACEAE (1)					
Bombax costatum Pellegr. & Vuillet	CDR	N-SUD, S-SUD	Goat, Sheep	Leaves, flowers	
CAESALPINOIDEAE (8)					
Afzelia africana Smitex Pers.	CDS, HDS	N-SUD	Cattle	Leaves	FMD
Bauhinia rufescens Lam.	RS	S-SAH	Goat	Leaves	
Cassia siberiana DC.	CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Pods	Snake bites, diarrhea

Appendix 3.1 continued

Browse family and species	Season[1]	Zone[2]	Animal species	Browsed organ	Disease treated[3]
Daniela oliviera (Rolfe) Hutch. & Dalz.	CDS	N-SUD	Goat	Leaves	
Detarum microcarpum Guill. & Perr.	HDS	N-SUD	Goat	Pods	Placental retention, trypanosomiasis
Piliostigma reticulatum (DC.) Hochst.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, pods	
Piliostigma thonningii (Schumach) Milhne-Redh	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, pods	
Tamarandus indica L.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves	
CAPPARACEAE (2)					
Capparis tomentosa Lam.	CDS	N-SUD, S-SUD	Cattle	Leaves	
Maerua crassifolia Forssk.	CDS, HDS	S-SAH	Sheep, goat	Leaves	
CELASTRACEAE (1)					
Maytenus senegalensis (Lam.) Exell	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves	Snake bites
COMBRATACEAE (9)					
Anogeissus leiocarpus (DC.) Guill. & Perr.	RS, CDS, HDS	N-SUD, S-SAH	Goat, cattle, sheep	Leaves	FMD
Combretum fragans F. Hoffm.	RS, CDS, HDS	S-SAH, N-SUD	Goat, sheep	Leaves	Placental retention
Combretum glutinosum Perr.ex DC.	CDS, HDS	N-SUD, S-SUD, S-SAH	Goat, sheep, cattle	Leaves	FMD
Combretum molle R. Br. Ex G. Don	RS	N-SUD	Goat	Leaves	
Combretum micranthum G. Don	RS, HDS	S-SAH	Goat, sheep	Leaves	FMD
Combretum nigricans Lepr. ex Guill. & Perr.	CDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves	
Guiera senegalensis J.F.Gmel.	RS, CDS, HDS	N-SUD, S-SAH, S-SUD	Sheep, goat, cattle	Leaves	
Terminalia laxifolia Engl.	RS	N-SUD	Goat	Leaves	
Terminalia macroptera Guill. & Perr.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves	
EBENACEAE (1)					
Diospyros mespiliformis Hochst. ex A. Rich.	CDS, HDS	S-SAH	Sheep, goat, cattle	Leaves	
EUPHORBIACEAE (1)					
Securinega virosa (Roxb. ex Wild.)	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves	

Appendix 3.1 continued

Browse family and species	Season[1]	Zone[2]	Animal species	Browsed organ	Disease treated[3]
FABACEAE (4)					
Dalbergia boehmii Taub.	RS, HDS	N-SUD	Sheep	Leaves	
Pterocarpus erinaceus Poir.	HDS	S-SUD, N-SUD	Goat, cattle	Leaves	Diarrhea
Pterocarpus santalinoides L'Hér. ex DC.	HDS	N-SUD	Goat	Leaves	
Pterocarpus lucens Guill. & Perr.	HDS	S-SAH	Goat	Leaves	Snake bites
LOGANICEAE (1)					
Strichnos spinosa Lam.	CDS, HDS	N-SUD, S-SUD	Cattle, goat	Leaves	
Tapinanthus sp.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, flowers	FMD
MELIACEAE (2)					
Azadirachta indica A. Juss.	HDS	N-SUD	Goat	Leaves	
Khaya senegalensis (Desr.) A. Juss.	RS, HDS	N-SUD, S-SUD	Goat, cattle	Leaves	Trypanosomiasis, constipation, diarrhea, parasitism
MIMOSOIDEAE (15)					
Acacia dudgeoni Craib ex Hall.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, pods	Eye infections
Acacia gourmaensis A. Chev.	RS, CDS, HDS	N-SUD	Goat, sheep	Leaves	
Acacia laeta R. Br. ex Benth.	RS, HDS	S-SAH	Goat	Leaves	
Acacia macrostachya Reichenb. ex DC.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves, pods	
Acacia nilotica (L.) Willd. ex Del.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep	Leaves	FMD
Acacia polyacantha Willd.	RS, CDS	N-SUD	Goat, sheep	Pods	
Acacia senegal (L.) Willd.	RS	S-SAH	Goat	Leaves	
Acacia seyal Del.	RS, CDS, HDS	N-SUD, S-SAH	Goat, sheep, cattle	Leaves	Snake bites
Acacia sieberiana DC.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, pods	
Albizia lebbeck (L.) Benth.	RS	N-SUD	Goat, sheep	Leaves	
Dichrostachys cinera (L.) Wigth & Arn.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, pods	
Faidherbia albida (Del.) Chev.	RS, CDS	N-SUD	Goat, sheep, cattle	Leaves, pods	
Parkia biglobosa (Jacq.) R. Br. ex G. Don	RS, HDS	N-SUD	Goat, sheep, cattle	Leaves, fruit	Diarrhea
Prosopis africana (Guill. & Perr.) Taub.	CDS, HDS	N-SUD, S-SUD	Cattle	Fruit	Diarrhea
Prosopis juliflora (Sw.) DC.	CDS	S-SUD	Cattle	Fruit	

Appendix 3.1 continued

Browse family and species	Season[1]	Zone[2]	Animal species	Browsed organ	Disease treated[3]
MORACEAE (2)					
Ficus sycomorus L.	CDS, HDS	N-SUD	Sheep, goat	Leaves, fruit	
Ficus sur Forssk.	CDS, HDS	S-SUD	Cattle	Leaves, fruit	Placental retention
OLACACEAE (1)					
Ximenia americana L.	RS, CDS, HDS	N-SUD	Goat, sheep, cattle	Leaves, fruit	
RHAMNACEAE (2)					
Ziziphus sp.	RS	N-SUD	Goat	Leaves	
Ziziphus mauritiana Lam.	RS, CDS, HDS	N-SUD, S-SAH	Goat, cattle	Leaves	
RUBIACEAE (5)					
Feretia apodentera Del.	RS, CDS, HDS	N-SUD	Goat, sheep, cattle	Leaves	
Gardenia aquala Stapf & Hutch.	RS, HDS	N-SUD, S-SUD	Goat, cattle	Leaves	
Gardenia erubescens Stapf & Hutch.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, fruit	Trypanosomiasis
Gardenia ternifolia Schumach & Thonn.	CDS	N-SUD	Cattle	Leaves	
Zanthoxylum zanthoxyloides (Lam.) Watermann	CDS, HDS	S-SUD	Goat, sheep, cattle	Leaves	
SAPINDACEAE (1)					
Paulina pinnata L.	CDS	N-SUD	Cattle	Leaves	
SAPOTACEAE (1)					
Vitellaria paradoxa Gaertn. f.	RS, CDS, HDS	N-SUD, S-SUD	Goat, sheep, cattle	Leaves, fruit	FMD, snake bites, placental retention
TILIACEAE (3)					
Grewia bicolor Juss.	RS, CDS	N-SUD	Goat	Leaves	
Grewia flavescens Juss.	RS	N-SUD	Goat, sheep	Leaves	Placental retention
Grewia mollis Juss.	RS, CDS	N-SUD	Sheep, cattle	Leaves	

1 RS rainy season; CDS cool dry season; HDS hot dry season.
2 N-SUD northern Sudanian zone; S-SUD southern Sudanian zone; S-SAH sub-Sahelian zone.
3 FMD Foot and mouth disease.

Chapter 4

Perception of and adaptation to climate change by pastoralists and agro-pastoralists across three agro-ecological zones of Burkina Faso

Perception of and adaptation to climate change by pastoralists and agro-pastoralists across three agro-ecological zones of Burkina Faso

Abstract

Due to the dependence of its economy on rainfed agriculture and livestock, Burkina Faso, like other Sahelian countries, is particularly vulnerable to climate change. Adaptation is needed to reduce anticipated drawbacks of climate change on crop and livestock productivity. We examined climate change perceptions of pastoralists and agro-pastoralists and analyzed their adaptation strategies. To this end, focus group discussions were held in six locations distributed across three agro-ecological zones. In three of these locations, 162 farmers were also individually interviewed. Perceptions of farmers were compared to actual trends of different climatic parameters extracted from official long-term meteorological records (1988 - 2008). Results showed that farmers in Burkina Faso are fully aware of climate change, particularly of changes in temperature and rainfall patterns. The most important adaptation strategies mentioned by agro-pastoralists were crop diversification, combination of cropping and livestock operations, use of water harvesting technologies and anti-erosive measures such as half-moons or stone dikes. Adaptive practices of pastoralists included seasonal, annual, and permanent migration and taking up of cereal cropping. Logistic regression analysis indicated that agro-ecological zone, cultivated surface, ruminant herd sizes, household size and education were the most important factors affecting farmers' choice of adaptation strategies. These factors should be taken into account in the development and implementation of any programme of adaptation to climate change in Burkina Faso.

Keywords: Climate variability; coping strategies; local knowledge; mixed farming systems; Sahelian zone; Sudanian zone.

4.1. Introduction

Consensus exists within the scientific community that climate change is reality, which is expected to worsen through recurrent extreme events such as floods or droughts in the next decades (IPCC, 2001; Solomon et al., 2007). Global mean temperature increased by 0.6°C in the last century, with the hottest temperatures ever recorded in the last two decades. Climate change is also expected to have serious environmental, economic, and social impacts particularly on rural farmers in Africa, whose livelihoods depend on the use of natural resources (Thornton et al., 2006; Gbetibouo, 2009). In most of the Sahelian countries in Africa, agriculture is of critical importance given its multiple roles for food security, employment and contribution to the gross domestic product (Kandji et al., 2006).

In Burkina Faso, agriculture and its cropping, livestock, forestry and fisheries sub-sectors occupy more than 86% of the active population and generate 40% of the country's GDP, to which the crop and livestock sub-sector contribute 25% and 12% (MAHRH, 2004). The country is particularly vulnerable to the impact of climate change because its crop and livestock production are heavily dependent on rainfall (Thornton et al., 2006; MECV, 2007), and because of recurrent droughts and high climate variability combined with an uneven distribution of arable land and other natural resources (Brook, 2006). A national programme of adaptation to climate change was adopted in Burkina Faso in 2007. It identified the decrease in staple crop yields, forage and water resources, diminution of grazing areas and livestock productivity as major threats of climate change to the agricultural sector and called for rapid implementation of effective mitigation strategies.

Several empirical studies showed that negative economic effects of climate change on African agriculture can be significantly reduced through adaptation (Benhin, 2006; Maddison, 2006; Mano and Nhemachena, 2006; Seo and Mendelsohn, 2006), but only few of them analysed the factors affecting farmers' choice of adaptation strategies (Hassan and Nhemachena, 2008; Deressa et al., 2009). Furthermore, although these studies used the Ricardian approach developed to account for farmer adaptation in response to global climate change (Mendelsohn et al., 1994), they focussed on the continental, regional and/or national levels and only partially captured local adaptation strategies that are largely site-specific (Mary and Majule, 2009).

Farmers are more concerned with and respond more to short-term climate variability than long-term climate change; hence their ability to cope with current climate variability is an important indicator of their capacity to adapt to future climate change (Gbetibouo, 2009). Brooks (2006) argued that African crop farmers and pastoralists, and particularly those living in the Sahelian zone, developed indigenous mechanisms and strategies to cope with the recurrent very severe droughts in the early 1970s and 1980s, and with the continuous decline in rainfall observed during the last century. Understanding their perception of climate change and their location-specific adaptive responses is crucial for the design of supportive mitigating strategies, because mitigation and adaptation yield better results if both strategies are seen as complementary (Nyong et al., 2007).

In view of these considerations, the aim of the present study was to recognize pastoralists' and agro-pastoralists' perception of climate change and its impacts, and to analyse their adaptation strategies and the factors influencing these decisions across three agro-ecological zones of Burkina Faso.

Table 4.1: Climate characteristics at six study sites distributed across three agro-ecological zones of Burkina Faso. For location of sites see Fig. 1.1 (Chapter 1)

Study sites	Agro-ecological zone	Annual rainfall (mm)	Rainy days per season	Rain season length (days)	Mean Annual T° (°C)
Taffogo, Zogoré	Sub-Sahelian	300-600	<45	110	29
Noberé, Safané	Northern Sudanian	600-900	50-70	150	28
Sokouraba, Karangasso Vigué	Southern Sudanian	900-1200	85-100	180-200	27

Source: Adapted from PANA (2007)

4.2. Materials and methods

4.2.1. Study sites

The study was carried out in six villages located in the three major agro-ecological zones of Burkina Faso: Taffogo and Zogoré in the sub-Sahelian zone, Safané and Noberé in the Northern Sudanian zone, and Sokouraba and Karangasso Vigué in the Southern Sudanian zone (Table 4.1). The sub-Sahelian zone, approximately located between latitudes 15°N and 14°N, is characterised by an annual precipitation of 300 - 600 mm which falls from June to September. Moving southwards, rainfall increases to 600 - 900 mm in the Northern Sudanian zone (14°00'N to 11°30'N) and to more than 1000 mm in the Southern Sudanian zone (11°30'N to 9°00'N), while the length of the rainy season increases to 5 – 6 months (May/June to October/November). Farmers in the sub-Sahelian zone cultivate millet (*Pennisetum glaucum* (L.) R. Br.), cowpea (*Vigna unguiculata* (L.) Walp.), bambara groundnut (*Voandzeia subterranea* (L.) Thouars ex DC.), and groundnut (*Arachis hypogaea* L.), whereas those in the Northern and Southern Sudanian zone grow sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.), rice (*Oryza sativa* L.) and cotton (*Gossypium hirsutum* L.). Cattle, sheep and goats are the most important livestock species, kept by the majority of farmers at the study sites. Pastoralists and agro-pastoralists were differentiated according to the area of their crop land and size of their livestock herd. At all sites, a full meteorological station was installed in November 2008 or earlier for detailed and continuous recording of weather data.

4.2.2. Assessment of perceptions and adaptation strategies

Methods used to assess farmers' perception of natural environmental degradation (Dolisca et al., 2007; Regassa, 2008) and of climate change and adaptation (Nyong et al., 2007; Cooper et al., 2008; Deressa et al., 2009) were adopted for the present study. These methods included different participatory rural appraisal (PRA) techniques such as semi-structured and open interviews, resource mapping and transect walks with farmers, complemented by the collection of relevant background information from local administrations, development projects and non-governmental organisations (NGOs) during February – May 2009.

Each village meeting and focus group discussion addressed 30 - 60 and 15 - 20 participants, respectively, composed of pastoralists, crop-livestock farmers (agro-pastoralists) and crop farmers. The discussion focused on the most important bio-physical and socio-economic characteristics pertaining to crop production and livestock husbandry in the respective village, the perception of climate change (mainly changes in temperature and rainfall patterns), and its effects on crop and animal production over the last two decades, as well as the local responses to perceived changes. The information gathered served as basis for the elaboration of the semi-structured questionnaire used in the individual interviews of farm household heads. A total of 162 households (HH) were interviewed from January - May 2010 in Noberé, Sokouraba and Taffogo. The questionnaire encompassed detailed information on each household's socio-economic status (HH size, head of HH age, education , cropland surface, animal herd size) and farmers' perception of climate change and variability (CCV) over the past 20 years (increase, decrease or unaltered quantity of rainfall per year, number of rainy days and duration of rainy season, and maximum and minimum temperatures, as well as length of dry season), and of its impacts on their crop and livestock farming activities. Subsequently, the respondents were asked to list for each perceived impact their current coping actions, and the strategies they would adopt if climate change worsened.

Before being applied to the 126 households the questionnaire was pre-tested on fifteen key informant farmers; all interviews were conducted in local language. Temperature and rainfall data covering the period 1988 - 2008 was collected from three sites of the National Meteorological Station (Tougouri in the sub-Sahelian zone, Manga in the Northern Sudanian zone, Orodara in the Southern Sudanian zone).

4.2.3. Data analysis

The qualitative and quantitative information gathered were edited, coded and analysed using Excel® spread sheets and PASW Statistical Package software version 18.1 (PASW, IBM Inc. 2010). Frequencies of responses were reported; cross tabulations, Chi-square test and the non-parametric Kruskal-Wallis test were used to explore the factors influencing farmers´ choices of specific adaptation strategies. Subsequently, a binary logistic regression with a stepwise backward elimination of predictors was performed to identify the most determinant variables affecting farmers´ choices of future adaptation strategies. The fit of the final model was assessed by the model Chi-square (Model χ^2) and the goodness-of-fit test of Hosmer and Lemeshow (Archer and Lemeshow, 2006). Well-fitting models show significance ($P \leq 0.05$) on the Model χ^2 and non-significance ($P > 0.05$) on the goodness-of-fit test. Trends of annual rainfall and maximum temperature over the past 20 years (1988 - 2008) were calculated using simple linear regression.

Table 4.2: Results of focus group discussions on perceived impacts of climate change and local adaptation strategies in six villages distributed across three agro-ecological zones of Burkina Faso. Note that solutions are to be seen general, mostly responding to several problems mentioned in the second column.

Community	Negative impacts of climate change on production system	Local solutions
Agro-pastoralists (n= 3 groups, 180 participants)	Crop yields and production decreasing	Use of manure and compost
	Soil fertility decreasing, soil erosion increasing	Use of water and soil conservation techniques
	Desertification and recurrent droughts	Change of cropping practices
	Increased incidence of crop pests and weeds	Tree planting, abandonment of bush fires
	Conflicts between communities about resources use	Migration and off farm activities
	Recurrent food insecurity due to early cessation of rainy season	Integration of livestock and crop husbandry
	Pauperisation of farmers due to income reduction	Vegetable gardening during dry season
Pastoralists (n= 3 groups, 78 participants)	Animal mortality increasing due to forage lack and diseases	More prophylaxis and veterinary treatments
	Lack of drinking water for animals in dry season	Migration to humid zones
	Decreased animal productivity (milk and meat yield, fertility)	Intensified transhumance practices
	More difficulties for animal keeping due to crop field encroachment of pastures	Adoption of cropping
	Migration of pastoralists to southern zones	Sedentarisation of some pastoralists
	Persistence and apparition of (new) animal diseases	Increased shift to small ruminants
	Conflicts between communities about resources use	Shift to poultry keeping
	Food insecurity and pastoralists' pauperisation	Herd destocking to buy food
	Reduction and degradation of grazing areas and tracking corridors	Use of crop by-products and crop residues as animal feeds
	Decreased forage availability and quality	Concentrate feeding

Table 4.3: Impacts of climate change and variability on crop and livestock production as perceived by individual farmers from three villages located in three agro-ecological zones of Burkina Faso.

Study location (agro-ecological zone)	Farming (sub-)system	Variable	Increasing (%)	Decreasing (%)
Northern Sudanian (Noberé)	Agriculture (n=32)	Crop yields per hectare	5.3	94.7
		Total crop production	5.3	94.7
		Crop pests	31.6	68.4
		Soil fertility	0.0	100.0
	Livestock (n=26)	Herd size	33.3	66.7
		Livestock fertility	49.1	50.9
		Meat and milk yield	28.1	71.9
		Forage availability	14.0	86.0
Southern Sudanian (Sokouraba)	Agriculture (n=25)	Crop yields	0.0	100.0
		Crop production	0.0	100.0
		Crop pests	46.9	53.1
		Soil fertility	0.0	100
	Livestock (n=25)	Herd size	81.6	18.4
		Livestock fertility	36.7	63.3
		Meat and milk yield	0.0	100.0
		Forage availability	2.0	98.0
Sub-Sahelian (Taffogo)	Agriculture (n=27)	Crop yields	0.0	100.0
		Crop production	0.0	100.0
		Crop pests	76.9	23.1
		Soil fertility	0.0	100.0
	Livestock (n=25)	Herd size	14.8	85.2
		Livestock fertility	11.1	88.9
		Meat and milk yield	13.0	87.0
		Forage availability	0.0	100.0

4.3. Results

4.3.1. Recorded changes of temperature and rainfall variables

Rainfall and temperature data from 1988 to 2008 from three National Meteorological Stations are shown in Figure 4.1. Irrespective of the agro-ecological zone, there was a noticeable increase in the average annual maximum temperature. In contrast, rainfall trends differed between the zones. In the Southern Sudanian and Sahelian zones the annual rainfall was slightly increasing, whereas it decreased in the northern Sudanian zone; a remarkably high variation in precipitation from one year to the next showed for all zones.

4.3.2. Perceptions of long-term changes in temperature and rainfall

In all three agro-ecological zones the majority of interviewed farmers reported changes in temperature patterns, namely increasing dry season temperatures and longer duration of the dry season (Figure 4.2). Similarly, more than 70% of the respondents across the three zones perceived changes in rainfall variables: while 50% of the respondents in Noberé perceived an increase in the amount of rain received in the rainy season, this perception was not shared in Sokouraba (affirmative: 0%) and Taffogo (affirmative: 2%). Irrespective of the site, participants of the focus group discussions agreed that today inter-annual rainfall variability is high, and that the beginning and duration of the rainy season has become less predictable, rendering planning of cropping and pastoral activities difficult. Differences in the perceived number of rainy days and duration of the rainy season were significant ($P<0.05$) between Noberé and the two other locations, while there was no significant difference between the three locations in the perceived prolongation of the dry season.

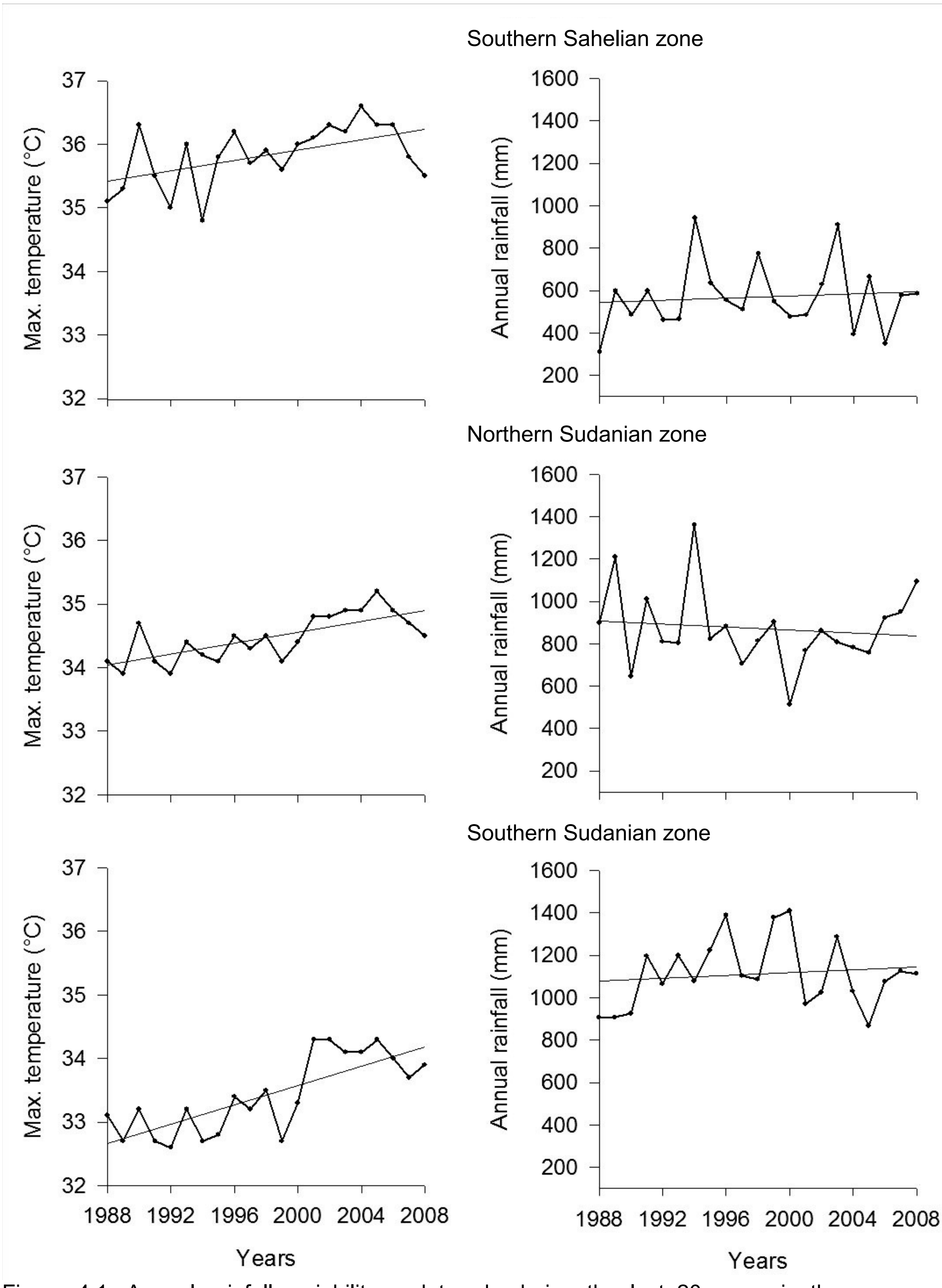

Figure 4.1: Annual rainfall variability and trends during the last 20 years in three agro-ecological zones of Burkina Faso

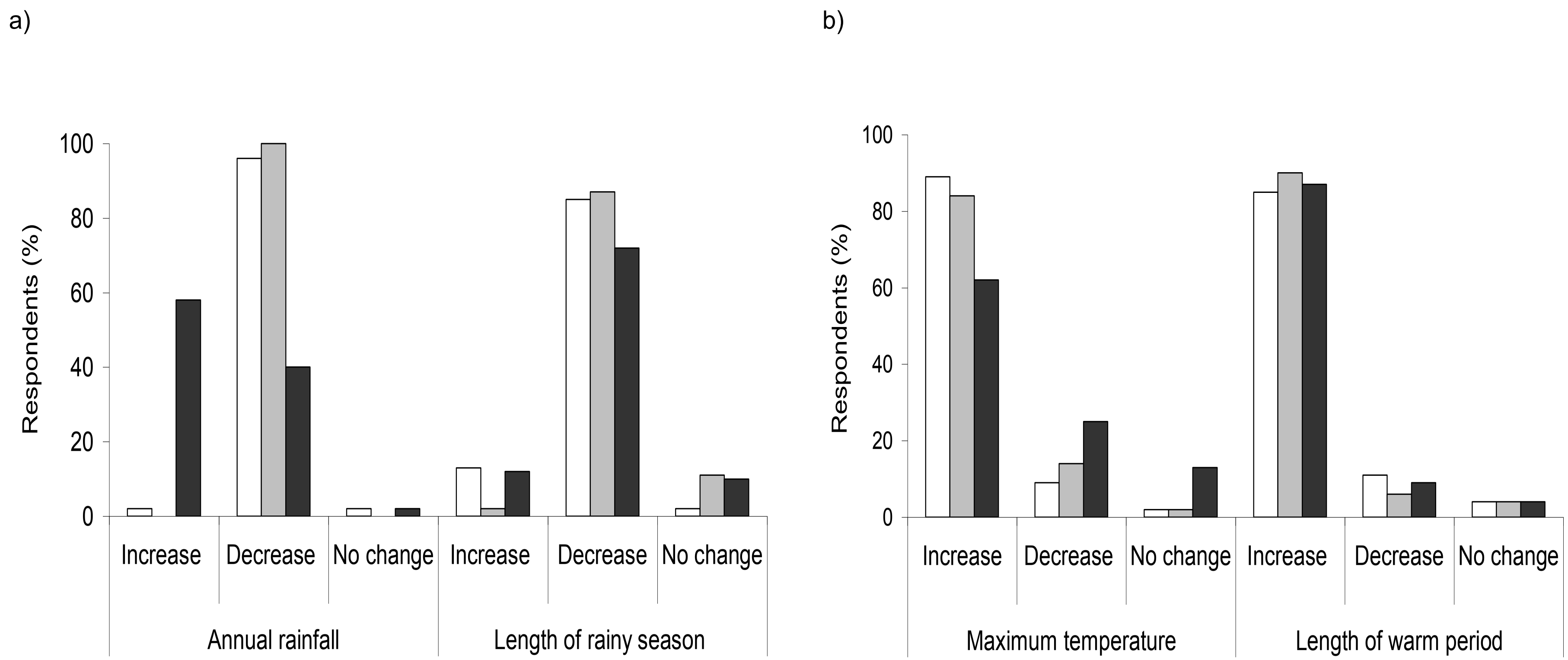

Figure 4.2: Distribution of farmers' (n=162) perception of changes in rainfall patterns (a) and temperature patterns (b) over the last 20 years across the sub-Sahelian (white), southern Sudanian (gray) and northern Sudanian (black) zone of Burkina Faso.

Table 4.4: Descriptive statistics of factors affecting the adaptation strategies of livestock husbandry to perceived climate change and variability by pastoralist households (HH) from three villages located in three agro-ecological zones of Burkina Faso.

Adaptation measures	Change in herd composition		Change of animal species		Transhumance		Permanent migration		Herd destocking	
Adoption	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Number of respondents	23	53	18	58	69	6	43	33	25	50
Agro ecological zone	Percentage of respondents									
Sub-Sahelian (n=25)	8	92	24	76	88	12	85	15	84	16
Northern Sudanian (n=27)	28	72	20	80	92	8	32	68	80	20
Southern Sudanian (n=25)	56	44	44	56	96	4	52	48	36	64
P- value (Chi-square test)	**		**		*ns*		**		**	
HH characteristics	Mean (SD)									
Age of head of HH (years)	49.2	48.4	49.2	48.5	49.5	40.2	48.4	49.0	48.0	49.2
	(11.10)	(11.14)	(10.48)	(11.32)	(11.12)	(6.43)	(11.72)	(10.30)	(10.89)	(11.28)
Education ratio†	0.4^{a}	0.2^{b}	0.5^{a}	0.1^{b}	0.2	0.3	0.2	0.2	0.5^{a}	0.2^{b}
	(0.35)	(0.29)	(0.39)	(0.26)	(0.33)	(0.24)	(0.33)	(0.32)	(0.37)	(0.25)
Goat herd size (number of animals)	6.5^{a}	11.1^{b}	7.4	10.4	9.9	8.2	9.4	10.1	6.4^{a}	11.4^{b}
	(5.11)	(9.51)	(5.54)	(9.34)	(8.94)	(5.31)	(8.12)	(9.43)	(5.36)	(9.58)
Cattle herd size (number of animals)	47.0	34.3	51.6	34.0	40.9^{a}	12.3^{b}	34.1^{a}	43.5^{b}	42.4	36.7
	(42.88)	(27.55)	(45.66)	(27.40)	(33.48)	(10.61)	(36.45)	(27.96)	(40.57)	(29.02)

† = Number of household members who went at least to primary school, divided by total number of household members.

*P-value, Chi-square test: **P≤0.01; ns = differences not significant.*

[ab] Within single adaptation practice, row means with different superscripts differ significantly (Mann-Whitney-U test, P≤0.05).

Table 4.5: Descriptive statistics of factors affecting the adaptation strategies of crop husbandry practices to perceived climate change and variability by agro-pastoralist households (HH) from three villages located in three agro-ecological zones of Burkina Faso.

Adaptation measures	Use of new crop varieties		Use of improved seeds		More fertilisation		Change in cropping practices		Permanent migration	
Adoption	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Number of respondents	42	41	69	16	47	38	60	25	37	47
Agro ecological zone	Percentage of respondents									
Sub-Sahelian (n=28)	59.4	40.6	96.9	3.1	34.0	65.6	71.9	28.1	67.7	32.3
Northern Sudanian (n=32)	60.9	39.1	68.0	32.0	100.0	0.0	72.0	28.0	88.0	12.0
Southern Sudanian (n=25)	32.1	67.9	75.0	25.0	55.3	60.7	67.9	32.0	14.3	85.7
P- value (Chi-square test)	*		**		**		*ns*		**	
HH characteristics	Mean (SD)									
Farm size (hectares)	6.1 (6.35)	4.3 (3.17)	5.6 (6.38)	6.0 (4.43)	7.8[a] (7.34)	3.1[b] (1.88)	6.0[a] (6.40)	5.1[b] (4.94)	3.4[a] (2.06)	7.5[b] (7.46)
Age of head of HH (years)	50.2 (10.62)	55.3 (14.08)	53.6 (12.28)	48.8 (13.30)	52.3 (12.49)	52.5 (12.78)	53.8 (11.66)	50.0 (14.36)	50.3 (12.03)	54.2 (12.70)
HH size (number of persons)	17.3 (9.53)	13.7 (6.59)	16.1 (7.91)	13.6 (9.81)	16.1 (8.48)	15.1 (8.13)	16.8 (7.75)	12.8 (9.02)	15.6 (7.87)	15.7 (8.77)
Education ratio[†]	0.2 (0.14)	0.2 (0.19)	0.2 (0.14)	0.3 (0.22)	0.2 (0.18)	0.2 (0.13)	0.2 (0.15)	0.3 (0.19)	0.2 (0.15)	0.3 (0.17)

[†]= Number of household members who went at least to primary school, divided by total number of household members.

*P-value, Chi-square test: **P≤0.01; *P≤0.05; ns = differences not significant.*

[ab] Within single adaptation practice, row means with different superscripts differ significantly (Mann –Whitney-U test, P≤0.05).

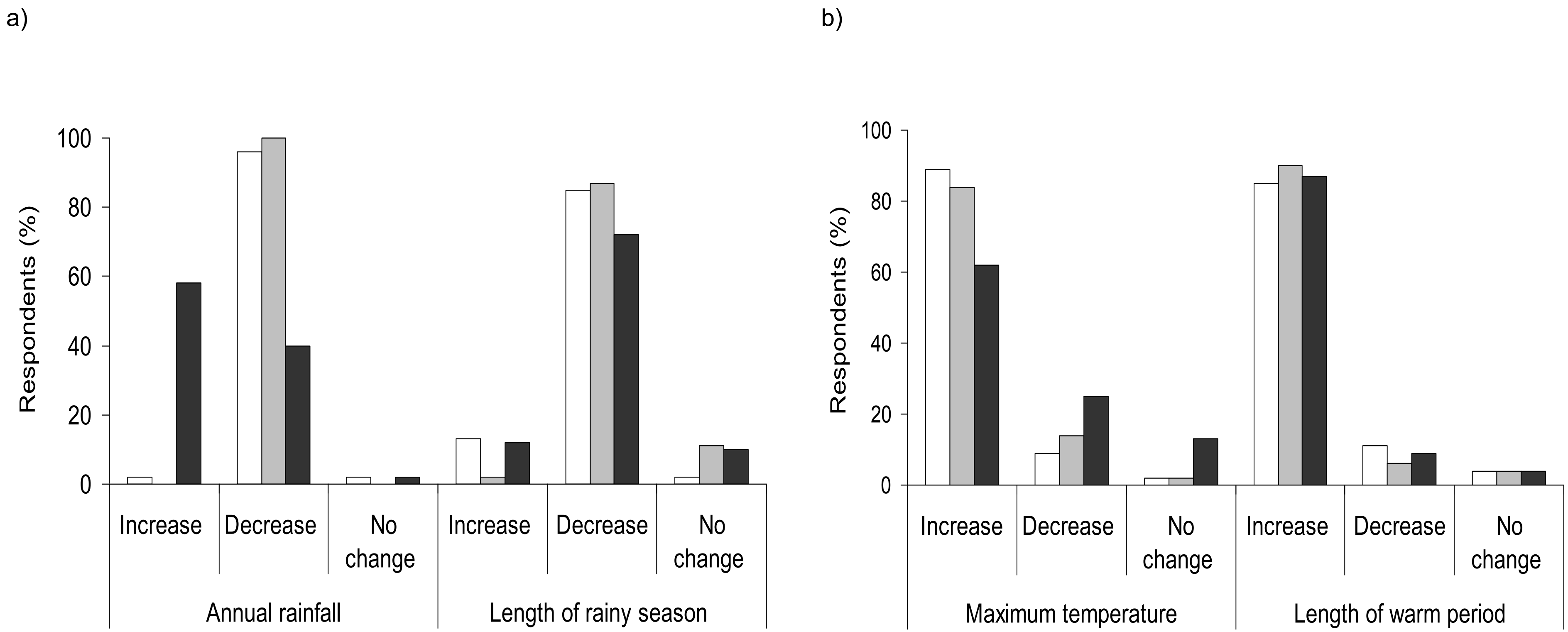

Figure 4.2: Distribution of farmers' (n=162) perception of changes in rainfall patterns (a) and temperature patterns (b) over the last 20 years across the Sub-Sahelian (white), Southern Sudanian (gray) and Northern Sudanian (black) zone of Burkina Faso.

4.3.3. Perceived impacts of temperature and rainfall change on crop and livestock production

Farmers in all agro-ecological zones reported that their traditional land management systems and related livelihoods have been affected by the observed changes in rainfall and temperature (Table 4.2). Decline in crop yields, decreased soil fertility, and increased erosion and land degradation were the major impacts of climate change as perceived by the crop farmers. For pastoralists and agro-pastoralists major impacts of climate change on their livestock were the shrinkage of grazing areas and decline of forage resources with consequently lowered animal productivity (offspring numbers, milk and meat yields). Since pasture areas and livestock corridors are increasingly cut-off by crop fields that cannot be trespassed during the rainy season until crop harvest, livestock mobility is restricted. Further problems named were limited access to watering places and increased conflicts over natural resource use with crop farmers. All participants mentioned increased vulnerability and poverty as important consequences of climate change.

The results obtained through individual interviews were similar to those of the group discussions (Table 4.3). Almost all respondents perceived negative impacts of climate change on their production systems and livelihoods. As far as forage availability for livestock was concerned, 86%, 98% and 100% of farmers from Noberé, Sokouraba and Taffogo, respectively, reported its decrease over the past 20 years. In the same villages, between 63 - 89%, and 50 - 100% of the interviewed livestock keepers reported that livestock fertility and meat and milk yields, respectively, had also decreased over the past 20 years. All crop farmers (100%) reported decreasing soil fertility and hence lowered crop yields per area across the three zones during the past 20 years (Table 4.3).

4.3.4. Current and anticipated adaptations to climate change

During the focus group discussions, all village communities reported that they have taken measures to reduce the negative impacts of climate change on their farming systems and livelihoods. These included strategies to increase cereal yields, reduce food insecurity, support household income and mobility of livestock herds (Table 4.2). Water and soil conservation measures, such “zai” and “half-moon” techniques, anti-erosive stone dikes and selective land clearing techniques were claimed to be used to improve soil fertility, water retention and efficiency of use of organic and mineral fertiliser (Appendix 4.1). Farmers also reported the use of improved seeds of locally adapted varieties of sorghum and millet (further referred to as “improved seeds”) provided by the National Agricultural Research Institute (INERA) through extension activities. Strategies developed to challenge food insecurity and sustain household income included diversification of farm activities (combination of crop, livestock and gardening activities) and seasonal migration of young household members to cities where they sought temporary jobs. In addition to resorting to seasonal transhumance and splitting livestock herds into small groups kept in different locations across the country, pastoralists were diversifying their activities by cultivating cereals. They also mentioned a shift in livestock species from cattle to goats and sheep, especially in the sub-Sahelian zone where water and forage resources declined strongly over the past two decades. As far as individual farmers' actions were concerned, 20% of the respondents in Sokouraba mentioned that they did not have any adaptation strategy (Figure 4.3), whereas this was true for only 5% of farmers in Noberé and Taffogo ($P<0.05$). However, between 88% and 96% of the livestock keepers intended to resort on transhumance and permanent migration if climate change effects worsened (Table 4.4). This was particularly true for the respondents from Taffogo, who stated that they would migrate to the sub-humid zone of Burkina Faso and/or to the neighbouring countries of Ghana and Ivory Coast where availability and accessibility of feed and water resources seemed to be better. Regardless of the agro-ecological zone, most crop farmers stated that in case of worsening conditions they would change cropping practices and production systems to deal with increased soil degradation and decreased soil fertility (Table 4.5). Additionally, more than 70% mentioned that they would introduce improved seeds and new crop varieties to their cropping systems.

4.3.5. Factors affecting anticipated adaptations

From the binary logistic regression analysis (Table 4.6) it appeared that agro-ecological zone was the most determinant factor for pastoralists to anticipate herd destocking, permanent migration from the present location and change of herd composition as future adaptation strategies. Pastoralists from the Northern Sudanian zone were 10 times (odds ratio = 9.8) more likely than those from the other agro-ecological zones to adopt destocking, and 15 times (odds ratio = 15.3) more likely to change their herd composition, but were less likely to embrace far-distance migration. Furthermore, the larger their cattle herd size and smaller their goat herd size, the more likely pastoralists were to resort on transhumance. Shifting to other livestock species was most likely to occur when the pastoralist household had a high education ratio. In contrast to the pastoralists, agro-pastoralists from the Northern Sudanian zone were three times more likely to migrate than those from the other agro-ecological zones (Table 4.7). Size of cropland was significant ($P<0.01$) in determining the adoption of fertilization of sorghum, millet and maize with mineral and/or organic fertilisers such compost, household wastes and crop residues. The likelihood of farmers to adopt new crop varieties was significantly ($P<0.01$) affected by the age of the household head, the agro-ecological zone and the household size, whereas the use of improved seeds was significantly ($P<0.01$) affected by the education ratio of the farm household and the agro-ecological zone. The higher the education ratio in a household from the sub-Sahelian zone, the less likely the farmer was to adopt improved seeds.

Table 4.6: Results of the logistic regression analysis on factors affecting future adaptation strategies of pastoralist households to climate change and variability across three agro-ecological zones of Burkina Faso.

Predictors	β	SE β	Wald's χ2	df	P≤	eβ (odds ratio)
Herd destocking						
Constant	-1.312	0.589	4.959	1	0.001	0.269
Agro-ecological zone			13.009	2	0.001	
Sub-Sahelian (1)	0.535	0.773	0.479	2	0.489	1.708
Northern Sudanian (2)	2.284	0.701	10.628	1	0.001	9.819
Test			*χ2*	*df*		
Overall model evaluation			*17.950*	*1*	*0.001*	
*Goodness-of-fit**			*8.470*	*7*	*0.293*	
Transhumance						
Constant	-6.972	4.795	2.114	1	0.146	0.001
Goat herd size	-0.354	0.175	4.084	1	0.043	0.702
Cattle herd size	0.258	0.111	5.441	1	0.020	1.294
Test			*χ2*	*df*		
Overall model evaluation			*19.298*	*5*	*0.002*	
*Goodness of fit**			*1.329*	*7*	*0.988*	
Migration						
Constant	1.913	0.760	6.341	1	0.012	6.775
Agro-ecological zone			11.869	2	0.003	
Sub-Sahelian (1)	-2.388	0.698	11.699	1	0.001	0.092
Northern Sudanian (2)	-1.671	0.684	5.972	1	0.015	0.188
Test			*χ2*	*df*		
Overall model evaluation			*16.434*	*3*	*0.001*	
Goodness-of-fit			*10.440*	*7*	*0.165*	
Changing livestock species						
Constant	-1.898	0.395	23.037	1	0.001	0.150
Education ratio**	2.527	0.820	9.504	1	0.002	12.515
Test			*χ2*	*df*		
Overall model evaluation			*10.125*	*1*	*0.001*	
Goodness-of-fit			*3.285*	*6*	*0.772*	
Changing herd composition						
Constant	-2.485	0.736	11.400	1	0.001	0.083
Agro-ecological zone			11.516	2	0.003	
Sub-Sahelian (1)	1.540	0.860	3.206	1	0.073	4.667
Northern Sudanian (2)	2.726	0.839	10.556	1	0.001	15.273
Test			*χ2*	*df*		
Overall model evaluation			*15.142*	*2*	*0.001*	
Goodness-of-fit			*0.000*	*1*	*1.000*	

* Hosmer & Lemeshow goodness of fit test (Archer and Lemeshow 2006).
** Number of household members who went at least to primary school, divided by total number of household members.

Table 4.7: Results of the logistic regression analysis on factors affecting future adaptation strategies of agro-pastoralist households to climate change and variability across three agro-ecological zones of Burkina Faso.

Predictors	β	SE β	Wald's χ2	df	P≤	eβ (odds ratio)
Migration						
Constant	-0.314	0.301	1.086	1	0.297	0.730
Agro-ecological zone			23.880	2	0.001	
Sub-Sahelian (1)	-1.250	0.726	2.9710	1	0.085	0.286
Northern Sudanian (2)	3.159	0.651	23.576	1	0.001	3.546
Test			*χ2*	*df*		
Overall model evaluation			*34.957*	*2*	*0.001*	
*Goodness-of-fit**			*0.000*	*1*	*1.000*	
Changing cropping practices						
Constant	0.607	0.690	0.774	1	0.379	
Household size (members)	0.064	0.036	3.188	1	0.074	1.067
Education ratio**	-2.929	1.514	3.740	1	0.053	0.053
Test			*χ2*	*df*		
Overall model evaluation			*8.691*	*2*	*0.013*	
Goodness-of-fit			*6.809*	*7*	*0.449*	
Fertilisation						
Constant	-1.384	1.201	1.328	1	0.249	0.251
Farm size (hectares)	0.343	0.108	10.096	1	0.001	1.409
Test			*χ2*	*df*		
Overall model evaluation			*21.578*	*4*	*0.001*	
Goodness-of-fit			*5.108*	*7*	*0.647*	
Use of new crops						
Constant	1.943	1.137	2.921	1	0.087	6.982
Agro-ecological zone			8.411	2	0.015	
Sub-Sahelian (1)			0.919	1	0.338	0.231
Northern Sudanian (2)	-0.805	0.840	5.646	1	0.017	0.447
Age of household head (years)	-0.065	0.023	7.604	1	0.006	0.937
Household size (members)	0.082	0.038	4.726	1	0.030	1.086
Test			*χ2*	*df*		
Overall model evaluation			*20.815*	*6*	*0.002*	
Goodness-of-fit			*3.459*	*8*	*0.902*	
Use of improved seeds						
Constant	2.683	0.623	18.558	1	0.001	14.622
Agro-ecological zone			7.701	2	0.021	
Sub-Sahelian (1)	3.752	1.359	7.619	1	0.006	0.023
Northern Sudanian (2)	-0.765	0.794	0.927	1	0.336	0.465
Education ratio**	-3.896	1.868	4.347	1	0.037	0.020
Test			*χ2*	*df*		
Overall model evaluation			*19.191*	*6*	*0.004*	
Goodness-of-fit			*5.016*	*7*	*0.658*	

* Hosmer & Lemeshow goodness of fit test (Archer and Lemeshow 2006).
** Number of household members who went at least to primary school, divided by total number of household members.

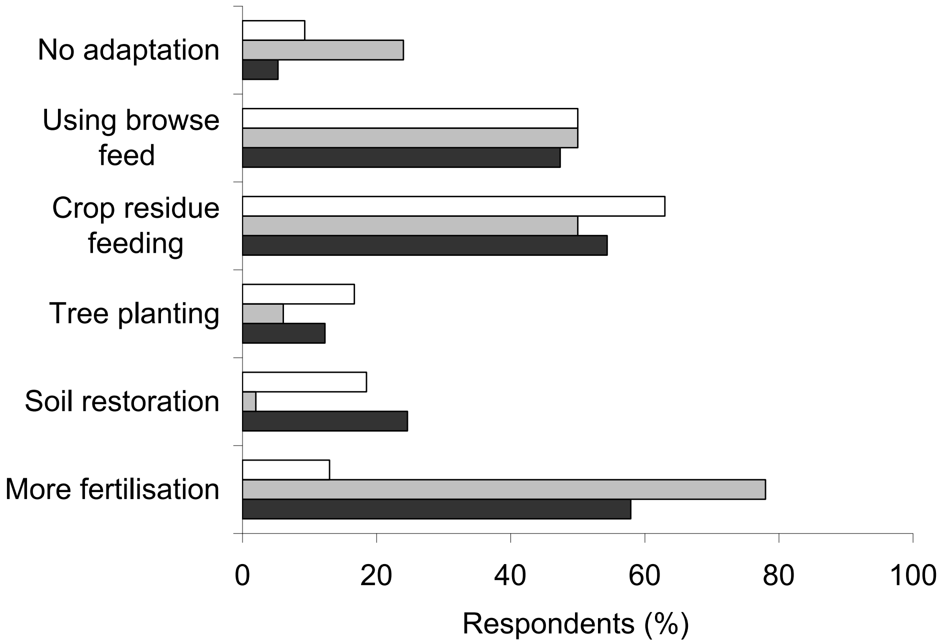

Figure 4.3: Current measures adopted by pastoralists and agro-pastoralists (n=160) in Burkina Faso in response to climate change and variability in the Sub-Sahelian (white), Southern Sudanian (gray) and Northern Sudanian (black) zone of Burkina Faso.

4.4. Discussion

4.4.1. Perception of changes in temperature and rainfall and of their impacts

Across the three investigated agro-ecological zones of Burkina Faso, farmers were aware of climate change and perceived changes in temperature and rainfall. Similar perceptions were reported from farmers in the Eastern Saloum region of Senegal, which is located between the Sudano-Sahelian and Sudanian climatic zones (Mertz et al., 2009) and from the Nile Basin of Ethiopia (Deressa et al., 2011). Interestingly, the perception of changes in rainfall patterns by crop farmers and pastoralist from our Southern Sahelian and Sudanian sites (Sokouraba and Tougouri) did not match well the metrological data on evolution of rainfall in these areas. Farmers' perceptions might probably have been affected by the poor rainy seasons of 2000/2001 and 2004/2005 (Figure 4.1), and some might even have had in mind the severe droughts of 1972-1973 and 1984 (CILSS, 2009). Crane (2011) pointed out that single heavy rainfall events occur less frequently since the 1990s than prior to the 1970s drought. A similar discrepancy between farmers' perception and recorded weather data was reported by Meze-Hausken (2004) from the Sudanian savannah zone of Central Senegal. In Burkina Faso, like in any other Sahelian country, temperature and rainfall are the most important climatic factors influencing availability of natural resources and livelihood strategies (MECV, 2007). Hence, any significant changes in temperature and rainfall will affect both feed resources for livestock and cropping activities (Seo and Mendelsohn, 2006; Hassan and Nhemachena, 2008). In the current study, farmers' views on the potential impacts of changes in temperature and rainfall patterns agree well with perceptions reported from other countries in sub-Saharan African. Ringle et al. (2010) showed that climate change affects the area cropped, per area yields and total grain production in sub-Saharan Africa. Case studies undertaken in Senegal, Mali, Burkina Faso and Niger predicted that yields of millet and sorghum, the two major staples in the Sahel, will decrease by 15 - 25% until 2080 for Niger and Burkina Faso (Sarr, 2007). Climate change is expected to increase problems linked to animal keeping, especially the availability of water and feed resources, which will have distinct negative impacts on livestock productivity and livelihoods of livestock keepers (CILSS, 2009); this is mirrored by the views of pastoralists interviewed in our study. Seo and Mendelssohn (2006), when assessing the economic impact of climate change on animal husbandry in eleven African countries, found that livestock net revenues are highly sensitive to climate, with larger herd sizes increasing the sensitivity to rising temperatures.

4.4.2. Novelty of farmers' adaptation strategies

The high frequency and severity of extreme climate events (floods, droughts) and the high climate variability in the Sahelian countries are threatening farmers' adaptive capacity, which is already weakened by negative effects of past droughts and poverty (Kandji et al., 2006). As climate models predict worsening climatic conditions for the Sahelian region, ensuring food security will be a major challenge for the majority of people in this region (GIEC, 2007). Our respondents used several coping strategies to reduce the adverse impacts of climate change. Innovative strategies for crop farmers in this study were the systematic use of improved seeds (millet and sorghum) and the introduction of new crop varieties of rice and maize. Secondly, the adoption of better fertilisation practices with mineral and organic amendments such as compost and animal dung pointed to their willingness of intensifying cropping practices. All mentioned strategies aim at improving the yields of major cereals and therefore could reduce poverty and food insecurity. The adoption of these strategies is supported by the government of Burkina Faso through policies of food insecurity reduction and the national programme of adaptation to climate change.

The strategies adopted by pastoralists are very traditional practices but are apparently viewed as still valid to respond to climate change and variability. If practiced consequently, the ruminant herd splitting as well the shift from cattle (vulnerable to warming) to sheep and goats (both heat tolerant and, on an individual basis, requiring less water and feed than cattle) rearing in the sub-Sahelian zone can be judged quite innovative and effective for a risk-spread use of natural resources and reduced risk of livestock losses during extreme climate events across the region (Fratkin and Smith, 1994; Seo et al., 2010). Ajibade (2007) and Salik et al. (2007) hypothesized that local adaptation strategies are based on coping experience acquired over time which is transmitted from generation to generation. The practice of transhumance provides an illustrative example of this. Transhumance is the regular movement of herds between fixed points to exploit seasonal availability of fodder, and herd splitting is one of its characteristic features (Blench, 2001). It is a culturally revered way of life and a central social institution around which West African Fulani households and their cultural practices have historically been organized (Crane, 2011). It creates ethnic identity across the Sahelian region (De Bruijn and Van Dijk, 2001) and has since centuries been a way of adapting to the unbalanced and changeable agro-ecological conditions of the Sahel, making use of ecological complementarities between the Sahelian and Sudanian region (Blench, 2001). Consequently the question arises whether transhumance is a long-term adaptive strategy to climate change, especially when considering the “Sahelisation” of the Sudanian zone (Wittig et al., 2007) and the shrinkage of its pastoral resources. In our study, cattle herd size was found to be a determinant factor for the practice of transhumance, whereby pastoralists owning a large number of cattle were more likely to continue this practice. This is probably due to the fact that cattle require more of the scarce feed and water resources than small ruminants. Pastoralists from the Northern Sudanian zone of Burkina Faso were much more likely to reduce herd sizes through animal sales, probably because they are close to large urban livestock markets

(Ouagadougou and Pô for Noberé, and Niangologo for Sokouraba) where animals fetch better prices than in the other two zones where larger cities are only sparsely distributed.

For all farmers the most important innovation was the diversification of farming activities including the cultivation of different types of crops and the adoption of an integrated crop-livestock farming system which is more risk adverse than a specialized system and well-adapted to the conditions of the Sahelian and Sudanian zone (Seo, 2010).

While some of the above strategies can be considered pertinent towards addressing negative impacts of climate variability on land-based activities, most are neither recent nor developed specifically to address climate change. From Northern Burkina Faso, Barbier et al. (2009) reported that farmers adopted most of the innovative agricultural technologies not because of climate variability alone but also because of growing land scarcity and new market opportunities. Nevertheless, Sahelian crop and livestock farmers possess valuable local knowledge that could be harnessed to confront climate change and variability (Mortimore et al., 2001; Parry et al., 2007; Nyong et al., 2007).

4.4.3. Effectiveness of farmers' adaptation strategies

As discussed above, several strategies are adopted by farmers. New strategies such as the use of improved seeds and new crop varieties, and efficient crop fertilisation are promoted by the government of Burkina Faso. Such measures might play an important role in increasing the country's production of maize, millet, rice and sorghum and therefore help the farmers to cope with food insecurity and negatives impacts of climate change in the crop but also the livestock sector – the latter benefiting indirectly from the increased amounts of crop residue feedstuff. Despite government support, timely access to improved seeds and fertilisers is difficult, and for the adoption of composting practices lack of material and knowledge are obstacles. The adoption of improved seeds in Burkina Faso is still low, ranging from 2.6 - 6% for all crops (Bikienga, 2002) and being less than 5% for sorghum (Trouche et al., 2001). As stated by Maddison (2006), the availability of improved seeds and their accessibility are probably the most significant determinants of their adoption, and the same holds true for the use of mineral fertilizer. In our study, the adoption of better fertilization strategies was positively affected by cropland size. This suggests that the evident decline in farm sizes in Sahelian countries over time due to land degradation and cultivation area restriction (Jayne et al., 2003) may constitute an obstacle to the adoption of some technologies.

According to OECD/SWAC (2008) some of the adaptation strategies reported by our respondents, such as uptake of cropping (pastoralists) and crop field expansion (agro-pastoralists) as well as migration, transhumance and herd splitting (pastoralists) have not proven effective in mitigating negative impacts of climate change. Although transhumance is a strategy adapted to drylands such as the Sahel that are characterised by scarce resources and high climate variability (Brook, 2006), especially cropland expansion provokes social conflicts between farmers and pastoralists over natural resources exploitation.

The soil and water conservation practices of “zai” and “half-moon” mentioned by crop farmers became popular in the Sahelian zone since the early 1980s (OECD/SWAC, 2008). However, farmers from different agro-ecological zones opted for different adaptation strategies, which is in agreement with the observations of Deressa et al. (2009). The “zai” technique, for example, has proven successful in improving soil physical properties (Somé et al., 2004; Zougmoré et al., 2004) and ensuring high crop yields in the dry Sahelian zone (Sawadogo et al., 2008), but digging the pits requires considerable labour (Barro et al., 2005) that can prevent the full adoption of this technique by small households; this seems to be reflected by an adoption rate of only 41% among farmers in Northern Burkina Faso (Barbier et al., 2009).

The positive effect of household size on choices of new agricultural practices as determined in this study may be linked to the higher labour endowment of larger rural families (Croppenstedt et al., 2003; Deressa et al., 2009). The use of improved seeds can enhance crop productivity, but according to our insights the adoption of the strategy might be restricted to larger households which are more likely to test new management practices given their higher family labour endowment, which also makes them less risk averse than smaller households. Surprisingly, the age of the farm household head was negatively related to the probability of adoption of a new crop variety. This result sharply contrasts with the argument that, because of their accumulated knowledge, capital and experience, older farmers are more likely than younger ones to adopt a new technology (Abdulai and Huffman, 2005), but might be explained by the fact that risk aversion increases with age (Forsfält, 1999).

4.5. Conclusions

This study showed that in Burkina Faso, pastoralists and agro-pastoralists have already adopted some coping strategies to secure their livelihoods in view of perceived and actually occurring climate change and variability. Some of these strategies are well-established and well-known, and initially targeted climate variability rather than climate change. The already partial adoption and the strong willingness to further use improved seeds and new crop varieties, and to improve fertilisation of crop fields should be used as the basis for national strategies to stabilise and secure the country’s cereal production. A consequent and systematic application of herd splitting strategies and the shift from cattle to sheep and goat rearing by pastoralists would be a valid risk aversion strategy ensuring optimized use of pastoral resources across the country. However, farmers’ adaptation practices are in general more of spontaneous and short-term nature. Consequently, the adoption of medium- and long-term adaptation measures needs to be based on national and regional policies that provide efficient technical and financial assistance to vulnerable groups when extreme events such as floods and droughts occur. Due to the high spatio-temporal variability of natural resources as well as infrastructure, development and implementation of adaptation strategies aiming at counteracting climate change effects must be site-specific.

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Appendix 4.1: Definition of several adaptation practices in cropping and livestock keeping encountered across three agro-ecological zones of Burkina Faso.

Farming system	Adaptation strategy	Meaning
Cropping	More fertilisation	Increased use of organic fertiliser (manure and/or compost) and mineral fertiliser by farmers for millet, sorghum and maize.
	Use of improved seeds (of local cereals)	Local sorghum, millet and maize seeds selected and improved by the national agricultural research institute (INERA), which obtain higher grain yields and are adapted to different climatic zones of Burkina Faso.
	New crop varieties	New varieties of sorghum, millet, rice and maize, as well as of cowpea (*Vigna unguiculata* L. (Walp.)) selected and introduced by agricultural extension services.
	Zai technique	Traditional land restoration technology of farmers in Burkina Faso to rehabilitate degraded drylands and to restore soil fertility. Small pits of 20-30 cm diameter and 10-20 cm depth are dug into degraded soils, often hardpans. At the bottom of the pits farmers place about two handfuls of organic material (animal dung or crop residues). Pearl millet or sorghum seeds are planted in these pits as soon as rainfall starts.
	Half-moon technique	Variant of the Zai technique, larger diameter of the planting hole.
	Anti-erosive stone dikes	Technique in which larger stones are buried in rows to a depth of about one-third of their height, following contour lines. These small dams reduce the speed of surface water runoff and the loss of topsoil and organic matter.
Livestock keeping	Permanent migration	Movement of farmers across a specified boundary (village, region, or even the country) for the purpose of establishing a new and permanent residence where pastoral resources are available for livestock.
	Transhumance	Seasonal movement of herd and part of the household in search of qualitatively and quantitatively adequate grazing resources.
	Herd splitting	Separation of herd in two or three groups (often of similar physiological stage), each one kept at a different location across the country.
	Herd destocking	Sale of some animals to buy food or to reduce the number of animals per herd, primarily targeting young male cattle and small ruminants, and old and sick animals.

Chapter 5

General discussion, conclusions and recommendations

5.1. Contribution of browse fodder to livestock nutrition under climate change

Our study revealed an increased contribution of browse fodder to feed intake of grazing ruminants across the major three agro-ecological zones of Burkina Faso. Its contribution was greater for small ruminants than for cattle, which however make a considerable use of browse fodder especially during the hot dry season. As shown in Chapter 2, the contribution of browsing to the daily feeding time of goats makes ligneous forages a complementary source of quality feed for this species in the sub-Sahelian and northern Sudanian zone of Burkina Faso. Although for cattle and sheep browse contribution to daily feeding time is less than of grazing herbaceous species, browse is the main source of protein for pastoral cattle herds in the agro-pastoral zone of Burkina Faso in the dry season, due the problem of accessibility and availability of concentrate feed for livestock keepers. Earlier studies showed the potential and contribution of browse fodder to alleviating nutritional problems of pastoral livestock, both qualitatively and quantitatively, during forage shortage periods and drought years in West Africa (Le Houerou, 1980; Baumer, 1992). The combination of interviews with livestock keepers, monitoring of grazing behavior and evaluation of the nutritive value of preferred browse plants in the present study confirmed that browse fodder is an integral part and significantly contributes to cattle, sheep and goat nutrition in the agro-pastoral livestock systems of the semi-arid and sub-humid regions of West Africa year-round. Browse fodder could therefore play an important role in view of climate change which is predicted to increase the nutritional stress for cattle and small ruminants in the Sahelian and Sudanian zone of West Africa. The increased use of browse species by grazing cattle and small ruminants that was reported by the interviewees (Chapter 3) indicates that livestock keepers are aware of its importance and role for their livestock husbandry system. Given the importance of the national livestock herd for the country's economy, and their role for household income as well as livestock's socio-cultural roles (Upton, 2004; Somda, 2005), a systematic and sustainable use of browse by livestock keepers could substantially improve livestock production in the studied regions, and particularly in the Sahel and reduce farmers' vulnerability to climate change impacts. Besides the direct use of browse by livestock on pasture, several studies reported an increased harvesting of leaves and fruits of some browse species such *Faidherbia albida, Piliostigma reticulatum* and *P. thoningui, Gliricidia sepium* and *Pterocarpus erinaceus* for trade on local markets in central Burkina Faso and upper eastern Ghana (Sanon, 2005; Husseini et al., 2011; Sanou et al., 2011). As stated in Chapter 3, most browse species preferred by livestock and selected on pasture are indigenous species and naturally occurring on common pasture areas, mainly the dry savannahs, parklands, fallows and the protected forests. While agro-forestry systems and systematic protection of trees in crop fields are promoted in Burkina Faso and adopted by farmers, due to their importance in nutrient cycling and soil fertility restoration (Kessler, 1992; Bayala et al., 2002; Nikiema, 2005), the silvo-pastoral system with browse species for forage purposes is little practiced by livestock keepers. Yet, a silvo-pastoral system with browse fodder banks could substantially contribute to increased qualitative forage supply and also reduce the pressure on preferred browse species occurring naturally. Such systems have been successfully developed in Latina America (Shelton, 2001) and have been well established in East Africa (Roothaert and Paterson, 1997; Paterson et al., 1998) while in West Africa only few and not very successful efforts were made to introduce this technology. For the actual livestock feeding practices in the agro-pastoral zones of Burkina Faso, fodder banks with legumes trees in addition to agro-forestry systems with multipurpose species could increase crop and livestock productivity and contribute to the protection of the environment against negative impacts of ongoing climate change (FAO, 1999; Le Houerou, 2006; Jose, 2009). Such measures would also significantly support reforestation of degraded agro-pastoral areas and increase their productivity through soil fertility restoration. Specific attention should be given to promote, for each agro-climatic zone, those preferred browse species that are drought tolerant.

5.2. Impact of climate change on livestock nutrition and grazing management

In pastoral and agro pastoral systems, livestock nutrition and grazing management strongly depend on rainfall and natural resources availability. Spatio-temporal variability in forage quality, quantity and accessibility affect the exploitation of grazing areas and livestock foraging behaviour (Schlecht et al., 2006; But, 2010a). In the agro-pastoral areas, the installment of crop fields during the rainy season and, to some extent, their distribution across the village territory also affects the mobility of grazing animals and the use of grazing areas (Ayantunde et al., 2008). The foraging behavior of cattle and small ruminants on pasture is highly variable across seasons and agro-ecological zones (Chapter 3). This variability of livestock foraging behaviour is a response to the spatio-temporal availability of forage resources and as such a flexible adaptation strategy of livestock to an unbalanced and changeable environment where mobility remains the key to sustainable use of the natural resources (Butt, 2010b) and enables livestock keepers to cope with recurrent forage shortage and scarcity. After the severe droughts in the 1970s and 1980s and the induced environmental changes which threatened pastoral livestock keeping, the opportunistic behaviour and herd mobility have help Sahelian pastoralist to persist (Basset and Turner, 2007) , and today even lead to increased livestock productivity per area and head (Nianogo et al., 2004).

As most climate models for the region suggest that rainfall will become increasingly erratic and unpredictable over the coming decades (Sarr, 2012), pastoral livestock nutrition and grazing systems will be negatively affected by declining pasture productivity and forage yields (MECV, 2007). Furthermore, cropland expansion and the increased agricultural pressure in agro-pastoral zones – the latter due to rapid population growth and negative impacts of climate change on crop yields – will limit livestock mobility on pasture and therefore challenge livestock keepers' adaptive capacities and livestock productivity. In fact, the agro-pastoral zones of Burkina Faso nowadays experience a high stocking rate of domestic ruminants paralleled by agricultural intensification (MRA, 2005), whereas herd mobility - both daily micro-mobility and seasonal transhumance - gets difficult. This increases the grazing pressure on the remaining grazing areas (Chapter 2). Among ruminants species monitored in this study, cattle seem to be more affected by climate change and variability than small ruminants. Due to higher requirement of cattle for forage and water resources, which are expected to drastically decrease in the sub-Sahelian and Sudanian zones, cattle will be under a higher pressure if herd mobility is not facilitated (Craine et al., 2010). Goats, on the other hand, with their ability to cope with harsh environments (Silanikove, 1996, 2000), their opportunistic use of various kinds of forages including browse species, and their genetic potential (Alexandre and Mandonne, 2005) should better cope with the expected climate and environnemental changes in the Sahelian and Sudanian zones. This seems to be supported by economic analyses which found that smallholder farmers who were able to shift from cattle to small ruminant keeping were more resilient to climate change effects than those who didn't make this change (Seo et al., 2010). A trend towards increasing numbers of small ruminants is in fact already observed in the southern Sahelian and northern Sudanian zone of Burkina Faso (MRA, 2005).

5.3. Adaptive capacity of pastoralist and agro-pastoralist systems to climate change and variability

Farmers in the Sahelian and Sudanian zones of West Africa are considered the most vulnerable to climate change due to their location at the southern fringe of the Sahara desert, which exposes them to a strongly variable, erratic and unpredictable rainfall (Kandji et al., 2006). Given the dependency of the majority of rural households on crop and livestock husbandry, and in view of the low resources endowment and poverty, the population's adaptive capacity to climate change is low, and the latter is expected to have severely negative impacts on the region (IPCC, 2007). Pastoralists and agro-pastoralists in the Sahelian and Sudanian zones do perceive changes in temperatures, but especially rainfall amount and patterns, and observe impacts on their farming system; they already have initiated and adopted some coping and adaptation strategies to secure their livelihoods (Barbier et al., 2009). Most of the coping and adaptation strategies of local farmers in the cropping and livestock sector are site-specific (Metz et al., 2011), spontaneous and primarily of short-term nature, while long-term strategies against the expected climate change and other environmental stresses are rare. However, the adopted coping strategies do not only address climate change but are also a consequence of increased food demand and market orientation of production (Metz et al., 2010a). Although some adaptation practices are judged innovative and effective, most are traditional methods and practices that are revisited and improved in the context of ongoing climate change because they seem to fit to the changing environment and farming conditions of the region (Ouedraogo et al., 2010). However, in the present situation in which climate change and variability will enhance poverty and food insecurity among poor farmers, adaptation strategies are fundamental to reduce the risk of primary production failure, to diversify the sources of food and livelihoods, and to create buffer against future food and livelihoods stress (Sissoko et al., 2010). Although agro-pastoral and transhumant pastoral livestock systems in the Sahelian and Sudanian zone of West Africa are in principal resilient, the rapid population growth and increasing agricultural pressure in addition to induced environnemental changes reduce the adaptive capacity of these systems (Mortimore, 2010). Therefore it is necessary to implement effective adaptation programs which sustain and improve household income of pastoralists and agro-pastoralists. Appropriate measures should be taken at local, regional, national and international level to tackle poverty and negative impacts of climate change in order to support local resilience and adaptive capacities. At regional and national level, policies supporting free and easy move of transhumant livestock herds are urgently needed in the Sahelian and Sudanian zone of West Africa, including also infrastructure such as vaccination parks and watering points along the transhumance corridors. On the other hand policies facilitating the domestic, regional and international trade in livestock and livestock products should be initiated to support local livestock-based income generation and contribute to national economic growth.

5.4. Main conclusions and recommendations

The analysis provided in this thesis showed that, while maximum temperatures are expected to increase in West Africa during the coming decades (and with these high evapo-transpiration losses of water), climate models fail to predict consistent trends for the future of amount and patterns of rainfall in the Sahelian and Sudanian zones. Impacts of climate change phenomena on livestock nutrition will differ between agro-ecological zones and livestock species, with small ruminants being less vulnerable to the expected changes than cattle. In the southern Sahelian and northern Sudanian zones, browse fodder contribution to livestock nutrition is important especially for goat and sheep, but cattle herd mobility is limited in these zones by agricultural activities.

Crop failure and cropland expansion induced by climate change and variability will further limit the already reduced livestock mobility and lower the adaptive capacity of the pastoralist and agro-pastoralist systems. Under escalating nutritional stress, browse fodder will play an increasingly important role for livestock, providing high quality forage to grazing ruminants year-round, but especially in the dry season. However, action has to be taken to support the regeneration of preferred browse species on grazed lands, and avoid a creeping disappearance of at least some of these species. Pastoralists and agro-pastoralists do perceive changes in climate variables and the impacts on their production systems. Most of them have already taken up various adaptation strategies to secure their livelihoods. Although those strategies are valuable and most farming practices are resilient, they remain inefficient against extreme events such as floods and droughts. To effectively support the regional livestock keepers in their efforts of coping with climate change and variability, the following measures seem therefore necessary:

1. Policies makers and extension services (governmental or NGOs) should recognize herd mobility as a key point for strengthening the adaptive capacity and resilience of pastoral and agro-pastoral ruminant production systems.

2. Shrub- and tree-based browse fodder bank systems with native preferred and adapted browse species should be introduce in the “national protected pastoral areas[2]” to improve qualitative forage supply for livestock specially during the dry season and drought periods; in addition, a promotion of protection of preferred browse species by better use and management should be initiated. Also, assisted natural regeneration actions should be promoted and supported for the protection and reforestation of valuable grazing areas such as *forests* and others *wooded lands*.

3. The national reforestation programs should highly encourage and support the plantation of multi-purpose species including livestock’s preferred browse species, and attention should also be given to native species which are adapted to each agro-ecological zone.

4. For West Africa’s farming systems in the Sahelian and Sudanian zone, the implementation of any adaptation strategy must account for the local communities’ experiences and socio-cultural realities.

[2]*Communal grazing areas delimited by the government in different locations across the country to enable free grazing and mobility of pastoral livestock herds. About 24 national pastoral zones have been created by the government of Burkina Faso.*

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