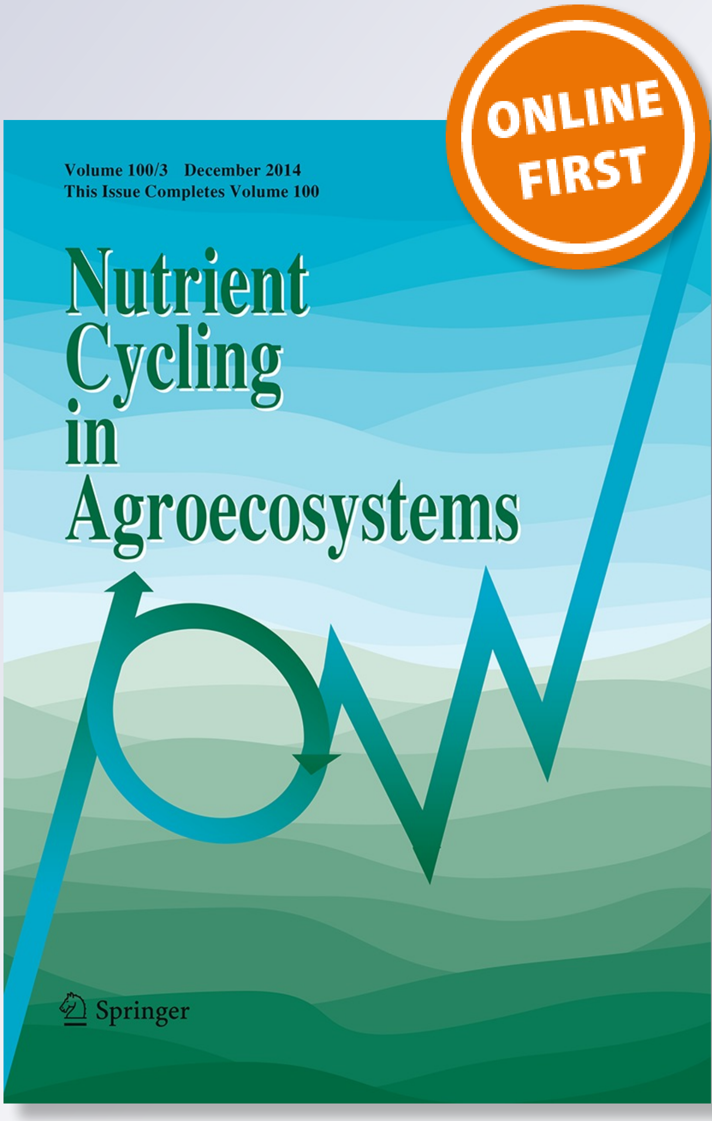
Nutrient use efficiency in peri-urban dairy cattle and sheep holdings in southern Mali

Hamadoun Amadou, Laban Konaté, Hamidou Nantoumé, Andreas Buerkert & Eva Schlecht

Nutrient Cycling in Agroecosystems
(formerly Fertilizer Research)

ISSN 1385-1314

Nutr Cycl Agroecosyst
DOI 10.1007/s10705-014-9666-1



Nutr Cycl Agroecosyst
DOI 10.1007/s10705-014-9666-1

ORIGINAL ARTICLE

Nutrient use efficiency in peri-urban dairy cattle and sheep holdings in southern Mali

Hamadoun Amadou · Laban Konaté · Hamidou Nantoumé · Andreas Buerkert · Eva Schlecht

Received: 16 October 2014 / Accepted: 7 December 2014

Abstract To analyse nutrient use efficiencies in peri-urban cattle and sheep production of West Africa with their complex combination of free grazing and homestead feeding, data on demographic events, live weight changes and milk offtake as well as types and amounts of feedstuffs provided at the homestead and manure deposited there were collected over 18 months in 9 cattle (C) and 13 sheep (S) herds in Sikasso, the second largest city of Mali. Herds were either grazing only (go; cattle: 4, sheep: 5) or grazing and supplemented at the homestead (gs; cattle: 5, sheep: 8). Bi-monthly collected samples of supplement feeds and manure were analyzed for their nutrient contents. In cattle, herd growth was higher in Cgs than in Cgo ($P < 0.05$), while it was similar in the two sheep groups. Live weight gains of cattle and sheep were higher in the rainy than in the dry season ($P < 0.05$), but in both seasons Cgo performed better than Cgs ($P < 0.05$), due to periodic short-distance transhumance of the former. Similarly across groups, the quantity of dry manure deposited at the homestead per animal and night ranged from 550 to 880 g in cattle and 50 to 135 g in sheep. Only 15–58 % of the dry matter and nutrients provided through the supplement feeds were recovered in manure at the homestead. We conclude that the current ruminant production systems around Sikasso are still very extensive in nature and not taking sufficiently advantage of the rising market potential for animal products.

Keywords Efficiency · Grazing · Manure quality · Nutrient recovery

H. Amadou · E. Schlecht (✉)
Animal Husbandry in the Tropics and Subtropics, Universität Kassel and Georg-August-Universität Göttingen, Steinstr. 19, 37213 Witzenhausen, Germany
e-mail: tropanim@uni-kassel.de

L. Konaté · H. Nantoumé
Institut d'Economie Rurale, B.P. 262, Bamako, Mali

A. Buerkert
Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, Universität Kassel, Steinstr. 19, 37213 Witzenhausen, Germany

Introduction

The estimated annual growth rate of 2 % of the regional livestock production in the Sahel and West African countries (SWAC) does not satisfy the rapidly increasing urban demand for meat, milk and eggs (SWAC-OECD/ECOWAS 2008). Multi-annual trends indicate that the gap between demand and supply may persist and even widen in the 2020s (SWAC-OECD/ECOWAS 2008). This is underlined by the region's continued strong dependency on extra-African imports of products such as milk, beef, and poultry meat.

With 10 million cattle, 13.7 million sheep, 19.1 million goats and 36.8 million poultry in 2013

Published online: 25 December 2014

(FAOSTAT 2014), the Republic of Mali is one of the most important livestock producing countries in West Africa; its livestock sector contributes about 44 % to the agricultural gross domestic product (SWAC-OECD/ECOWAS 2008). Several authors stated that Mali's livestock sector is rapidly developing towards specialized dairy farms (Debrah et al. 1995; Wymann 2005; Coulibaly et al. 2007), modern poultry farms producing eggs, chicks and broilers (Traoré 2006), and intensive sheep fattening units (Kolff 1985; Nantoumé et al. 2009) especially in urban and peri-urban areas. Here, livestock husbandry has become an important activity for many residents (Hamadou et al. 2004; Thys et al. 2005) to whom it provides food, income, employment and social security (Thys et al. 2005; PAM et al. 2006; Cohen and Garrett 2010). However, feed resources on pastures surrounding the cities are often insufficient to meet the growing demands for produce quantity and quality in urban and peri-urban livestock systems and must therefore be complemented by homestead feeding of agro-industrial by-products (Hamadou et al. 2008) and of forages and crop residues from the rural hinterland (Coulibaly et al. 2007; Graefe et al. 2008). This leads to a massive uni-directional flow of nutrients from the countryside to the urbanized areas; since animal excreta are not recycled back to the cities' hinterland, it also entails massive nutrient losses around urban areas (Buerkert and Hiernaux 1998). In this context judicious manure management is another major challenge of urban and peri-urban livestock systems (Thys et al. 2005; Powell et al. 2008; Diogo et al. 2013).

To contribute to filling major knowledge gaps on the resource use efficiency of peri-urban ruminant production systems in West Africa, the present study aimed at investigating inflows and outflows of dry matter, carbon, nitrogen and phosphorus, through feeds consumed and manure accumulated at typical, differently managed livestock farms near Sikasso, the second largest town in Mali, and to determine the efficiency of feed energy conversion into animal products.

Materials and methods

Location and climate

Located in south-eastern Mali, Sikasso ecologically belongs to the southern Sudanian savanna. The city covers an area of 3,745 ha (Ministère de l'Habitat et de l'Urbanisme 2005) and has a population of about 200,000 inhabitants. Its climate is characterized by a rainy season from May to October yielding a total precipitation of 800–1,100 mm and a dry season from November to April. Sikasso is of high agricultural and pastoral potential because its landscape embraces many lowlands that hold significant residual moisture during the first months of the dry season (Coulibaly et al. 2007). Feed resources for ruminant livestock consist of (1) the vegetation of natural pastures, and (2) crop residues from rotational or associative cropping systems based on cereals (maize—*Zea mays* L., rice—*Oryza sativa* L., millet—*Pennisetum glaucum* L. and sorghum—*Sorghum bicolor* L. Moench.), legumes (groundnut—*Arachis hypogaea* L. and cowpea—*Vigna unguiculata* Walp.) and cotton (*Gossypium hirsutum* L.). The herbaceous layer of the pastures, most relevant to grazer species such as cattle and sheep (Van Soest 1994), is characterized by perennial C4 grasses of the genera *Andropogon*, *Aristida*, *Cenchrus*, *Digitaria*, *Diheteropogon*, *Heteropogon*, *Hyparrhenia*, *Loudetia*, *Pennisetum*, *Schizachyrium and Setaria*, and in depressions with longer-term stagnating water also by *Echinochloa* spp. (Schmidt et al. 2011).

Livestock herds and management

At total of 9 dairy cattle (C) and 13 sheep (S) herds were covered by this study, whereby 6 of the 9 cattle-keeping households included in this study also kept sheep. All livestock enterprises were located within a 15 km radius around the center of the town and are further referred to as peri-urban units. The herds were selected out of 125 livestock enterprises that had been characterized in a previous study (Dossa et al. 2011; Abdulkadir et al. 2012). For the present study focusing on energy and nutrient use efficiency, grazing only systems (go) were distinguished from systems that combined grazing with supplement feeding (gs) at the homestead; from the farmers initially approached for the present study (5 each practicing go or gs in cattle, 10 each practicing go or gs in sheep) 16 agreed to participate. All cattle were of the local N'Dama and Méré (zebu × N'Dama cross) breeds that are with their small body size less productive than exotic breeds, but more tolerant to heat and trypanosomiasis, and have the ability to survive on poor quality feeds

(Bosso et al. 2009). Typical for peri-urban production systems all cattle and sheep herds grazed natural pastures and harvested crop fields at the city fringes while receiving supplements at the homesteads. The animals' daily time on pasture averaged 11.5 h in the dry season and 9 h in the rainy season. During April–June and August–October, short distance transhumance of ≤30 km around the city was practiced by the 4 Cgo herds. In the 5 Cgs herds lactating cows, and sometimes also sick animals, were supplemented as a group with maize bran, cottonseed expeller and occasionally rice straw during the dry season. Overnight, all herds were confined at the homestead in corrals made from tree branches. During this time calves stayed with their mothers, being separated 2–3 h before morning milking. Prior to the hand milking, which in all dairy farms was only done in the morning, the calves were allowed to suckle their mothers for a few minutes to stimulate milk ejection.

For sheep only the Djallonke breed, which is of relatively small body size but quite productive under the conditions of the Sudanian savanna, was kept in the studied herds. Animals were confined in pens near the homestead overnight; lactating ewes were not milked and lambs younger than 3 months were grazed close to the homestead after morning departure of their mothers to pasture. Five herds were only grazing (Sgo), while the other eight herds were grazing during daytime and as a herd received supplement feeds at the homestead (Sgs) during the dry season; these mainly consisted of maize bran, cowpea pods and dry or fresh purchased grasses.

Data collection

Monitoring of homestead-based feed dry matter (DM) and nutrient inflows and manure DM and nutrient accumulation in the 9 dairy and 13 sheep herds covered a period of 18 months (July 2008–December 2009). At the initial farm visit, animals in each herd were individually ear-tagged, weighed and phenotypically described for future identification. At each subsequent visit spaced 6–8 weeks apart, a structured questionnaire was used to record information on demographic events (animal exits for any reason, and entries through purchases, births and gifts) that had occurred since the previous visit. Types and amounts of feeds offered at the homestead, feed additives (i.e. minerals, vitamins) and veterinary products used as well as the offtake of milk were also recorded. This was accompanied by weighing the daily amounts of feedstuffs offered at the homestead using a portable electronic weighing scale (50 kg capacity, 0.02 kg accuracy). Two representative samples (corresponding to 250 g DM) of all types of feedstuffs offered were taken at each visit and pooled per type and household for subsequent analysis.

In addition, the live weight (LW) of all animals was recorded at each visit. Sheep and calves were weighed with a suspended electronic scale (100 kg capacity, 0.5 kg accuracy). To minimize variations in LW due to feeding and watering, weighing was carried out in the early morning. LW of cattle above 100 kg was estimated from body measurements using the equation (Eq. 1) developed by Dodo et al. (2001) for the zebu Azawak breed:

$$Y = 0.0281x^2 - 3.294x + 125.217 \quad (1)$$

where Y = live weight (kg); x = breast width (cm).

The amount of milk extracted by hand milking (further referred to as 'milk offtake', since it excludes the amount of milk suckled by the calf) per animal was quantified by weighing the milk (portable electronic scale, 5 kg capacity, 1 g accuracy) on two successive mornings at intervals of 8 weeks.

The amount of manure (faeces plus urine plus organic material such as feed residues) accumulating at the homestead was quantified by scooping the complete dung heap into plastic sacks and weighing these on the suspended 100 kg weighing scale every 8 weeks. Since farmers were informed about the importance of this data, earlier transfers of the manure heap from the homestead towards a field or garden were signaled to the research team. Five representative fresh dung samples (corresponding to 250 g DM each) were collected per assessment date in each household and pooled to one sample of 250 g DM per visit and farm, but in contrast to the study of Lompo et al. (2012) no further data on soils or crop yields of manure target sites were collected for this study.

Chemical analyses of supplement feeds and manure samples

For chemical analysis, the samples of feedstuffs collected at the farms and the manure samples were dried to constant weight at 60 °C and ground to pass a

1-mm screen. Duplicates of all samples were analyzed for DM concentration by drying 3 g air-dry sample material at 105 °C for 5 h. Organic matter (OM) concentration was calculated after dry-ashing the sample at 550 °C for 4 h in a muffle furnace (Naumann et al. 2004). A CN analyzer (Elementar Analysensysteme GmbH, Hanau, Germany) was used to determine the nitrogen (N) and carbon (C) concentration with phenylalanine as a standard. Total phosphorus (P) was measured using a colorimeter (Hitachi U-2000 spectrophotometer, Schwaebisch Gmuend, Germany) according to the vanado-molybdate method (Gericke and Kurmies 1952). Organic matter digestibility (OMD) and metabolizable energy (ME) content of feedstuffs were derived from the gas production of sample material incubated in triplicate with rumen liquor in vitro for 24 h (Menke et al. 1979) using the equations of Close and Menke (1986) and Menke and Steingass (1987). Sample analyses were conducted by the laboratories of ICRISAT Sahelian Center at Niamey, Niger, and the Faculty of Organic Agriculture at Universität Kassel, Germany.

Calculation of nutrient and energy use

To assess efficiency of energy and nutrient use, the ME provided by feeds offered at the homestead was expressed per metabolic body mass ($kg^{0.75}$ LW) and day. The ME requirements for maintenance (0.43 MJ/$kg^{0.75}$ LW), locomotion (0.38 MJ ME/100 kg LW per kilometer) and growth of adult (30 MJ ME/kg LWC) and suckling sheep (Eq. 2) as well as for suckling calves (Eq. 3) were taken from Jeroch et al. (2008). For cattle, the ME requirements published by Menke and Huss (1987) for maintenance (0.45 MJ/$kg^{0.75}$ LW), adult live weight gain (34 MJ/kg LWC), and milk production (5.3 MJ/kg milk with 4 % fat) were used.

$$\text{Lamb: ME req. (MJ/d)} = 0.43 \times \text{LW}^{0.75} + ((14.6 + 0.131 \times \text{LW} + 23.9 \times \text{LWC}) \times \text{LWC}) \quad (2)$$

$$\text{Calf : ME req. (MJ/d)} = 0.53 \times \text{LW}^{0.75} + (15 \times \text{LWC}) \quad (3)$$

where LW is live weight in kg and LWC is daily live weight change in kg.

Since in international literature quantitative intake data is neither available for grazing cattle nor sheep in the southern Sudanian zone around Bobo Dioulasso given the multiple difficulties to reliably determine these in the vast rangelands, we based our assessment of daily feed intake on pasture on research from the West African Sahelian zone, even though sward structure and botanical composition of pastures may not be fully comparable. However, such differences in botanical composition of pastures should not have major effects on daily feed intake which is why the following values can be confidently used across Sudano-Sahelian West Africa. Averaged across the year, a DM intake of 8 g/h per $kg^{0.75}$ LW (Ayantunde et al. 2002) was adopted for cattle and a value of 55 g DM/day per $kg^{0.75}$ LW for sheep (Fernández-Rivera et al. 2005); for the yearly average ME concentration of grazed forage the value of 8.7 MJ/kg DM published by Herrero et al. (2013) for African grazing systems in the sub-humid and humid zone was accepted. Collection efficiencies of DM, carbon and nutrients at the homestead were calculated as the ratio between the quantities (DM, C, N, P) recovered in the manure heap and the respective quantities offered in supplement feeds (Powell et al. 2008).

Statistical analysis

Data were analyzed with SPSS/PASW version 18.0 (SPSS Inc. 2010). To this end residuals of all data were initially tested for normal distribution and homogeneity of variances before *t* tests were performed for all continuous variables that were normally distributed. The independent variables system (go, gs) and season (rainy, dry) were only compared within, but not across livestock species (C, S). Since supplementation of cattle and sheep was only practiced in the dry season, season × system interactions were not tested. All comparisons were performed at the herd level. Dependent variables comprised inputs and outputs of DM/OM, C, N and P as well as LW changes of animals and milk offtake from cows.

For variables that were not normally distributed, the Chi square test was used in case of categorical variables and the Mann–Whitney-U-test was applied to continuous variables. In all cases, significance of differences between means was declared at $P < 0.05$.

Results

Herd structure and dynamics

The average initial size of a dairy herd comprised 36 animals (28.6 TLU[1]) and 29 animals (23.2 TLU) for in Cgo and Cgs herds, respectively (Table 1). Although cows aged >40 months represented 40 and 65 % of the initial Cgo and Cgs herds, there were no significant differences between the two groups in terms of herd structure. Animal inflow ($P < 0.001$), outflow and herd growth rates ($P < 0.05$) were significantly higher for Cgs than for Cgo herds. In both groups births (83 % in Cgo, 42 % in Cgs, averaged across all herds) and purchases (17 % in Cgo, 58 % in Cgs, averaged across all herds) were the only sources of cattle inflow, these were significantly higher in the rainy season than in the dry season ($P < 0.05$). Animal inflows through purchases of mostly adult animals were more common ($P < 0.05$) during the rainy season than during the dry season, whereas no significant differences were observed between seasons for inflows due to births. Cattle deaths due to weakness or disease (Cgo: 53 %; Cgs: 11 % of all outgoing animals, thereof 70 % animals aged less than 2 years), and outflows due to slaughter (Cgo: 11 %; Cgs: 0 %), sale (Cgo: 16 %; Cgs: 70 %) and as gifts (Cgo: 21 %; Cgs: 18 %) were on average much higher, but extremely variable in Cgs compared to Cgo herds ($P > 0.05$).

In sheep, the initial structures of Sgo and Sgs herds were similar to those at the end of the study, since numbers of incoming and outgoing animals during the study period were comparable (Table 1). Except for a few cases of gifting and exchange of male animals in Sgs herds, the main incoming routes were births (38 %) and purchases (58 %). Among the 171 sheep leaving the 13 herds during the study period, 47 % died due to diseases (92 % adult sheep, 8 % lambs), 24 % were slaughtered for ceremonies, 18 % were sold, 8 % were stolen and 3 % were gifted to relatives or friends.

Live weight changes, milk production and reproductive performance

The daily LW gain of lactating cows across the 18-months study period averaged 63 g (±126.1; Cgo) and 15 g (±158.5; Cgs), whereby gains were higher in the rainy season than in the dry season ($P < 0.05$). In both groups lactating cows lost weight during the dry season (Table 2). Across the study period, the number of lactating cows per herd and year averaged 8.5 (±3.69; Cgo) and 12.6 (±4.33; Cgs). Daily milk offtake from Cgo cows averaged 0.77 l (±0.287; n = 38) in the dry season and 0.9 l (±0.328; n = 41) in the rainy season ($P > 0.05$). At 0.79 l (±0.212; n = 63) the average daily milk offtake from Cgs cows in the dry season was lower ($P \leq 0.05$) than the milk offtake in the rainy season (1.04 l ± 0.245; n = 70). The differences in daily milk offtake between the two types of cattle herds were insignificant in each season. Across the two groups, milk extraction spanned an extended period of 354 days (± 31). The age at first calving and the calving interval, respectively (Table 3), did not differ ($P > 0.05$) between the two groups, whereas the prolificacy rate was lower and the overall mortality rate was higher in Cgo than in Cgs ($P > 0.05$). At 6 months of age, the average LW of a Cgo calf was 70 kg (±19.3) as compared with 60 kg (±13.6) of a Csg calf, pointing to an average daily LW gains of 217 g (±202.9, Cgo) and 185 g (±143.5 Cgs; $P > 0.05$) between the second and sixth month *post natum* (Table 2).

On average, adult sheep of the Sgo and the Sgs group lost weight during the rainy season, but the variation of the individual values was very high (Table 2). The losses were just compensated by average daily LW gains of 28 g (±26.7) in Sgo and 24 g (±48.7) in Sgs ($P > 0.05$) in the 6 months of dry season. The lambing rate was 0.52 (Sgo) and 0.77 (Sgs) newborn per adult female, with a prolificacy rate of 1.22 (Sgo) and 1.13 (Sgs); differences between the two groups were insignificant in all cases. Average age at first lambing and lambing interval were also not different ($P > 0.05$) between the two groups (Table 3). The average LW of a one month old lamb was 3.3 kg (±1.40) and 4.5 kg (±2.11) for Sgo and Sgs, respectively ($P > 0.05$). Daily LW gain during the first 6 months of life averaged 62.5 g (Sgo) and 48.5 g (Sgs), resulting in a LW of 20.3 kg (±5.11; Sgo) and 15.6 kg (±6.79; Sgs) for a 6 months old sheep.

Homestead-based feed ingestion and manure accumulation

Dry season supplement feeds for lactating cows in Cgs herds consisted mainly of maize bran and cotton seed

[1] TLU, Tropical Livestock Unit: standardized animal of 250 kg live weight; 1 cattle = 0.8 TLU, 1 sheep = 0.1 TLU.

Table 1 Dynamics of two types of differently managed cattle and sheep herds in peri-urban livestock holdings in Sikasso, Mali, during 07/2008 (start) and 12/2009 (end)

Parameter	Feeding management	Cattle						Sheep					
		Herds (n)	Mean	SD	Females[α] (%)	Calves[α] $\leq$ 6 mo (%)	Adults[α] > 40 mo (%)	Herds (n)	Mean	SD	Females[α] (%)	Lambs[α] $\leq$6 mo (%)	Adults[α] >21 mo (%)
Herd size at start	Grazing only	4	35.5	8.81	60	11	40	5	9.8	1.30	71	21	50
	Grazing + stall feeding	5	28.8	5.16	66	17	65	8	13.2	9.54	60	30	45
	$P \leq$				n.s.	n.s.	n.s.				n.s.	n.s.	n.s.
Incoming animals	Grazing only	4	5.7	1.89	52	83	9	5	7.8	4.97	46	69	15
	Grazing + stall feeding	5	22.4	24.50	64	43	44	8	13.8	6.87	51	77	11
	$P \leq$				n.s.	0.001	0.001				n.s.	n.s.	n.s.
Outgoing animals	Grazing only	4	4.7	4.28	68	16	42	5	9.6	6.87	46	27	35
	Grazing + stall feeding	5	17.0	20.11	69	6	69	8	15.1	6.35	45	25	27
	$P \leq$				n.s.	0.05	0.05				n.s.	n.s.	n.s.
Herd size at end	Grazing only	4	36.7	6.18	58	23	36	5	9.2	5.71	71	44	44
	Grazing + stall feeding	5	36.0	13.30	64	33	51	8	13.4	11.26	66	58	27
	$P \leq$				n.s.	n.s.	n.s.				n.s.	n.s.	n.s.

mo months

[α] Differences between systems tested by Chi square test; *P*-values given in rows in between parameters

Table 2 Milk offtake and live weight changes of lactating cows and their calves, and of adult sheep and their lambs in two peri-urban production systems in Sikasso, Mali, during 07/2008–12/2009

Variable	Grazing only			Grazing + stall feeding		
	n	Mean	SD	n	Mean	SD
Dairy cattle: milk offtake (l/day)						
Dry season	38	777	286.9	63	791[b]	211.9
Rainy season	41	903	328.2	70	1,036[a]	245.4
Dairy cattle: live weight change (g/day)						
Dry season	34	−21.5[a]	65.21	44	−90.7[a]	120.57
Rainy season	32	235.9[b]	97.60	52	192.5[b]	85.32
Calves: live weight change (g/day)						
Dry season	24	188.3	143.88	38	204.3	120.82
Rainy season	29	284.9	114.77	49	146.4	106.68
Adult sheep (>21 months): live weight change (g/day)						
Dry season	24	27.8[a]	26.66	90	24.2[a]	48.71
Rainy season	15	−12.0[b]	42.57	40	−25.3[b]	41.65
Lambs (1–6 months): live weight change (g/day)						
Dry season	9	72.5[a]	37.28	20	67.4[a]	34.52
Rainy season	6	27.7[b]	34.88	13	28.7[b]	28.61

[a,b] Significant differences ($P < 0.05$) between seasons

No significant differences ($P > 0.05$) between systems

Table 3 Reproductive parameters and overall mortality rates in two types of peri-urban herds of dairy cows and sheep in Sikasso, Mali, during 07/2008–12/2009

Species and management	Adults (n)	Newborn (n)	Yearly calving/lambing rate[a]	Prolificacy	Mortality rate	First parturition (months)			Parturition interval (months)		
						n	Mean	SD	n	Mean	SD
Cows											
Grazing only	47	19	0.27	0.94	6.1	23	45.2	6.05	15	24.1	5.34
Grazing + stall feeding	123	47	0.38	1.00	3.0	29	51.0	9.89	10	20.7	2.79
Sheep											
Grazing only	51	25	0.52	1.22	35.5	4	12.2	2.75	9	12.1	2.26
Grazing + stall feeding	96	73	0.77	1.13	20.9	10	11.2	2.74	22	11.6	2.38

Yearly calving/lambing rate = number of newborns (dead or alive) during 12 months per 100 females in the herd

Prolificacy = number of living newborn/birth

expeller (Table 4). Rice bran, *Acacia albida* (Del.) A. Chew. pods and powder made of fruits from *Parkia biglobosa* (Jacq.) R. Br. ex G. Don were also used, but in lower proportions and frequencies. All Cgo herds went on short-distance transhumance to the countryside, staying within a 30 km radius around the city of Sikasso twice a year: firstly when the grazing space was reduced due to field cropping (mid-August to October, about 75 days), and secondly when the crop residues on harvested fields were depleted (mid-April to June, about 60 days). Across the study period, the daily DM intake from feeds offered at the homestead averaged 1.51 kg for a lactating Cgs cow and provided 389 g of crude protein (CP), 1.0 kg of digestible organic matter (DOM) and 12.9 MJ of ME. Daily DM intake during grazing was 4.5 kg in Cgs and 5.5 kg in Cgo cattle, providing 38.8 and 47.6 MJ ME, respectively (Table 5). Taking into account the energy requirements for maintenance, milk synthesis and LW changes of the adult animal and its suckling calf, the energy balance was strongly positive for a Cgs cow and slightly positive for a Cgo cow.

Homestead feeding of sheep was based on maize bran, grass mixtures and cowpea hay and pods (Table 4). Whereas homestead feeding of Sgs herds provided 0.29 kg DM, 32 g CP, 200 g DOM and

Table 4 Types and proximate composition of supplement feeds used in five peri-urban dairy cattle units and eight sheep units in Sikasso, Mali, during the dry season of 2008/09

Supplement feed	Farmers using the feed (n)	Proportion (%) of use across farms and animals	OM (g/kg DM)	CP (g/kg OM)	P (g/kg OM)	OMD (g/kg OM)	ME (MJ/kg OM)
Cattle							
Maize bran	5	52.5	866	101	7.1	727	9.5
Cotton seed expeller	4	23.6	894	175	7.4	625	7.2
Parkia biglobosa seeds	2	12.2	940	138	2.4	554	8.8
Faidherbia albida pods	1	10.1	950	73	2.6	565	8.5
Rice bran	1	1.6	896	106	8.3	733	6.4
Sheep							
Maize bran	7	48.6	869	97	5.7	759	9.6
Grass mixtures	5	33.5	866	131	3.2	577	7.0
Cowpea hay	6	7.6	887	133	2.6	694	7.6
Cowpea grain	1	4.4	866	96	2.0	623	9.4
Rice bran	2	3.7	872	39	1.4	469	6.0
Sorghum bran	1	1.2	865	113	10.4	773	9.7
Cabbage leaves (fresh)	1	0.5	876	186	4.6	630	7.2
Cotton seed expeller	1	0.4	885	181	8.1	640	7.4

DM dry matter, *OM* organic matter, *CP* crude protein, *P* phosphorus, *OMD* organic matter digestibility, *ME* metabolizable energy

2.4 MJ ME per animal and day (Table 5), daily intake on pasture averaged 0.72 kg DM for Sgs and 0.75 kg DM for Sgo, providing 6.3 and 6.5 MJ ME. The yearly energy balance was slightly positive for Sgs and slightly negative for Sgo animals.

Faeces and urine excreted in the corral near the homestead were occasionally mixed with feed leftovers in Cgs and Sgs groups, whereas bedding material was not used in cattle corrals and sheep pens. All manure was heaped without any cover in the courtyard; from there it was usually shifted to a crop field just before the beginning of the rainy season, and again after crop harvest. With no significant differences between groups, the quantity of manure deposited at the homestead and potentially available for cropland fertilisation was close to 600 g DM per animal and night in cattle, and between 48 and 135 g in sheep (Table 6). For both livestock species, no significant differences were observed between groups and between seasons, respectively, in the amount of accumulated manure DM and in manure nutrient concentrations (Table 6). Based on the partial nutrient balance of homestead supplement feeding and manure recovery in the corral (Cgs and Sgs herds only), the resulting capture efficiencies for DM and nutrients ranged from a minimum of 15 % to a maximum of 58 % (Table 7).

Discussion

Herd structure and dynamics

The herd sizes recorded in our study were larger than the average of 1.4–2.4 TLU reported by Diogo et al. (2010) for Niamey, Niger, and the 12.4 heads observed by Thys et al. (2005) in Ouagadougou, Burkina Faso, but lower than the values reported by Mattoni et al. (2007) for Bobo Dioulasso, Burkina Faso. In terms of size and breed diversity, the dairy herds in Sikasso also differed from those in the capitals Bamako, Mali (Bonfoh et al. 2005), and Dakar, Senegal (Diao et al. 2006), where herd sizes were large and local breeds were substituted by imported ones. The relatively smaller herds in Sikasso might be due to the fact that the city's dairy sector is developing only recently and the degree of urbanization is lower than in other cities mentioned. The average increase in Cgs herd sizes of 25 % over the time of study points to the willingness of dairy farmers to expand their production (Amadou

Table 5 Daily intake (g/animal) of feed dry matter and nutrients, live weight (LW) and daily live weight changes (LWC), daily milk extraction as well as daily energy intake and requirement (MJ ME/animal) of two differently managed groups of peri-urban dairy cows and sheep in Sikasso, Mali, during 07/2008–12/2009

Parameter values are averaged across the 18-months study period)	Dairy cows				Sheep			
	Grazing + stall feeding		Grazing only		Grazing + stall feeding		Grazing only	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Supplement feed intake at homestead (g/day)								
Dry matter	1,506	647.0	n.a.		293	150.4	n.a.	
Nitrogen	62.3	67.04	n.a.		5.2	2.61	n.a.	
Phosphorus	9.8	4.11	n.a.		1.2	0.46	n.a.	
Organic matter	1,326	557.6	n.a.		255	130.5	n.a.	
Intake of dry matter at pasture[a]	4,460		5,472		719		750	
Performance per animal								
LW adults (kg)	228	20.05	246	10.76	30.8	8.20	32.6	2.37
LWC adults (g/day)	15.4	158.49	63.4	126.14	6.8	51.33	14.5	35.97
Milk extraction (g/day)	914	255.7	849	306.4	n.a.		n.a.	
LW newborn (kg)	29	12.73	31	9.24	4.5	2.11	3.3	1.40
LWC suckling offspring (g/day) during: 1–6 months (calf) and 1–3 months (lamb)[b]	62.6	47.85	72.6	67.64	12.0	6.78	16.8	52.48
Energy intake per animal (MJ ME/day)								
From supplement feed	12.9		0.0		2.4		0.0	
From grazing[a]	38.8		47.6		6.3		6.5	
Energy requirements per animal (MJ ME/day)								
Maintenance requirement, adult	26.40		27.95		5.60		5.86	
Extracted milk energy	4.84		4.50		0		0	
LWC energy, adult	0.52		2.16		0.20		0.44	
LWC energy, suckling offspring	7.56		8.05		1.51		1.31	
Energy balance (ME intake − ME requirements)	12.4		4.9		1.4		−1.1	

n.a. not applicable

[a] Estimated as outlined in "Calculation of nutrient and energy use" section

[b] Calculated as a weighted average for 12 months from LWC of suckling offspring, and average number of offspring per female and year

et al. 2012). In contrast to the dairy herds, sheep herd sizes remained almost constant in both management groups during the study period. This indicates that sheep keepers across the two groups had similar production objectives such as sale of animals for cash and fulfillment of social and religious obligations (Dossa et al. 2011; Amadou et al. 2012), and similar reasons for keeping sheep were reported from other West African cities (Siegmund-Schultze and Rischkowsky 2001; Thys et al. 2005; Graefe et al. 2008). Yet, the stagnant sheep herd sizes also reflected the high mortality rate in both groups, due to the high sensitivity of sheep to diseases (Lesnoff 1999) such as ovine rinderpest and trypanosomiasis. Osaer et al. (1999) reported increasing trypanosomiasis prevalence in Djallonke sheep in The Gambia due to loss of trypano-tolerance, particularly against *Trypanosoma congolense* and *T. vivax* (Geerts et al. 2008), due to crossbreeding with susceptible Sahelian sheep breeds.

Live weight changes, milk production and reproductive performance

The insignificant differences between the two dairy cattle groups in live weight gains during the rainy season is due to the same pasture-based feeding

Table 6 Amount of manure dry matter (DM) excreted per night, and nitrogen (N), phosphorus (P), and carbon (C) concentration in cow and sheep manure from two peri-urban livestock systems in Sikasso, Mali, during 07/2008–12/2009

Species and management	Season	Herds (n)	Duration of night rest (h)	Manure DM (g/animal/night) Mean ± SD	Nutrient concentration (%) in manure DM			
					N Mean ± SD	P Mean ± SD	C Mean ± SD	C/N Mean
Dairy cows								
Grazing only	Dry	4	12	618 ± 326.0	1.5 ± 0.30	0.4 ± 0.07	35.1 ± 4.66	23.4
	Rainy	4	14	543 ± 244.6	1.3 ± 0.34	0.3 ± 0.06	30.8 ± 2.34	23.7
Grazing	Dry	5	13	586 ± 277.3	1.6 ± 0.12	0.5 ± 0.20	37.9 ± 7.65	23.7
+ stall feeding	Rainy	5	16	880 ± 34.4	1.3 ± 0.31	0.3 ± 0.06	35.3 ± 8.60	27.2
Sheep								
Grazing only	Dry	5	13	72 ± 37.89	1.4 ± 0.67	0.4 ± 0.19	33.0 ± 9.66	23.6
	Rainy	5	14	48 ± 31.44	1.1 ± 0.79	0.4 ± 0.25	32.8 ± 11.16	29.8
Grazing	Dry	8	14	135 ± 96.60	1.4 ± 0.34	0.7 ± 0.46	37.2 ± 8.79	26.6
+ stall feeding	Rainy	8	16	108 ± 94.42	1.3 ± 0.22	0.4 ± 0.17	30.3 ± 9.09	23.3

Table 7 Amount of dry matter (DM), nitrogen (N), phosphorus (P), and carbon (C) ingested and recovered at the homestead of dairy cows and sheep in the peri-urban grazing + stall feeding systems in Sikasso, Mali, during 07/2008–12/2009

Variable	DM	N	P	C
Dairy cow herds (n = 5)				
Feed intake at homestead	1,506 ± 647.0	62.2 ± 67.04	9.8 ± 4.11	531 ± 223.3
Manure	619 ± 278.4	9.6 ± 4.60	2.7 ± 1.31	229 ± 117.2
Nutrient recovery in manure[a]	0.41	0.15	0.27	0.43
Sheep herds (n = 8)				
Feed intake at homestead	292.6 ± 150.43	5.2 ± 2.61	1.2 ± 0.46	102.3 ± 52.45
Manure	98.6 ± 78.61	1.4 ± 1.15	0.7 ± 1.02	35.3 ± 33.78
Nutrient recovery in manure[a]	0.33	0.26	0.58	0.34

Values are means (g/animal/day) ± SD

[a] Ratio between intake of dry matter and nutrients offered at the homestead, and manure deposited at the homestead-based corral

management during this period of the year. The present live weight gains are higher than those reported for adult cattle in high (+37 g/day) and low (+8 g/day) input systems in Niamey (Diogo et al. 2010), which is most likely due to differences in the pasture vegetation around Sikasso (Sudanian savanna; C4 grasses, high mass) and Niamey (Sahelian zone; C3 grasses and forbs, lower mass). The dry season weight losses of 22 and 91 g/day observed in Cgs and Cgo cattle were in line with dry season live weight losses of up to 22 % in unsupplemented cattle in Central Mali (Schlecht et al. 1999) and much lower than losses of −300 g/day reported by Fernández-Rivera et al. (2005) for night grazing and supplemented village cattle herds near Niamey. The dry season live weight losses of Cgs cows indicate that despite supplement feeding the animals' energy requirements were not fully met. Cgo cows, on the other hand, nearly maintained their live weight during the dry season due to the two transhumance periods away from the city's immediate neighborhood (Fernández-Rivera et al. 2003; Ayantunde et al. 2011). Although practicing transhumance requires investment in labour and travel time, this is economically advantageous (Turner 2000) over the purchase of too little but expensive (Debrah et al. 1995) crop residues and agro-industrial by-products in urban and peri-urban livestock systems across the Sahelian and Sudano-Sahelian zones.

The age at first calving of heifers observed in our study was slightly lower than values reported for Méré cows under traditional management at Koutiala (Sanogo 2011), a Malian town located about 121 km north of Sikasso. However, the values were higher than those reported for local taurine (N'Dama and Baoulé) and zebu cows under traditional management in Northern Ivory Coast (Sokouri et al. 2010). Similarly, the present calving rate was higher than the one reported by Ba et al. (2011) for traditional cattle husbandry systems in eight villages located about 50 km west of Sikasso.

Across seasons, there was no significant difference between the two management groups in daily milk offtake per cow, although Cgs cows received supplement feed during the dry season. Values for milk offtake are similar to those reported from Koutiala for N'Dama × zebu crossbreed cows which were also grazing and supplemented during the dry season (Sanogo 2011). Values also compare well to those reported for zebu breeds (Maure and Sudanese Fulani) kept under controlled conditions at Niono in central Mali (Coulibaly and Nialibouly 1998). However, the present milk offtake is lower than the 1–2 l per cow and day reported by Sanogo (2011) for stall-fed crossbreed N'Dama × zebu cattle, by Bonfoh et al. (2005) for local breeds in traditional pasture-based production systems in Mali, and by Millogo et al. (2008) for urban and peri-urban dairy holdings in Ouagadougou and Bobo Dioulasso. Although low milk offtake may partly be due to the genetically low milk production potential of the N'Dama crossbreeds, the above-mentioned deficient feed energy supply during the dry season also has a negative effect on milk yield and hence calf development as well as on live weight development and reproductive performance of the cow (Remppis et al. 2011). Certainly, the individual herder's decision on how much milk to take off and how much to feed to the calf also had a marked influence, but this was not further investigated in this study.

The live weight gains of sheep recorded in this study were lower than those reported for a low input sheep system in Niamey (Diogo et al. 2010). This can in part be ascribed to the high prevalence of diarrhea during the rainy season that was visually observed, but not systematically recorded. From southern Mali Tembely et al. (1995) reported that in the rainy season the daily weight gain of lambs treated with anthelmintic drugs was higher than of untreated lambs. When lambing for the first time, sheep in the present study were younger than sheep in agro-pastoral systems of the Sudano-Sahelian zone in Mali (Niaré 1996) and Senegal (Lesnoff and Lancelot 2010), as well as traditionally managed sheep in central Mali (Wilson and Durkin 1983). This indicates that the sheep husbandry systems around Sikasso are presently transforming from a traditional and input-extensive to a more input-intensive management, even though the preset lambing interval was longer than that reported by Niaré (1996) for sheep in agro-pastoral systems of the Sudano-Sahelian zone in Mali.

Homestead feed intake and manure accumulation

The shrinkage of pasture areas and pressure on natural resources in the surroundings of Sikasso is related to the flooding of many lowlands during the rainy season which offers opportunities for sorghum and rice cultivation and challenges livestock feeding (Coulibaly et al. 2007). Similarly, farmers from the region of Koutiala reported that the quantity of forage is decreasing on their communal grazing areas due to cropland expansion and increased grazing pressure on the remaining pastures (Sanogo 2011). Since the major constraint to urban and peri-urban livestock productivity is feed (Decruyenaere et al. 2009), the owners of Cgo herds in Sikasso opted for periodic short-distance transhumance, while those of Cgs herds provided supplement feeds during the dry season. Yet, the amounts of supplement feeds offered to Cgs herds were lower than the quantities of supplement feeds given to cattle in Niamey (Diogo et al. 2010), and did also not meet the recommendations for dairy cattle published for the region of south-eastern Mali (Sanogo 2011) and neighboring south-western Burkina Faso (Ouédraogo et al. 2008). The maintenance energy balances calculated for Sikasso indicate that with the current feeding practices, 51 % of the ME ingested above maintenance requirements was converted into products (live weight gain of cows, suckling calfs and milk offtake) in Cgs cattle, while Cgo cows converted 75 % of the ME ingested above maintenance into these products. The practice of sending Cgo herds on short-term dry season transhumance in order to compensate decreasing feed availability on pastures surrounding Sikasso seems thus to be more energy efficient.

As far as sheep are concerned, the positive energy balance in Sgs and their use efficiency of 55 % of the metabolizable energy supplied above maintenance requirements for live weight gain of ewe and offspring strongly contrasts the slightly negative energy balance of Sgo animals and their very high use efficiency (200 %) of the metabolizable energy supplied above maintenance requirements. The latter indicates of course energy mining or loss and thus in the long term lowered overall productivity of Sgo herds. The divergences must partly be ascribed to the approximation of daily feed intake on pasture. However, the energy losses could in parts also have been due to the above mentioned gastrointestinal problems that occurred especially in the rainy season. During this season, the risk of trypanosomiasis infection is also high; the latter has been reported to reduce weight gain in Djallonke sheep in the subhumid zone of West-Africa (Sangaré et al. 2010).

Nutrient excretion and manure quality are highly affected by the amount and quality of the ingested feed (Paul et al. 2009). Hence, the absence of significant differences in the amounts of manure produced and manure quality between the supplemented and unsupplemented groups of cattle and sheep, respectively, throughout the study period, may primarily be the result of grazing-only based nutrition in the rainy season as well as indifferent manure handling on all farms. In the supplemented herds, about 24 % of N and 25 % of P imported into livestock holdings through purchased supplement feeds were recovered in the manure heap accumulating at the homestead and reused on crop fields. During the several months of unprotected manure storage, however, nutrients are continuously lost. Studies by Predotova et al. (2010) showed that without protection of manure heaps from nutrient leaching in the rainy season and gaseous emissions due to high temperatures throughout the year, yearly amounts of N and P lost from manure heaps can reach 0.3 and 1.2 kg per 100 kg of dung dry matter, respectively, under the climatic conditions prevailing in sub-Saharan Africa. Covering the storage heap with a simple plastic sheet or stover-made roof and judicious use of bedding material in the corral can prevent such losses (Camara 1996, Predotova et al. 2010) and substantially increase the collection efficiency of nutrients at the farm level (Rufino et al. 2007; Tittonell et al. 2009), especially since manure is often the only (cheap) nutrient source available to smallholder farmers.

Conclusions

This study showed that peri-urban dairy production and sheep husbandry systems in Sikasso exhibit a surprisingly low productivity. Especially in herds receiving homestead supplementation energy use efficiency and nutrient capture efficiencies are unsatisfactory, particularly when compared with traditional, purely pasture-based systems. At the current production intensity and output level even the small amounts of supplement feeds offered to dairy cattle seem a waste of resources compared with the practice of periodic short-distance transhumance at times when grazing resources near the city are exhausted. We conclude that the described livestock systems' productivity may only increase if market incentives from a growing (and at least partly well-off) urban population and supportive extension and veterinary services emerge. In secondary West African cities such as in Sikasso, where these incentives are lacking, the ruminant production systems are therefore still of very rural rather than peri-urban character.

Acknowledgments We are grateful to the farmers in Sikasso for their time and willingness to participate in our study. We thank our colleagues Dr. L. H. Dossa and Mr. Y. Diarra for continued support with field work and data analysis, and Dr. A. Berthé from IER at Bamako/Mali for administrative support. We also thank the administrative and laboratory staff at ICRISAT Sahelian Center, Niamey, Niger, for their collaboration and the service of samples analysis; support in sample analysis by Mrs. E. Wiegard and Mrs. C. Thieme at Kassel University is appreciated as well. This study was funded by the Volkswagen Stiftung, Hannover, Germany, in the framework of the project "UrbanFood" (No. I/82 189) within the collaborative program "Resources, their dynamics, and sustainability".

References

Abdulkadir A, Dossa LH, Lompo DJ-P, Abdu N, van Keulen H (2012) Characterization of urban and peri-urban agroecosystems in three West African cities. Int J Agric Sustain 10:289–314

Amadou H, Dossa LH, Lompo JPD, Abdulkadir A, Schlecht E (2012) A comparison between urban livestock production strategies in Burkina Faso, Mali and Nigeria in West Africa. Trop Anim Health Prod 44(7):1631–1642

Ayantunde AA, Fernández-Rivera S, Hiernaux PH, van Keulen H, Udo HMJ (2002) Day and night grazing by cattle in the Sahel. J Range Manag 55:144–149

Ayantunde AA, de Leeuw J, Turner MD, Said M (2011) Challenges of assessing the sustainability of (agro)-pastoral systems. Livest Sci 139:30–43

Ba A, Lesnoff M, Poccard-Chapuis R, Moulin C-H (2011) Demographic dynamics and off-take of cattle herds in southern Mali. Trop Anim Health Prod 43(6):1101–1109

Bonfoh B, Zinsstag J, Farah Z, Simbe CF, Alfaroukh IO, Aebi R, Badertscher R, Collomb M, Meyer J, Rehberger B (2005) Raw milk composition of Malian Zebu cows (*Bos indicus*) raised under traditional system. J Food Compos Anal 18:29–38

Bosso NA, van der Waaij EH, Kahi AK, van Arendonk JAM (2009) Genetic analyses of N'Dama cattle breed selection schemes. Livest Res Rural Dev 21. http://www.lrrd.org/lrrd21/8/boss21135.htm

Buerkert A, Hiernaux P (1998) Nutrients in the West African Sudano-Sahelian zone: losses, transfers and role of external inputs. J Plant Nutr Soil Sci 161:365–383

Camara OS (1996) Utilisation des résidus de récolte et du fumier dans le cercle de Koutiala: bilan des éléments nutritifs et analyse économique. Rapport du projet Production Soudano-Sahélienne PSS No. 18. Wageningen, The Netherlands

Close W, Menke KH (1986) Selected topics in animal nutrition. Deutsche Stiftung fur Internationale Entwicklung (DSE), Feldafing

Cohen MJ, Garrett JL (2010) The food price crisis and urban food (in) security. Environ Urban 22:467–482

Coulibaly M, Nialibouly O (1998) Effect of suckling regime on calf growth, milk production and offtake of Zebu cattle in Mali. Trop Anim Health Prod 30:179–189

Coulibaly D, Moulin CH, Poccard-Chappuis R, Morin G, Sidibé SI, Corniaux C (2007) Evolution des stratégies d'alimentation des élevages bovins dans le basin d'approvisionnement en lait de la ville de Sikasso au Mali. Rev Elev Med Vet Pays Trop 60:103–111

Debrah S, Sissoko K, Soumare S (1995) Etude économique de la production laitière dans la zone périurbaine de Bamako au Mali. Rev Elev Med Vet Pays Trop 48:101–109

Decruyenaere V, Buldgen A, Stilmant D (2009) Factors affecting intake by grazing ruminants and related quantification methods: a review. Biotechnol Agron Soc Environ 13:559–573

Diao MB, Dieng A, Seck MM, Ngomibé RC (2006) Pratiques alimentaires et productivité des femelles laitières en zone périurbaine de Dakar. Rev Elev Med Vet Pays Trop 59:43–49

Diogo RCV, Buerkert A, Schlecht E (2010) Resource use efficiency in urban and peri-urban sheep, goat and cattle enterprises. Animal 4:1–14

Diogo RVC, Schlecht E, Buerkert A, Rufino MC, van Wijk MT (2013) Increasing nutrient use efficiency through improved feeding and manure management in urban and peri-urban livestock units of a West African city: a scenario analysis. Agric Syst 114:64–72

Dodo K, Pandey VS, Illiassou MS (2001) Utilisation de la barymétrie pour l'estimation du poids chez le zébu Azawak au Niger. Rev Elev Med Vet Pays Trop 54:63–68

Dossa LH, Abdulkadir A, Amadou H, Sangaré S, Schlecht E (2011) Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. Landsc Urban Plann 102:197–206

FAOSTAT (2014) FAO Statistical Databases. http://www.fao.org. Accessed on 30 Sept 2014

Fernández-Rivera S, Salla A, Hiernaux P, Williams TO (2003) Transhumance and dry-season supplementation for cattle in the Sahel. J Anim Sci 81(S1):15–16

Fernández-Rivera S, Hiernaux P, Williams TO, Turner MD, Schlecht E, Salla A, Ayantunde AA, Sangaré M (2005) Nutritional constraints to grazing ruminants in the millet-cowpea-livestock farming system of the Sahel. In: Ayantunde AA, Fernández-Rivera S, McCrabb G (eds) Coping with feed scarcity in smallholder livestock systems in developing countries, pp 157–182. Animal Sciences Group, UR, Wageningen, The Netherlands, University of Reading, Reading, UK, Swiss Federal Institute of Technology, Zurich, Switzerland and International Livestock Research Institute, Nairobi, Kenya

Geerts S, Osaer S, Goossens B, Faye D (2008) Trypanotolerance in small ruminants of sub-Saharan Africa. Trends Parasitol 25:132–138

Gericke S, Kurmies B (1952) Die kolorimetrische Phosphorsaeurebestimmung mit Ammonium-Vanadat-Molybdat und ihre Anwendung in der Pflanzenanalyse. Zeitschrift fuer Pflanzenernaehrung und Bodenkunde 59:235–247

Graefe S, Schlecht E, Buerkert A (2008) Opportunities and challenges of urban and peri-urban agriculture in Niamey, Niger. Outlook Agric 37:47–56

Hamadou S, Marichatou H, Kamuanga M (2004) Croissance désordonnée des élevages périurbains et approvisionnement de la ville de Bobo de Bobo-Dioulasso: problématiques et hygiène. Etudes et Recherches Sahélienne 8–9:107–115

Hamadou S, Tou Z, Toé P (2008) Le lait, produit de diversification en zone périurbaine à Bobo Dioulasso (Burkina Faso). Cah Agric 17:473–478

Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Bluemmel M, Weiss F, Grace D, Obersteiner M (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc Natl Acad Sci USA (PNAS) 110(52):20888–20893

Jeroch H, Drochner W, Simon O (2008) Ernährung landwirtschaftlicher Nutztiere. Ernährungsphysiologie, Futtermittelkunde, Fütterung. 2. überarbeitete Auflage. Verlag Eugen Ulmer, Stuttgart, Germany

Kolff HE (1985) Livestock production in Central Mali: the mouton de case system of smallholder sheep fattening. Agric Syst 16:217–230

Lesnoff M (1999) Dynamics of a sheep population in a Sahelian area (Ndiagne district in Senegal): a periodic matrix model. Agric Syst 61:207–221

Lesnoff M, Lancelot R (2010) Assessment of age at first parturition by accounting censored data: the example of small ruminants in agropastoral herds in Senegal. Trop Anim Health Prod 42:1155–1159

Lompo DJ-P, Sangaré SAK, Compaoré E, Sedogo MP, Predotova M, Schlecht E, Buerkert A (2012) Gaseous emissions of nitrogen and carbon from urban vegetable gardens of Bobo Dioulasso, Burkina Faso. J Plant Nutr Soil Sci 175(6):846–853

Mattoni M, Bergero D, Schiavone A (2007) Assessment of structural traits and management related to dairy herds in the peri-urban area of Bobo Dioulasso (South West of Burkina Faso). J Agric Rural Dev Trop Subtrop 108:41–50

Menke KH, Huss W (1987) Tierernaehrung und Futtermittelkunde. Verlag Eugen Ulmer, Stuttgart

Menke KH, Steingass H (1987) Schaetzung des energetischen Futterwertes aus der in vitro mit Pansensaft bestimmten

Gasbildung und der chemischen Analyse. II. Regressionsgleichungen. Uebersichten Tierernaehrung 15:59–94
Menke KH, Raab L, Salewski A, Steingass H, Fritz D, Schneider W (1979) The estimation of the digestibility and metabolisable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor. J Agric Sci 93:217–222
Millogo V, Ouedraogo GA, Agenäs S, Svennersten-Sjaunja K (2008) Survey on dairy cattle milk production and milk quality problems in peri-urban areas in Burkina Faso. Afr J Agric Res 3(3):215–224
Ministère de l'Habitat et de l'Urbanisme (2005) Schéma directeur d'urbanisme de la ville de Sikasso et environs. Direction Nationale de l'Urbanisme et de l'Habitat, Bamako, République du Mali
Nantoumé H, Diarra CHT, Traoré D (2009) Performance et rentabilité économique de la valorisation des fourrages pauvres par le tourteau de coton dans l'engraissement des moutons Maures au Mali. Livest Res Rural Dev 21(12). http://www.lrrd.org/lrrd21/12/nant21207.htm. Accessed on 29 April 2014
Naumann K, Bassler R, Seibold R, Barth K (2004) Die chemische Untersuchung von Futtermitteln. Loseblattausgabe mit Ergaenzungen 1983, 1988, 1993, 1997 and 2004. Methodenbuch, Band III. VDLUFA-Verlag, Darmstadt
Niaré T (1996) Performance de reproduction des ovins dans deux noyaux d'élevage traditionnel et cycle fourrager en zone Soudano-sahélienne au Mali. Agron Afr VIII:41–50
Osaer S, Goossens B, Kora S, Gaye M, Darboe L (1999) Health and productivity of traditionally managed Djallonke sheep and West African dwarf goats under high and moderate trypanosomosis risk. Vet Parasitol 82:101–119
Ouédraogo GA, Millogo V, Anago-Sidibé AG, Kanwé BA (2008) Relationship between somatic cell counts, dairy cattle milk yield and composition in Burkina Faso. Afr J Biochem Res 2(2):56–60
PAM, CSA/SAP, UNICEF (2006) Mali—Analyse de la sécurité alimentaire et de la vulnérabilité (CFSVA), Données de décembre 2005. Programme Alimentaire Mondial, Commissariat à la Sécurité Alimentaire, Système d'Alerte Précoce, UNICEF; Commission Européenne
Paul S, Onduru D, Wouters B, Gachimbi L, Zake J, Ebanyat P, Ergano K, Abduke M, van Keulen H (2009) Cattle manure management in East Africa: review of manure quality and nutrient losses and scenarios for cattle and manure management. Wageningen UR Livestock Research, ISSN 1570-8616. Report 258. p 21
Powell JM, Li Y, Wu Z, Broderick GA, Holmes BJ (2008) Rapid assessment of feed and manure nutrient management on confinement dairy farms. Nutr Cycl Agroecosyst 82:107–115
Predotova M, Schlecht E, Buerkert A (2010) Nitrogen and carbon losses from dung storage in urban gardens of Niamey, Niger. Nutr Cycl Agroecosyst 87:103–114
Remppis S, Steingass H, Gruber L, Schenkel H (2011) Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation—a review. Asian-Aust J Anim Sci 24(4):540–572
Rufino MC, Tittonell P, van Wijk MT, Castellanos-Navarrete A, Delve RJ, de Ridder N, Giller KE (2007) Manure as a key resource within smallholder farming systems: analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livest Sci 112:273–287
Sanogo O (2011) Le lait, de l'or blanc? Amélioration de la productivité des exploitations mixtes cultures-élevage à travers une meilleure gestion et alimentation des vaches laitières dans la zone de Koutiala. PhD thesis, Wageningen University, The Netherlands, p 158
Sangaré M, Bengaly Z, Marichatou H, Toguyeni A, Tamboura HH (2010) Influence d'une infection expérimentale à Trypanosoma congolense sur la fonction sexuelle des béliers Djallonké et Sahéliens en zone subhumide. Biotechnol Agron Soc Environ 14:409–416
Schlecht E, Sangaré M, Susenbeth A, Becker K (1999) Supplementation of zebu cattle grazing Sahelian pastures. II. Development of body mass and empty body composition. J Agric Sci (Cambridge) 133:83–95
Schmidt M, Thiombiano A, Zizka A, König K, Brunken U, Zizka G (2011) Patterns of plant functional traits in the biogeography of West African grasses (*Poaceae*). Afr J Ecol 49:490–500
Siegmund-Schultze M, Rischkowsky B (2001) Relating characteristics to urban sheep keeping in West Africa. Agric Syst 67:139–152
Sokouri DP, Yapi-Gnaore CV, N'guetta ASP, Loukou NE, Kouao BJ, Toure G, Kouassi A, Sangaré A (2010) Performances de reproduction des races bovinés locales de Cote d'Ivoire. J Appl Biosci 36:2353–2359
SPSS Inc. (2010) PASW (Predictive Analytics Software) 18.0. SPSS Inc., Chicago, IL, USA
SWAC-OECD, ECOWAS (2008) Livestock and regional markets in the Sahel and West Africa: potentials and challenges. Sahel and West Africa Club/OECD, Paris
Tembely S, Bengaly K, Berckmoes W (1995) Effect of strategic anthelmintic treatments on growth performance and survival rate of indigenous lambs in sub-humid Mali. Small Rumin Res 16:77–82
Thys E, Oueadraogo M, Speybroeck N, Geerts S (2005) Socioeconomic determinants of urban household livestock keeping in semi-arid Western Africa. J Arid Environ 63:475–496
Tittonell P, Rufino MC, Janssen BH, Giller KE (2009) Carbon and nutrient losses during manure storage under traditional and improved practices in smallholder crop-livestock systems—evidence from Kenya. Plant Soil 328:253–269
Traoré A (2006) Première évaluation de la structure et de l'importance du secteur avicole commercial et familial en Afrique de l'Ouest. Organisation des Nations Unies pour l'Alimentation et l'Agriculture, Système de Production Avicole. Rapport du Mali, p 21
Turner MD (2000) Drought, domestic budgeting, and changing wealth distribution within Sahelian households. Dev Change 31:1009–1035
Van Soest PJ (1994) Nutritional ecology of the ruminant, 2nd edn. Cornell University Press, Cornell
Wilson RT, Durkin JW (1983) Livestock production in central Mali: weight at first conception and ages at first and second parturitions in traditionally managed goats and sheep. J Agric Sci 100:625–628
Wymann MN (2005) Calf mortality and parasitism in peri-urban livestock production in Mali. PhD thesis, University of Basel, Switzerland, p 167