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Institut d'Economie Rurale

# Effect of management strategies on the performance of ruminant livestock production systems and the safety of plant and animal products in the city of Sikasso, Mali

**Hamadoun Amadou**

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**Hamadoun Amadou**

Dissertation presented to the
Faculty of Organic Agricultural Sciences/
Section Animal Husbandry in the Tropics and Subtropics
University of Kassel
January 2012

This work has been accepted by the Faculty of Organic Agricultural Sciences of the University of Kassel as a thesis for acquiring the acadmic degree of Doktor der Agrarwissenschaften (Dr. agr.).

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| Supervisor: | Prof. Dr. Eva Schlecht, Universities of Kassel and Göttingen |
| Co-Supervisor: | Prof. Dr. Andreas Buerkert, University of Kassel |
| Examiner: | Prof. Dr. Albert Sundrum, University of Kassel |
| Examiner: | Dr. Hamidou Nantoumé, Institut d'Economie Rurale |

Malien Co-Supervisors: Dr. Abou Berthé and Dr. Hamidou Nantoumé,
Institut d'Economie Rurale, Bamako, Mali

Defense day: 24th February 2012

## Table of contents

## Dedication

To the memory of my
Uncle Allassane Bossi Touré,
Uncle Garba Halilou Maïga
and Aunt Badji Bossi Touré
who have been torn from our affection during this study.
May your souls rest in peace.
Amen.

A la mémoire de
Oncle Allassane Bossi Touré,
Oncle Garba Halilou Maïga
et Tante Badji Bossi Touré
qui ont été arrachés de notre affection au cours de cette étude.
Que vos Ames reposent en paix.
Amen.

**Acknowledgements**

First of all I want to thank The Volkswagen Foundation, Hannover, Germany, for funding the UrbanFood project. I am grateful to the University of Kassel and Georg-August-Universität Göttingen through the Sections of Animal Husbandry in the Tropics and Subtropics and Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, the “Institut d’Economie Rurale” (IER), Mali, the “Institut de l'Environnement et des Recherches Agricoles” (INERA), Burkina Faso and to Ahmadu Bello University at Zaria, Nigeria, for their administrative support.

I would like to thank the following people for their help and contributions to this work:
My heartfelt gratitude goes to Professor Dr. Eva Schlecht, my supervisor, for her exemplary guidance and support during this study. Your constructive suggestions and helpful comments were also central to the success of this work. Thanks for all the things learned about methods and the meticulous way of teaching scientific writing. Special thanks to your family for all the dinners and barbecues we had.

Professor Dr. Andreas Buerkert for your untiring support wherever it was needed. Special thanks to your generous family for all the personal invitations

Dr. Abdoulaye Hamadoun for always giving me support and technical advice and always being willing to set aside time to provide helpful advices. Dr. Luc H. Dossa, for improving my skills in using SPSS statistical package. Your constant attention is duly appreciated. My colleagues from the UrbanFood project, Laban Konaté, Jean P.D. Lompo, Scheick Sangaré, Aisha Abdulkadir and Drs. Martina Predetova and Nafiu Abdou for stimulating scientific exchange and an excellent working environment during this study.

Mr. Yaya Diarra, Mr. Diakaridia Diabate and Mr. Issouf Coulibaly for their hardworking and friendly help during the field work, despite difficult conditions. Your contribution was enormous.
Mr. Barthélémy Compaoré and Mr. Tiemtoré Robert for their friendly help.
Drs. Christian Huelsebusch, Abou Berthé, Adama Traoré, Hamidou Nantoumé, Rodrigue V.C. Diogo, Katja Brinkmann and Prof. Dr. Jens Gebauer for support and help. I would like to thank Mrs. Haber for her excellent secretarial and administrative support. I am also very grateful to Mrs. Eva Wiegard and Mrs. Claudia Thieme-Fricke as well as to Dr. Ilyassou Oumarou for analyses of a multitude of samples and guiding me during my laboratory analyses.

I am grateful to the (peri-) urban farmers at Sikasso, Bobo Dioulasso and Kano for their excellent and friendly cooperation during the field work. I would like to thank all staff of the Regional IER Research Centres at Sikasso and at Sotuba for spiritual support and encouragement. I am also very grateful to Mr. Allaye Koné and the staffs of health centers of Sikasso for the secondary data on human diseases.

My thanks also go to Mrs. Melanie Willich for translating the thesis summary into German. I greatly enjoyed the company of Nouhoun Zampaligre, Sahar Babiker, Francesca Beggi, Ishtiag Abdalla, Mohamed Al-Rawahi, Martin Wiehle, Sven Gönster and Miriam Ehret during my stay in Germany. Many thanks.

My dear wife Adam Coulibaly, my children Kadidiatou, Khalidi and Mariam, your support is immeasurable. You are indeed an invaluable treasure to me. I am also deeply grateful for the understanding and the patience of all my family members during the past years.

**Summary**

**Effect of management strategies on the performance of ruminant livestock production systems and the safety of plant and animal products in the city of Sikasso, Mali**

The regional population growth in West Africa, and especially its urban centers, will bring about new and critical challenges for urban development policy, especially in terms of ensuring food security and providing employment for the growing population. (Peri-) urban livestock and vegetable production systems, which can contribute significantly to these endeavours, are limited by various constraints, amongst them limited access to expensive production factors and their (in)efficient use. To achieve sustainable production systems with low consumer health risks, that can meet the urban increased demand, this doctoral thesis determined nutrient use efficiencies in representative (peri-) urban livestock production systems in three West African cities, and investigated potential health risks for consumers ensuing from there.

The field study, which was conducted during July 2007 to December 2009, undertook a comparative analysis of (peri-) urban livestock production strategies across 210 livestock keeping households (HH) in the three West African cities of Kano/Nigeria (84 HH), Bobo Dioulasso/Burkina Faso (63 HH) and Sikasso/Mali (63 HH). These livestock enterprises were belonging to the following three farm types: commercial gardening plus field crops and livestock (cGCL; 88 HH), commercial livestock plus subsistence field cropping (cLsC; 109 HH) and commercial gardening plus semi-commercial livestock (cGscL; 13 HH) which had been classified in a preceding study; they represented the diversity of (peri-) urban livestock production systems in West Africa.

In the study on the efficiency of ruminant livestock production, lactating cowsand sheep herd units were differentiated based on whether feed supplements were offered to the animals at the homestead (Go: grazing only; Gsf: mainly grazing plus some supplement feeding). Inflows and outflows of nutrients were quantified in these herds during 18 months, and the effects of seasonal variations in nutrient availability on animals' productivity and reproductive performance was determined in Sikasso.

To assess the safety of animal products and vegetables, contamination sources of irrigated lettuce and milk with microbiological contaminants, and of tomato and cabbage with pesticide residues in (peri-) urban agriculture systems of Bobo Dioulasso and Sikasso were characterized at three occasions in 2009. Samples of irrigation water, organic fertilizer and

lettuce were collected in 6 gardens, and samples of cabbage and tomato in 12 gardens; raw and curdled milk were sampled in 6 dairy herds. Information on health risks for consumers of such foodstuffs was obtained from 11 health centers in Sikasso.

In (peri-) urban livestock production systems, sheep and goats dominated (*P*<0.001) in Kano compared to Bobo Dioulasso and Sikasso, while cattle and poultry were more frequent (*P*<0.001) in Bobo Dioulasso and Sikasso than in Kano. Across cities, ruminant feeding relied on grazing and homestead supplementation with fresh grasses, crop residues, cereal brans and cotton seed cake; cereal grains and brans were the major ingredients of poultry feeds. There was little association of gardens and livestock; likewise field cropping and livestock were rarely integrated. No relation existed between the education of the HH head and the adoption of improved management practices (*P*>0.05), but the proportion of HH heads with a long-term experience in (peri-) urban agriculture was higher in Kano and in Bobo Dioulasso than in Sikasso (*P*<0.001). Cattle and sheep fetched highest market prices in Kano; unit prices for goats and chicken were highest in Sikasso.

Animal inflow, outflow and dairy herd growth rates were significantly higher (*P*<0.05) in the Gsf than in the Go cattle herds. Maize bran and cottonseed expeller were the main feeds offered to Gsf cows as dry-season supplement, while Gsf sheep received maize bran, fresh grasses and cowpea pods. The short periodic transhumance of Go dairy cows help them maintaining their live weight, whereas Gsf cows lost weight during the dry season despite supplement feeding at a rate of 1506 g dry matter per cow and day, resulting in low productivity and reproductive performance. The daily live weight gains of calves and lambs, respectively, were low and not significantly different between the Go and the Gsf system. However, the average live weight gains of lambs were significantly higher in the dry season (*P*<0.05) than in the rainy season because of the high pressure of gastrointestinal parasites and of *Trypanosoma* sp. In consequence, 47% of the sheep leaving the Go and Gsf herds died due to diseases during the study period.

Thermo-tolerant coliforms and *Escherichia coli* contamination levels of irrigation water significantly exceeded WHO recommendations for the unrestricted irrigation of vegetables consumed raw. Microbial contamination levels of lettuce at the farm gate and the market place in Bobo Dioulasso and at the farm gate in Sikasso were higher than at the market place in Sikasso (*P*<0.05). Pesticide residues were detected in only one cabbage and one tomato sample and were below the maximum residue limit for consumption. Counts of thermo-tolerant coliforms and *Escherichia coli* were higher in curdled than in raw milk (*P*<0.05). From 2006 to

2009, cases of diarrhea/vomiting and typhoid fever had increased by 11% and 48%, respectively, in Sikasso.

For ensuring economically successful and ecologically viable (peri-) urban livestock husbandry and food safety of (peri-) urban foodstuffs of animal and plant origin, the dissemination and adoption of improved feeding practices, livestock healthcare and dung management are key. In addition, measures fostering the safety of animal products and vegetables including the appropriate use of wastewater in (peri-) urban agriculture, restriction to approve vegetable pesticides and the respect of their latency periods, and passing and enforcement of safety laws is required. Finally, the incorporation of environmentally sound (peri-) urban agriculture in urban planning by policy makers, public and private extension agencies and the urban farmers themselves is of utmost importance.

To enable an efficient (peri-) urban livestock production in the future, research should concentrate on cost-effective feeding systems that allow meeting the animals' requirement for production and reproduction. Thereby focus should be laid on the use of crop-residues and leguminous forages. The improvement of the milk production potential through crossbreeding of local cattle breeds with exotic breeds known for their high milk yield might be an accompanying option, but it needs careful supervision to prevent the loss of the local trypanotolerant purebreds.

## Zusammenfassung

Das regionale Bevölkerungswachstum in Westafrika wird neue und entscheidende Herausforderungen für die städtische Entwicklungspolitik mit sich bringen, insbesonders hinsichtlich der Nahrungssicherung und der Bereitstellung von Arbeitsplätzen. (Peri-) urbane Tierhaltungs- und Gemüseproduktionssysteme, die einen erheblichen Beitrag dazu leisten, werden durch verschiedene limitierende Parameter wie Einsatz von Produktionsfaktoren und deren Nutzungseffizienz begrenzt. Um nachhaltige Produktionssysteme mit geringerem Gesundheitsrisiko für die Verbraucher zu identifizieren, die auch die steigende Nachfrage nach Nahrungsmitteln in der Stadt befriedigen, werden in dieser Doktorarbeit die Nutzungseffizienzen von Nährstoffen in repräsentativen (peri-) urbanen Tierhaltungssystemen dreier westafrikanischer Städte erfasst und mögliche Gesundheitsrisiken ermittelt.

Die Untersuchungen, die zwischen Juli 2007 und Dezember 2009 durchgeführt wurde, gingen aus von einer vergleichende Analyse von (peri-) urbanen Tierproduktionssystemen in 210 Haushalten (HH) der drei westafrikanischer Städte Kano/Nigeria (84 HH), Bobo Dioulasso/Burkina Faso (63 HH) und Sikasso/Mali (63 HH). Diese Tierhaltungssysteme waren anhand einer Clusteranalyse unterteilt worden in folgende drei Typen: 88 HH mit kommerziellem Gartenbau, Anbau von Feldfrüchten und Haltung von Nutztieren (cGCL), 109 HH mit kommerzieller Tierproduktion und Subsistenzackerbau (cLsC), sowie 13 HH mit kommerziellem Gartenbau und semi-kommerzieller Tierproduktion (cGscL).

In der Studie zur Effizienz der Tierproduktionssysteme wurden Milchkuh- und Schafherden untersucht und, basierend auf der täglich angebotenen Menge an Ergänzungsfutter, unterteilt in Herden mit ausschließlichem Weidegang (Go) und Herden mit Weidegang und zusätzlicher Stallfütterung (Gsf). Die in die einzelnen Herden eingehenden (Futter) und ausgehenden (Produkte, Dung) Nährstoffflüsse wurden über einen Zeitraum von 18 Monaten quantitativ erfasst, und die Effekte der Fütterung auf die tierische Leistungs- und Reproduktionsfähigkeit wurde ermittelt.

Im Hinblick auf die Lebensmittelsicherheit von tierischen und pflanzlichen Produkten wurden im Jahr 2009 für Salat, Rohmilch, sowie für Tomaten und Kohl die Verunreinigung mit Fäkalkeimen und die Belastung mit Pestizidrückständen bestimmt; diese Studie fand in Bobo Dioulasso und Sikasso statt. In sechs Gärten wurden sowohl von Bewässerungswasser, von organischem Dünger und von Salat Proben entnommen. Darüber hinaus wurden Proben von Kohl und Tomaten aus zwölf Gärten sowie rohe und angesäuerte Milch aus sechs

Milchviehherden untersucht. Informationen zur Inzidenz von Durchfallerkrankungen und anderen Lebensmittelvergiftungen, die mit dem Verzehr von belasteten Lebensmitteln einhergehen können, wurden in elf Gesundheitszentren von Sikasso erhoben.

In den (peri-) urbanen Tierproduktionssystemen Kanos wurden vorwiegend Schafe und Ziegen gehalten ($P<0.001$), während Rinder und Geflügel den Bestand in Bobo Dioulasso und Sikasso dominierten ($P<0.001$). In allen Städten fand für Wiederkäuer üblicherweise Weidegang mit Zufütterung im Stall statt; eingesetzte Futtermittel waren frisches Gras, Ernterückstände, Getreidekleien und Baumwollsaatkuchen, wobei in der Geflügelhaltung überwiegend Getreidekörner und -kleie gefüttert wurden. Gärten und Tierhaltung standen in nur geringer Verbindung. Gleichermaßen wurden Ackerbau und Tierhaltung nur selten integriert praktiziert. Zwischen dem Bildungsniveau des Haushaltsvorstands und der Übernahme verbesserter landwirtschaftlicher Praktiken konnte kein Zusammenhang erkannt werden ($P>0.05$), wobei der Anteil an Haushaltsvorständen mit längerfristiger Erfahrung in der urbanen Landwirtschaft in Kano und Bobo Dioulasso höher war als in Sikasso ($P<0.001$). Rinder und Schafe erzielten die höchsten Marktpreise in Kano; die Preise für Ziegen und Hühner waren in Sikasso am höchsten.

Tierzu- und --abgänge sowie das numerische Wachstum der Herden war in den Gsf Milchviehherden signifikant höher ($P<0.05$) als in den Go Herden. Maiskleie und Baumwollsaatkuchen waren die wichtigsten Zusatzfuttermittel, die den Gsf Milchkühen angeboten wurden, während Gsf Schafe hauptsächlich mit Maiskleie, frischem Gras und Hülsen von Augenbohnen zugefüttert wurden. Während die Go Milchkühe aufgrund wiederholter kurzer Transhumanzphasen ihr Lebendgewicht in der Trockenzeit halten konnten, verloren Gsf-Tiere trotz einer Zusatzfütterung von 1506 g TM $Kuh^{-1}$ $Tag^{-1}$ an Gewicht. Dagegen unterschieden sich die beobachteten Gewichtszunahmen von Kälbern beziehungsweise Lämmern nicht wesentlich zwischen dem Go und dem Gsf System. Während der Trockenzeit war die durchschnittliche Lebensmassezunahme der Lämmer jedoch signifikant höher ($P<0.05$) als in der Regenzeit, aufgrund des dann vermehrten Auftretens von gastrointestinalen Erkrankungen und von Trypanosomiasis. Von den Schafen die während des Studienverlaufs die Schafherden verliessen verstarben 47% aufgrund von Krankheiten.

Das Konzentration von thermotoleranten coliformen Keimen und von *Escherichia coli* in Bewässerungswasser überstieg die WHO Empfehlung für uneingeschränkte Bewässerung von roh zu verzehrendem Gemüse deutlich. Die mikrobielle Kontamination von Salat im bäuerlichen Betrieb und auf dem Markt in Bobo Dioulasso und im bäuerlichen Betrieb in Sikasso waren jeweils höher als die des Salates auf dem Markt in Sikasso ($P$<0.05), während Pestizid-Rückstände nur in einer Probe von Kohl sowie einer Probe von Tomaten nachgewiesen wurden und sich unterhalb des für den Verzehr bedenklichen Schwellenwertes bewegten. Die Anzahl an thermotoleranten coliformen Keimen und an *Escherichia coli* war in angesäuerter Milch höher als in Rohmilch ($P$<0.05). In den Gesundheitszentren von Sikasso hatten zwischen 2006 und 2009 Fälle von Diarrhöe/Erbrechen sowie von Typhus um 11% beziehungsweise 48% zugenommen.

Um ökonomisch erfolgreiche und ökologisch tragfähige (peri-) urbane Tierhaltungssysteme zu etablieren und die Lebensmittelsicherheit (peri-)urbaner Produkte tierischen und pflanzlichen Ursprungs sicherzustellen, muss die Verbreitung und Annahme folgender, aus dieser Studie resultierender Empfehlungen erfolgen: verbesserte Fütterungspraxis von Wiederkäuern in urbanen Haltungssystemen, Gesundheitsvorsorge in den Herden und gutes Management des tierischen Dungs (Kompostierung). Maßnahmen zur Förderung der Sicherheit von tierischen Produkten und von Gemüse beinhalten die sachgemäße Nutzung der Abwässer in der (peri-) urbanen Landwirtschaft, die Verwendung zugelassener Pestizide unter Beachtung ihrer jeweiligen Latenzzeit und das Verabschieden und Überwachen von entsprechenden Gesetzen sowie die Integration umweltverträglicher (peri-) urbaner landwirtschaftlicher Praxis in die Städteplanung unter Einbeziehung der politischen Entscheidungsträger, staatlichen und privaten Beratungsdienste und der Landwirte selbst.

Um nachhaltige (peri-) urbane Tierproduktionssysteme zukünftig zu unterstützen sollte entsprechende Forschung sich schwerpunktmäßig auf kosteneffiziente Fütterungssysteme konzentrieren, welche den tierischen Bedarf hinsichtlich Produktion und Reproduktionsleistung decken. Diese sollten insbesondere die Verwertung von Ernterückständen und die Einbeziehung von Futterleguminosen zur Steigerung der Milchleistung im Blick haben. Letzteres könnte auch durch die Kreuzung zwischen lokalen Rassen und exotischen Rassen mit charakteristisch hoher Milchleistung gefördert werden, wobei diese Strategie einer sehr sorgfältigen Überwachung bedarf, um einen Verlust der regionalen trypanotoleranten Rassen zu vermeiden.

**Résumé**

**Effet des stratégies de gestion sur la performance des systèmes de production des ruminants et la qualité sanitaire des produits végétaux et animaux dans la ville de Sikasso, Mali**

La population croissance de l'Afrique de l'Ouest entrainera de nouveaux défis et opportunités de politique de développement urbain, notamment en termes de sécurité alimentaire et de création d'emplois. Les systèmes urbain et périurbain d'élevage et de production des légumes qui peuvent contribuer de manière significative à ces efforts sont limités par diverses contraintes, parmi elles, l'accès limité ou couteux des facteurs de production et de leur utilisation (non)efficace. Pour parvenir à des systèmes de production durable avec moins de risques pour les consommateurs afin de supporter cette demande accrue, la présente thèse de doctorat déterminera l'efficacité de l'utilisation des nutriments dans des représentatifs systèmes de production animale en agriculture urbaine et périurbaine de trois villes de l'Afrique de l'Ouest. Aussi, elle étudiera les risques éventuels qui en suivent pour la santé des consommateurs.

L'étude de terrain, réalisée de juillet 2007 à décembre 2009, avait entrepris une analyse comparative des stratégies de production animale en zone urbaine et périurbaine à travers 210 exploitations (HH) d'élevage dans trois villes de l'Afrique de l'Ouest, Kano au Nigeria (84 HH), Bobo Dioulasso au Burkina Faso (63 HH) et Sikasso au Mali (63 HH). Ces entreprises d'élevage, sélectionnées sur la base d'une étude précédente, sont classées en trois types d'exploitation, à savoir 88 HH de jardinage commercial plus cultures de céréales et elevage d'animaux (CGCT), 109 HH élevage commercial plus cultures de subsistance (CLSC) et 13 HH jardinage commercial plus élevage semi-commercial (cGscL). Elles représentaient la diversité des systèmes urbains et périurbains d'élevage en Afrique de l'Ouest.

Dans l'étude de l'efficacité de la production des ruminants, des troupeaux de vaches laitières et de moutons ont été différenciées selon que l'alimentation proposée aux animaux à la ferme ait été complétée (Go: pâturage seulement; Gsf: pâturage plus supplément d'aliment à l'étable). Les entrées et sorties de nutriments ont été quantifiés dans ces troupeaux durant 18 mois et les effets des variations saisonnières dans la disponibilité des nutriments sur la productivité des animaux et la performance de reproduction ont été déterminés à Sikasso.

Concernant la qualité sanitaire des produits animaux et végétaux, les sources de contamination de la laitue irriguée et du lait par les contaminants microbiologiques, et de la

tomate et du chou par les résidus de pesticides dans les systèmes d'agriculture urbaine et périurbaine de Bobo Dioulasso (Burkina Faso) et de Sikasso (Mali) ont été caractérisées à trois différentes périodes en 2009. Des échantillons d'eau d'irrigation, d'engrais organique et de laitue ont été prélevés dans six jardins; des échantillons de choux et de tomates ont été collectés dans 12 jardins; le lait cru et caillé ont été échantillonnés dans six troupeaux laitiers. Des informations sur les risques sanitaires liés à la consommation de tels produits alimentaires pour les consommateurs ont été notées dans 11 centres de santé à Sikasso.

Dans les systèmes d'elevage urbain et périurbain, les moutons et les chèvres ont été dominants (p <0,001) à Kano comparé à Bobo Dioulasso et Sikasso tandis que les bovins et la volaille étaient plus fréquents (p <0,001) à Bobo Dioulasso et Sikasso qu'à Kano. A travers les villes, l'alimentation des ruminants était basée sur le pâturage et la supplémentation en ferme avec des herbes fraîches, les résidus de récolte, les sons de céréales et du tourteau de coton; les grains et les sons de céréales ont été les principaux aliments pour volaille. Il y avait peu d'association élevage et jardinage; la culture céréalière et l'elevage ont été également rarement intégrés. Aucune relation n'est signalée entre le niveau de formation du chef d'exploitation et l'adoption de pratiques améliorées de gestion du troupeau (p> 0,05). Toutefois, la proportion des chefs d'exploitations (91%; 75% et 44%) expérimentés de plus de 10 ans dans les domaines de l'agriculture urbaine et périurbaine a été supérieure à Kano et à Bobo Dioulasso qu'a Sikasso (p <0,001). Sur le marché de Kano, les prix unitaires des bovins et des ovins ont été les plus élevés tandis que ceux des caprins et des poulets l'étaient à Sikasso.

Le flux des entrées et des sorties des animaux, et les taux de croissance des troupeaux laitiers ont été significativement plus élevée (P <0,05) dans le Gsf que dans le Go. Le son de maïs et le tourteau de graines de coton ont été les principaux compléments d'aliments offerts aux vaches de Gsf pendant la saison sèche, tandis que les moutons de Gsf ont reçu du son de maïs, des herbes fraîches et les fanes de niébé. La courte période de transhumance a aidé les vaches laitières de Go à maintenir leur poids vif, alors que celles de Gsf ont perdu du poids pendant la saison sèche, malgré le complément l'aliment de 1506 g de matière sèche par vache et par jour, ce qui a entraîné une faible performance de productivité et de reproduction. Les gains quotidiens de poids vif des veaux et des agneaux étaient faibles et non significativement différents entre les systèmes Go et Gsf, respectivement. Toutefois, les gains moyens quotidien de poids vif des agneaux étaient significativement plus élevés pendant la saison sèche (P <0,05) que la saison des pluies en raison de la forte pression des parasites gastro-intestinaux et de Trypanosoma sp. En conséquence, 47% des brebis qui avaient quitté le troupeau Go et Gsf étaient morts de  maladies pendant la période d'étude.

Les niveaux de contamination des eaux d'irrigation par les coliformes thermotolérants et Escherichia coli ont largement dépassé les recommandations de l'OMS pour l'irrigation de légumes consommés crus sans restriction. Les niveaux de la contamination microbienne de la laitue au jardin et au marché à Bobo-Dioulasso et au jardin à Sikasso étaient supérieurs à ceux du marché à Sikasso ($P < 0,05$), tandis que les résidus de pesticides détectés seulement dans un échantillon de chou et un échantillon de tomate et de chou étaient au-dessous de la limite maximale de résidus (LMR) pour la consommation. Les taux de coliformes thermotolérants et de Escherichia coli ont été élevés dans le lait caillé que dans le lait cru ($P < 0,05$). De 2006 à 2009, les cas de diarrhée/vomissement et de fièvre typhoïde ont augmenté de 11% et 48%, respectivement, à Sikasso.

Pour assurer la réussite économique et écologiquement viable des systèmes d'élevage et de la qualité sanitaire des produits d'origine animale et végétale en agriculture urbaine et périurbaine, la diffusion et l'adoption de pratiques d'alimentation améliorée, de la santé animale et de la gestion du fumier sont les éléments clés. En outre, des mesures favorisant la qualité sanitaire des produits d'origine animale et végétale en agriculture urbaine et périurbaine sont nécessaires. Il s'agit en l'occurrence, de l'usage approprié des eaux usées, l'utilisation de pesticides éprouvés pour les légumes et le respect de leurs périodes de latence, et de l'application et le contrôle des lois respectives. Aussi, l'intégration de technologies écologiquement rationnelles de l'agriculture urbaine et périurbaine dans la planification urbaine par les décideurs, les agences de vulgarisation publiques et privées et les agriculteurs urbains et périurbains eux-mêmes est d'une importance capitale.

Par ailleurs, une efficace production animale en agriculture urbaine et périurbaine à l'avenir devrait s'appuyer sur des recherches de systèmes d'alimentation rentable devant satisfaire l'exigence de l'animal pour la production et la reproduction. Pour ce faire un accent particulier devrait être mis sur l'utilisation des résidus de cultures et de légumineuses fourragères. L'amélioration du potentiel de production de lait par le croisement des races bovines locales avec des races exotiques connues pour leur production élevée de lait pourrait être une option d'accompagnement, mais a besoin dune minutieuse supervision pour éviter la perte des races locales pure trypanotolérantes.

**Preface – the "UrbanFood" project**

"Challenges and opportunities for nutrient efficient agriculture in West African cities" is a research and training network funded by the Volkswagen Foundation Hannover, Germany, which was set up by a team of senior scientists from African (Burkina Faso, Mali, Nigeria), and European research institutions (University of Kassel; Germany, Wageningen University; The Netherlands; Université Catholique de Louvain, Belgium), and the pan-African research and training network AfNet. The project, which started in March 2007 and will end in May 2012, embarked on a quantitative characterization of urban and peri-urban agriculture (UPA) in three secondary cities Sikasso (Mali), Bobo Dioulasso (Burkina Faso) and Kano (Nigeria). This comprised the determination of horizontal and vertical flows of nutrients in different types of UPA crop and livestock enterprises with a special emphasis on their seasonal and spatial variation, the qualitative examination of selected UPA products for pathogens as well as heavy metals, and the assessment of environmental pollution that might originate from ineffective or inappropriate use of inputs. The project hypothesized that improved nutrient use efficiency would reduce environmental and human health risks linked to UPA activities. In consequence, the ultimate goals of the project were (i) the reduction of nutrient losses from UPA crop and livestock husbandry by closing nutrient cycles and increasing nutrient use efficiency, (ii) the avoidance of produce contamination with heavy metals, pathogens and pesticides by careful use of wastewater, and (iii) an increased reliance on organic approaches of food production. The analysis of the production efficiency of urban and peri-urban ruminant enterprises and the contamination of UPA products (vegetables, milk) with faecal parasites, pathogens and pesticide residues are the main themes addressed in this dissertation. The gained insights result in a range of suggestions for improved (i) management options for UPA livestock production systems and (ii) safety of animal products and vegetables for the benefits of UPA farmers, consumers and the environment.

## Chaper 1

## General introduction

## 1.1. Agriculture and urban development in West Africa

### *1.1.1. Urbanization and the niche for urban agriculture*

Due to the current demographic and urbanization trends, millions of people live under appalling slum conditions in the vastly expanding cities of West Africa (SWAC-OECD/ECOWAS 2008). The regional population growth is amongst the highest in recorded history - there may be 430 million people living all across West Africa in 2020 of which 63% will be found in urban centers (Cofie et al. 2003). This will bring about new and critical challenges for urban development policy, especially in terms of ensuring food security and providing employment. Presently a key factor for urban growth in West Africa is the exodus of people from rural areas for escaping poverty, obtaining wedding goods and agricultural equipments. Since urbanization stimulates agricultural activities in cities or their vicinities, it creates a market for specialized food production with a high added value, particularly livestock rearing including poultry farming, and market gardening (Lovell 2010). Most urban and peri-urban farmers are from the poorer social strata (De Zeeuw et al. 2011) or are migrants who start as labourers in urban and peri-urban agriculture (UPA) and gradually become UPA farmers by renting free land for their activities. An estimated 56% of urban employment throughout Africa is based on this and other informal sectors (Nugent 2005). However, the lack of access to credit and investment is recognized as a factor limiting UPA development (Dubbeling and van Veenhuizen 2003). As a consequence, UPA operates in traditional ways geared towards labour-intensive and small-scale subsistence production.

### *1.1.2. Benefits and constraints of urban agriculture*

Various constraints hamper the swift growth of UPA, amongst them input factor prices, institutional problems and absent or poor legislation. Since 1999, the FAO was officially mandated by its members to deal with UPA as an integral part of agricultural production systems that feed the cities while creating jobs and generating income for the urban poor (FAO 2011). This suggests that UPA offers a number of benefits which are still underestimated and undervalued (Addo 2010), but which can make important contributions to a number of challenges in many West African cities. These are, among others, the provision of food supply and food security to the poor, particularly slum-dwellers, the generation of income for farmers, retailers and people transforming agricultural goods, the promotion of self-reliance and self-sufficiency, and environmental advantages (Obuobie et al. 2006; De Zeeuw et al. 2011). In Africa, UPA provides income and improves nutrition for 40 - 50% of the urban population; at the global scale UPA presently produces 15% of all foods consumed in urban areas and this percentage is likely to double in the next couple of decades (Garrett 2000). In addition, UPA can meet specific urban requirements for highly perishable goods by organizing their production in close proximity to the consumers (Lovell 2010). As a regenerative activity UPA restores degraded and unused land, recycles wastes as inputs to production and reduces urban pollution and energy consumption (Djabatey 1998).

The constraints of UPA are of economic, socio-cultural and institutional nature. They comprise, among others, access to production resources, inputs and services, aspects of land tenure and general legislation, product processing, conservation and marketing, credit facilities and extension services. The fact that most urban farmers are not organized in a formal way and lack recognition by city authorities, urban planners and government institutions, leads to inappropriate support infrastructure and services. In a number of countries the official attitude towards urban agriculture is very negative with deterring policies and constraining or even prohibiting laws and regulations (Cissé et al. 2005). However, Drechsel and Dongus (2010) argue that urban agriculture is worth of appropriate institutional recognition and direct public policy support. This necessitates its integration into urban planning and development goals, the identification of the various actors involved and the revision of laws and regulations. Within West Africa, Ghana is ahead in the process of setting up, since 2003, an institutional framework for the sustainability and productivity of urban and peri-urban agriculture (Egyir and Beinpuo 2009).

The control of land and resources are determinant issues for promoting market-oriented agriculture such as UPA, and for combating poverty. West African countries did not undertake any major land reform after independence except to adopt laws based on colonial legislation which upheld the state monopoly over land (Chauveau et al. 2006). Since agriculture is predominantly a rural activity, appropriate land legislation was never designed, but was left to the customary and traditional chiefs. In West African countries such as Ghana (1999), Guinea (2001), Sierra Leone (2005), Senegal (2006), Mali (2006), and Burkina Faso (2007), these legislations are nowadays under revision (Economic Commission for Africa 2010). The various processes showed that most countries design laws adapted to their local situation to facilitate their better implementation, but the main difficulty in implementing the reforms is that they are unable to integrate local practices and traditional institutions (Economic Commission for Africa 2007). However, the specific case of urban and peri-urban agriculture remains still unclear given the very many actors involved.

In summary it can be concluded that until today the multiple constraints touched upon here keep UPA from being as efficient and expansive as its potential suggests (Smit et al. 2001).

### 1.2. Urban and peri-urban livestock systems in West Africa

In any husbandry system, livestock provide foods and services, generate cash income, economic and social security, serve risk aversion or spreading, and their labour and dung enhance crop production (Seré and Steinfeld 1996; Williams et al. 2004). Value addition to livestock products can create the need for additional services and employment, diversify income and further reduce production risks (Kathiravan and Selvam 2011). There is no clear trend in terms of the livestock species kept and practices applied in urban livestock farming in different cities, but the most common species encountered are dairy cattle, sheep, goats, poultry, pigs and donkeys (Centrès 1996; Thys et al. 2005; Graefe et al. 2008). Cultural reasons are likely to influence preferences for certain species although people would like to have lactating cows, followed by small ruminants and expand their livestock production (Cofie et al. 2008). (Peri-) urban livestock systems can be categorized by their mode and/or the scale of production.

Grazing is the main source of livestock feed even in UPA livestock holdings, and scarcity of feed resources, especially in the dry season, was identified as a major limitation to urban livestock husbandry (Thys et al. 2005). However, (peri-) urban livestock keepers also feed harvested forages and crop residues from urban and rural surroundings as well as agro-industrial by-products (Sidibe et al. 2004; Graefe et al. 2008). In Ethiopia, Kenya, and Somalia, people have set up informal enterprises by collecting roadside grasses or cultivating grass-legume mixtures which are then sold to urban livestock keepers (Nyangaga et al. 2009). According to Diogo et al. (2010) such feeds are used in considerable quantities in many (peri-) urban livestock holdings, but their use-efficiency is low, as is the overall productivity of these production systems. Further problems for livestock production are endemic and epidemic diseases: Thys et al. (2005) reported that the first constraint to animal husbandry in Ouagadougou, capital of Burkina Faso, was animal health including drug and treatment delivery. For dairy herds in Bobo Dioulasso (Burkina Faso), Sidibe et al. (2004) reported that mastitis, foot and mouth disease, trypanosomiasis, pasteurellosis, and pest of small ruminants were the most frequent diseases in ruminants, while Newcastle disease, infectious bursal disease, and fowl pox were the most important poultry diseases.

Livestock production in the Sahel and West African (SWA) countries is growing at an estimated 2% per year, although the regional demand for livestock products is expected to increase by >250% until 2025 as compared to 2005 (SWAC-OECD/ECOWAS 2008). This discrepancy is mirrored in the region's persistent dependence on extra-African imports of milk, meat and eggs (Tacher et al. 2000). Although the SWA countries clearly have the numerical, genetic and zootechnical potential for enhanced livestock production, this is insufficiently exploited. For example, the peri-urban dairy farms in Mali contribute only 2% to the national milk production (Ministère de l'Elevage et de la Pêche 2008). Crossbreeding programmes were considered as ways to improve the productivity of local breeds of cattle and sheep across the region (Missohou and Adakal 2004; Bonfoh et al. 2005; Millogo et al. 2008), but were not very successful. Major drawbacks for livestock productivity across rural and urban settings are not primarily the genetic makeup but rather poor feeding, lack of breeding management and the impact of diseases (Hamadou et al. 2003; Coulibaly et al. 2007, Sanogo et al. 2010). The low productivity of West African livestock has thus to be improved through alleviation of insufficient nutrition, poor health and breeding management, disease control, and the provision of better access to inputs and information for farmers (Nkya et al. 2007).

## 1.3. Safety of urban and peri-urban agricultural products in West Africa

### *1.3.1. Animal products*

The health of consumers greatly depends on the quality of animal products such as meat, milk, and eggs; if these are originating from infected animals they might be contaminated with microbiological agents (bacteria, parasites, and viruses), residues of veterinary drugs, and drug-resistant bacteria (FAO/OMS 2003). The presence, prevalence, and transmission of diseases depend on the animal species, the livestock production system, environmental factors, and husbandry practices. Infectious organisms commonly encountered in animal products are *Salmonella*, *Campylobacter*, *E. coli*, and *Listeria*, *Staphylococcus*, and *Clostridium* (FAO/WHO 2008). Faecal pathogens excreted by animals and humans are recycled to the soil through wastewater (Amoah et al. 2005) and constitute a potential source of contamination for crops. Antibiotics are widely used in developing countries, partly due to the high incidence of infectious endemic and epidemic diseases and their move across national boundaries (Williams et al. 2004); their residues are very often found in animal products like milk (Hetzel et al. 2004), meat (Abiola et al. 2005), and eggs (Sasanya et al. 2005). Misuse of veterinary drugs through application of elevated doses or ignorance of latency periods for products of treated animals may affect consumers' health. Failure to adhere to recommended latency periods is the primary cause for violative levels of veterinary drug residues in food (Kukanich et al. 2005). In addition, antibiotic resistance can be developed by zoonotic agents (Alfredson and Korolik 2007) that are transferred to humans and/or transfer their resistance genes to other microbiota belonging to the endogenous flora of man (van den Bogaard and Stobberingh 2000). Although in African countries laws, norms and regulations exist that assure food safety, those tools are not applied efficiently. However, no official statistics for cases of food poisoning are available, but sporadic cases reporting the origins and causal agents are known (Ombui et al. 2001).

### *1.3.2. Crop products*

The vegetables from UPA are often accused of being contaminated with pathogens and chemical pollutants which come from inputs such as irrigation water, organic fertilizers, and pesticides. In UPA, irrigation water is frequently fetched from shallow wells, open drains, domestic sewage channels, and industrial wastewaters. Infectious pathogens have been recovered from organic fertilizers (solid household waste, livestock manure), soils, and irrigation waters used in urban vegetable production systems (Amoah et al. 2007), and on vegetables at the field and at the market level (Amponsah-Doku et al. 2010). Reported concentrations by far exceeded the standard for irrigation water of $10^3$ faecal coliforms per 100 ml (WHO 2006). The bacterial genera Escherichia, Shigella, Salmonella, and parasites including the genera *Ascaris*, *Ancylostoma*, *Endolimax, Entamoeba*, *Plasmodium, Schistosoma,* and *Trichiuris* have all been determined in irrigation water and/or livestock dung and night soil used for vegetable production (Niang 1996; Sonou 2001; Amoah et al. 2006).

In sub-Saharan Africa, the use of pesticides for crop protection and yield enhancement is significant; on urban markets pesticides are sold without regulations and controls. In nine countries (Burkina Faso, Cape Verde, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, and Chad), cotton pesticides such as endosulfan (which was banned by the Permanent Interstate Committee for Drought Control in the Sahel, CILSS, in 2007) were applied on (peri-) urban vegetables (Rosendahl et al. 2008). Farmers reported to rely on pesticides purchased from informal, unlicensed dealers (Bassole and Ouedraogo 2007). Because of the short cultivation cycle of vegetables, pesticide latency periods are very often ignored by vegetable producers (Graefe et al. 2008) and residues of pesticides were thus found in vegetables at market places in Ghana (Amoah et al. 2006) and Nigeria (Benson and Olufunke 2011). The consumption of chemically polluted vegetables can provoke diseases in humans and animals; long-term consumption of such products may provoke carcinogenic and mutagenic effects and damages to the central nervous system (Belpomme et al. 2007). Since many less developed countries lack resources to even assure food security, issues of food safety have a very low priority even if accredited control systems are already in place or are being worked out (Cannavan 2004).

### 1.4. Objectives, research hypotheses and conceptual framework of the present study

In view of the above reflections on the opportunities, but especially the constraints of urban and peri-urban agriculture in general, and of livestock husbandry in particular, this PhD research project aimed at a detailed analysis of management-based horizontal nutrient flows in differently managed (peri-) urban livestock production systems in West African cities in order to determine the sustainability of livestock production systems and environmental safety of vegetable and livestock products.

It departed from the following hypotheses:

(i) Livestock management strategies practiced by (peri-) urban livestock producers in West African cities differ according to the households' characteristics and their production objectives.

(ii) The livestock production systems in Sikasso (Mali) is characterized by inefficient feeding management, resulting in low growth rates of animals, low milk yield of beef cattle, and low nutrient use efficiency.

(iii) Milk produced in (peri-) urban dairy farms is contaminated with hazardous microbiological agents.

(iv) The use of untreated irrigation water, livestock dung, and of pesticides in (peri-) urban gardens leads to a contamination of vegetables with faecal pathogens and pesticides residues.

To address these hypotheses, a methodological approach was developed (Figure 1) that in a first step characterized UPA livestock production systems across three West African cities (chapter 2) and focussed on its role in terms of contribution to livelihoods via direct and indirect benefits (chapter 3) and in terms of problems which in the present context primarily concern nutrient use efficiency in the livestock unit (chapter 3) and the safety of milk and vegetables (chapter 4).

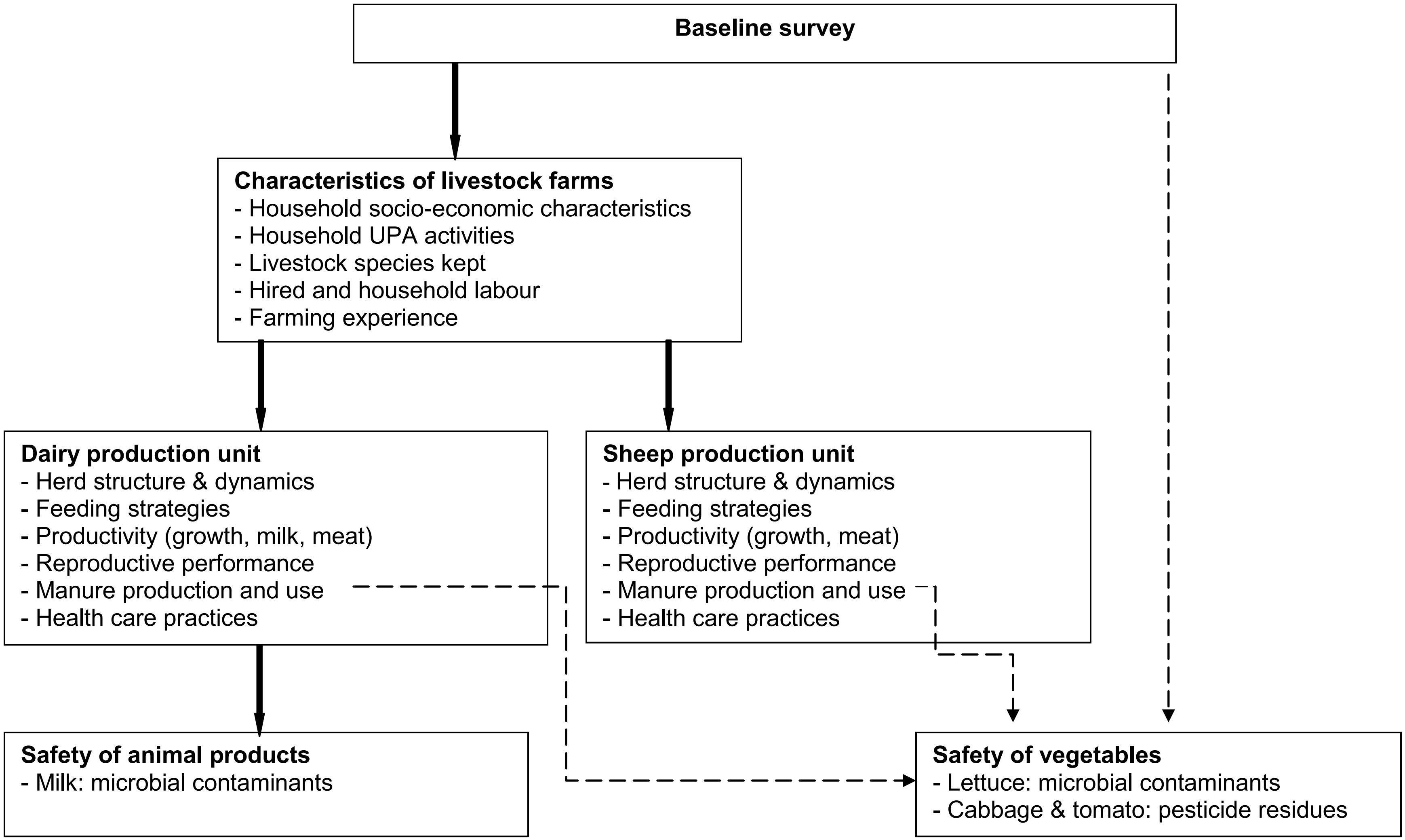


Figure 1: Methodological approach of the study.

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# Chapter 2

## A comparison between urban livestock production strategies in Burkina Faso, Mali and Nigeria

* Modified version accepted by Tropical Animal Health and Production.

**Abstract**

We undertook a comparative analysis of (peri-) urban livestock production strategies across three West African cities. Using a semi-structured questionnaire, livestock-keeping households (HH) were interviewed in Kano/Nigeria (84 HH), Bobo Dioulasso/Burkina Faso (63 HH) and Sikasso/Mali (63 HH). Questions covered livestock species kept, herd sizes and structure, feeds used, manure management, livestock marketing, and production constraints.

Sheep and goats dominated ($p<0.001$) in Kano (76% and 75% of HH) compared to Bobo Dioulasso (48% and 40%) and Sikasso (28% and 40%) while cattle and poultry were more frequent ($p<0.001$) in Bobo Dioulasso (82% and 69% of HH) and Sikasso (65% and 79%) than in Kano (29% and 20%). Across cities, ruminant feeding relied on grazing and homestead supplementation with fresh grasses, crop residues, cereal brans and cottonseed cake; cereal grains and brans were major ingredients of poultry feeds. Cattle and sheep fetched highest prices in Kano, unit prices for goats and chicken were highest in Sikasso. Across cities there was little association of gardens and livestock; likewise field cropping and livestock were rarely integrated. There was no relation between the education of the HH head and the adoption of improved management practices ($p>0.05$), but the proportion of HH heads with a long-term experience in UPA activities was higher in Kano and in Bobo Dioulasso than in Sikasso ($p<0.001$). We therefore postulate that the high illiteracy rate among (peri-) urban livestock keepers in West Africa does not threaten the acceptance of improved technologies and institutional innovations supporting the sustainability of their livestock production.

**Keywords:** Health care; Urban households; Feeding; Cattle, Small ruminants, Chicken, Burkina Faso, Mali; Nigeria.

## Une comparaison entre les stratégies urbaines d'élevage au Burkina Faso, au Mali et au Nigeria en Afrique de l'Ouest

**Résumé**

Nous avons entrepris une analyse comparative des stratégies urbaines et périurbaines d'élevage à travers trois villes de l'Afrique de l'Ouest. En utilisant un questionnaire semi-structuré, des exploitations d'élevage (HH) ont été interviewés à Kano au Nigeria (84 HH), à Bobo Dioulasso au Burkina Faso (63 HH) et à Sikasso au Mali (63 HH). Les questions ont porté sur les espèces animales élevées, la taille et la structure des troupeaux, les aliments offerts aux espèces animales, la gestion du fumier, la commercialisation des animaux et les contraintes de production.

Les élevages ovins et caprins ont été dominents ($p<0,001$) à Kano (76% et 75% des exploitations) par rapport à Bobo Dioulasso (48% et 40%) et Sikasso (28% et 40%) tandis que ceux des bovins et de la volaille ont été plus fréquentes ($p<0,001$) à Bobo Dioulasso (82% et 69% exploitations) et Sikasso (65% et 79% exploitations) qu'a Kano (29% et 20% exploitations). A travers les villes, l'alimentation des ruminants était basée sur le pâturage et la supplémentation à la ferme avec des herbes fraîches, des résidus de récolte, des sons de céréales et du tourteau de coton; les grains et les sons de céréales ont été les principaux aliments pour volaille. Sur le marché de Kano, les prix unitaires des bovins et des ovins ont été les plus élevés tandis que ceux les caprins et les poulets l'étaient à Sikasso. Il y avait peu d'association élevage et jardinage; la culture céréalière et l'élevage ont été également rarement intégrés. Aucune relation n'a été identifiée entre le niveau de formation des chefs d'exploitation et l'adoption de pratiques améliorées de gestion du troupeau ($p>0,05$) mais la proportion des chefs d'exploitations expérimentés dans les domaines de l'agriculture urbaine et périurbaine a été supérieure à Kano et à Bobo Dioulasso qu'a Sikasso ($p<0,001$). Il est important de constater que le taux d'analphabétisme élevé chez les éleveurs urbain et périurbain en Afrique de l'Ouest ne menace pas l'adoption des technologies améliorées et que des innovations institutionnelles soutenant la durabilité de leur production animale soient initiées..

**Mots-clés:** Soins de santé, Exploitations urbaines; Alimentation; Bovins, Petits ruminants, Poulet, Burkina Faso, Mali, Nigeria.

## 2.1. Introduction

The mainstay of the economy of most West African countries is agriculture and related activities. The contribution of the livestock sector to the agricultural gross domestic product is nearly 50% for West Africa as a whole, and 49%, 15%, and 44% for Nigeria, Burkina Faso, and Mali, respectively. While the growth rate of the regional animal production is estimated at 4% per year, the regional demand for livestock products is expected to increase by >250% until 2025 as compared to 2005 (SWAC-OECD/ECOWAS 2008). Given the current degree of urbanization of about 20% and an annual growth rate of the urban population of 5 - 7%, an important proportion of the total population of sub-Saharan West Africa will live in cities by the year 2020 (FAO 2003). Agricultural intensification will take place mainly in areas with good infrastructure and well-developed input and commodity markets, such as in and around urban centers (Graefe et al. 2008). Urban agriculture for food production and economic survival is an old and widespread practice in West Africa (Rakodi 1988; Kironde 1992) but has been neglected for a long time by policy makers. However, during the last two decades the interest in food production in and around West African cities has increased together with the fast growing urban population. The contribution of urban and peri-urban agriculture (UPA) to food security, household income, and job creation has since then been well recognized, along with the environmental benefits and problems resulting from its practices (Faye and Alary 2001; Smith and Olaloku 1999; Cissé et al. 2005; Graefe et al. 2008; Cohen and Garrett 2010; Tefera 2010; De Zeeuw et al. 2011). Livestock keeping constitutes an important part of UPA, but has received less attention than crop and vegetable cultivation. As a consequence, information on its extents, problems, and potentialities is limited. The types of animals kept include cattle for milk and meat, small ruminants for meat, and poultry for eggs and meat. Previous study in Bobo Dioulasso, Burkina Faso (Centrès 1996) showed that about 17% of the urban households were keeping small ruminants and 40% poultry. The same study reported about 20,000 owners of cattle in and around Bamako, the capital city of Mali. In Ouagadougou, capital of Burkina Faso, about 26.3% of households were involved in livestock keeping (Thys et al. 2005). From Niamey, capital of Niger, Graefe et al. (2008) reported that more than half of the households involved in UPA were rearing livestock. In Kano, Northern Nigeria, Muhammad (2008) found that keeping livestock was a considerable source of additional income for civil servants and traders. Generally, each of these case studies emphasized the growing numbers of urban households involved in livestock rearing, and identified related constraints and opportunities. However, the conclusions drawn and the recommendations made are not necessarily valid for the whole West African region. Cities in West Africa differ in size, structure, degree of urbanization, development history, environment, socioeconomic, and cultural circumstances (Akinbamijo et al. 2002; Cissé et al. 2005). It has been shown that different livestock species fulfill different functions in the households' economy and that especially poor families often keep a diversity of species (Anderson 2003). Furthermore, the legal framework within which urban agriculture in general and urban livestock husbandry in particular is practiced, varies across West African countries and cities (Cissé et al. 2005) and may significantly affect locally observed management practices, production strategies, and levels of crop-livestock integration. Cross-country comparisons are therefore needed to confirm if the findings of scattered case studies could be developed into region-wide recommendations towards sustainable urban and peri-urban livestock production systems. Based on the above past observation, this study was carried out to compare the management strategies applied by livestock producers in three West African cities.

## 2.2. Material and methods

### *2.2.1. Study locations*

The study was carried out in the three secondary West African cities of Kano, Nigeria (12º00 N, 8º31 E, 476 m a.s.l.), Bobo Dioulasso, Burkina Faso (11º16 N, 4º31 W, 460 m a.s.l.), and Sikasso, Mali (11º19 N, 5º40 W, 410 m a.s.l.).

Kano is the second largest city of Nigeria and is located in the northern part of the country, the Sudano-Sahelian zone. It covers an area of 55,000 ha (Tiffen 2001) and is currently populated by approximately 3.4 million people (UNPD 2009). The climate in Kano is characterized by two main seasons: a dry season from October to May and a rainy season from June to September. The annual average rainfall is less than 700 mm (Lynch et al. 2001).

Bobo Dioulasso is the second largest city of Burkina Faso, situated in the western part of the country at the crossroads between Ivory Coast and Mali, in the southern Sudanian savanna. It covers an area of 13,678 ha and hosted about 489,967 inhabitants in 2007 (Zida-Bangre 2009). Its climate is characterized by a rainy season (May - October), a cool dry season (November - February), and a hot dry season (March - May). The average annual rainfall varies between 900 and 1200 mm.

Sikasso is situated in the southern part of Mali, in the southern Sudanian savanna. Hosting about 200,000 inhabitants, it covers an area of 3,745 ha (Ministère de l'Habitat et de l'Urbanisme 2005). Like in Bobo Dioulasso, the climate in Sikasso is characterized by three seasons: a rainy season from May to October, a cool dry season from November to February, and a hot dry season from March to May; average annual rainfall ranges from 800 to 1100 mm.

### *2.2.2. Data collection*

A baseline survey using a semi-structured questionnaire was conducted simultaneously in the three cities between March and June 2007. A total of 335 (peri-) urban farm households (99 in Kano, 111 in Bobo Dioulasso and 125 in Sikasso) were selected and interviewed following a snowball sampling approach. The difference in sample size was due to the fact that for some households in Kano and Bobo Dioulasso the gathered information was incomplete, so that these had to be removed from the data set. The questionnaire was administrated in local languages and included questions related to the households' socio-demographic (household size, age, and sex structure, main occupation, and formal education of its members) and economic characteristics, and the characteristics of their gardening, livestock, and field cropping activities. The attendance (yes or no) of any formal school (primary, secondary or university) by the household head was used as proxy for his/her formal education. Data on livestock production were collected and included species kept, herd size, structure and dynamics, feeds and feeding strategies, manure management, health and diseases problems, access to veterinary services and uses of veterinary products, as well as livestock marketing. The households were classified into the following six farm types (Dossa et al. 2011): commercial gardening plus field crops and livestock cGCL (59% in Kano, 18% in Bobo Dioulasso, 37% in Sikasso), commercial livestock plus subsistence field cropping cLsC (14% in Kano, 41% in Bobo Dioulasso, 7% in Sikasso), commercial gardening plus semi-commercial field cropping cGscC (14% in Kano, 28% in Bobo Dioulasso, 30% in Sikasso), commercial gardening plus semi-commercial livestock cGscL (13% in Kano); commercial field cropping cC (13% in Bobo Dioulasso), and commercial gardening cG (26% in Sikasso, Table 1). Only households that were keeping livestock (cGCL, cLsC, cGscL) were considered in the current study.

Table 1: Distribution of the interviewed livestock keepers (n) across farming systems[1] and across the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso), and Sikasso (Mali).

| Production system | Total | Kano | Bobo Dioulasso | Sikasso |
|---|---|---|---|---|
| Commercial gardening plus field crops and livestock (cGCL) | 88 | 58 | 21 | 9 |
| Commercial gardening plus semi-commercial livestock (cGscL) | 13 | 13 | 0 | 0 |
| Commercial livestock plus subsistence field cropping (cLsC) | 109 | 13 | 42 | 54 |

[1]For classification and description of farming systems see Abdulkadir et al. (2011) and Dossa et al. (2011).

### *2.2.3. Data analysis*

Data analysis was done with SPSS/PASW version 18.0 (SPSS Inc. 2010). The family labor in man-day equivalents was calculated according to the definition of the International Labor Organization of working age group which excludes household members below 15 years and by applying conversion factors to male and female household members in different age groups as follows: 1.0 for males aged between 16 and 55 years, 0.75 for females between 16 and 55 years, 0.75 for males above 55 years and 0.5 for females above 55 years. Only non-household members who received a salary from the household against the performance of any kind of tasks in the livestock unit were considered as hired laborers.

Descriptive statistics were performed for all variables. Differences between groups within and across cities were explored using analysis of variance (ANOVA) and least significant difference (LSD) post-hoc comparison for all continuous variables that were normally distributed. For variables that were not normally distributed the Chi-square test was used in case of categorical variables and the Kruskal-Wallis test was applied to continuous variables, followed by the Mann-Whitney-U-test for post-hoc separation of group means. Differences between means were considered to be significant at $p<0.05$.

Logistic regression was used to assess the odds of livestock keepers' adoption of supplementary feeding of livestock (yes/no), the use of veterinary services (yes/no), curative medical treatment (yes/no), and prophylactic vaccination (yes/no) of their animals from a set of independent predictor variables. The latter included city (location), socio-economic characteristics such as formal education, geographical origin (native of city/migrant) and years of experience in urban agriculture of head of household, practice of gardening and field cropping, number of livestock species kept, and total number of Tropical Livestock Units (TLU[1]) owned. We performed a stepwise logistic regression procedure with backward elimination of predictors (Hair et al. 2006), whereby the analysis began with the full model [Eq. 1] that included all predictor variables. Variables that were not useful in predicting the dependent variables were eliminated automatically from the model in an iterative way.

$$\text{Logit}(Y) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \qquad \text{[Eq. 1]}$$

Where Y is the dependent variable, α the Y intercept, β the regression coefficient, and X the predictor.

[1] TLU, Tropical Livestock Unit: standardized animal of 250 kg live weight; 1 cattle/donkey=0.8 TLU; 1 sheep/goat =0.1 TLU, 1 chicken =0.01 TLU.

The positive or negative sign of the coefficient β indicates the direction of the relationship between a given independent variable and the dependent variable, while the odds ratio (eβ) indicates the magnitude of change in the probability of the dependent variable event in case of a one unit change in the independent variable. The fit of the final model was assessed by the model chi-square (Model $\chi^2$) and the goodness-of-fit test of Hosmer and Lemeshow (Hosmer and Lemeshow, 1989). Well–fitting models showed significance ($p \leq 0.05$) on the Model $\chi^2$ and non significance ($p>0.05$) on the goodness-of-fit test of Hosmer and Lemeshow.

## 2.3. Results

### *2.3.1. Household socio-economic characteristics*

Out of the 335 households (HH) surveyed, 210 were involved in animal husbandry. In Kano and Sikasso a higher proportion of livestock keeping HH was involved in gardening activities (Table 2) compared to Bobo Dioulasso ($\chi^2$ = 42.7, $p<0.001$), whereas in Bobo Dioulasso livestock keeping was mainly combined with field cropping. In Kano and in Sikasso, the head of a livestock-keeping HH was more frequently native of the city than in Bobo Dioulasso, while a higher proportion of HH heads had a longer-term experience in UPA activities in Kano and in Bobo Dioulasso than in Sikasso ($\chi^2$ = 42.2, $p<0.001$). The livestock-keeping families mainly belonged to the Hausa, Bobo-Dioula, and Sénoufo ethnic groups, which are the dominant ethnic groups in Kano, Bobo Dioulasso, and Sikasso, respectively. In Kano, a lower proportion of HH heads (16%) had formal education compared to their counterparts in Bobo Dioulasso and Sikasso ($\chi^2$ = 14.5, $p<0.01$).

Regardless of city, the major livestock species kept included cattle, small ruminants, donkeys, and chicken (Table 3). The proportion of HH keeping cattle was higher in Bobo Dioulasso than in Sikasso and Kano ($\chi^2$ = 45.7, $p<0.001$), whereas the proportion of HH keeping small ruminants was highest in Kano ($\chi^2$ = 33.6, $p<0.001$). Animals aged <24 months represent 38%, 27%, and 22% of the cattle herds in Kano, Bobo Dioulasso, and Sikasso, respectively, while small ruminants aged <24 months represented 39%, 35%, and 22% of the sheep and goat herds in Kano, Bobo Dioulasso, and Sikasso.

The average number of species kept per HH in Bobo Dioulasso, and Sikasso was higher ($p<0.001$) than in Kano. Farms of type cLsC kept a greater variety of species than cGCL farms. Within cLsC farms, the number of species kept was higher in Bobo Dioulasso, than in the other two cities ($p<0.05$). The average number of TLU per HH was higher ($p<0.01$) in Bobo Dioulasso than in Sikasso, and in Kano. However, there was no significant difference between the HH of the three cities in the average size of cattle, and small ruminant herds.

Table 2: Key characteristics of livestock keeping households (HH) across the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso), and Sikasso (Mali).

| Variables | Kano (n=84) | Bobo Dioulasso (n=63) | Sikasso (n=63) | $\chi^2$ | P< |
|---|---|---|---|---|---|
| Formal education of HH head [α] | | | | 14.5 | 0.001 |
| No (%) | 79 | 69 | 49 | | |
| Yes (%) | 21 | 31 | 51 | | |
| Origin of HH head [α] | | | | 42.2 | 0.001 |
| Native (%) | 92 | 43 | 74 | | |
| Immigrant (%) | 7 | 57 | 26 | | |
| Gardening α | | | | 42.7 | 0.001 |
| Yes (%) | 82 | 31 | 70 | | |
| No (%) | 18 | 69 | 30 | | |
| Field crop cultivation | | | | 1.7 | n.s. |
| Yes (%) | 92 | 97 | 92 | | |
| No (%) | 8 | 3 | 8 | | |
| Experience in urban agriculture [α] | | | | 40.3 | 0.001 |
| <5 years (%) | 4 | 11 | 31 | | |
| 6-10 years (%) | 5 | 14 | 25 | | |
| >10 years (%) | 91 | 75 | 44 | | |
| | | Mean ± SD | | | |
| Age of HH head (years) | 48.1 ± 12.81 | 51.6 ± 14.87 | 50.0 ± 15.71 | | n.s. |
| HH members formal education (n) | 4.5 ± 4.34 | 5.7 ± 3.13 | 6.6 ± 8.55 | | n.s. |
| Family labor (n) | $8.3^a$ ± 7.03 | $7.6^a$ ± 2.01 | $12.2^b$ ± 11.14 | | 0.05 |
| Hired labor (n) | $0.5^a$ ± 1.10 | 0 | $1.6^b$ ± 3.18 | | 0.05 |

n.s.: not significant

[α] Upper part of table: significant differences between cities; Chi-square test.

[a,b] Lower part of table: significant differences between means with different superscripts; Kruskal-Wallis test.

Across the three cities, 54% of the livestock keepers raised chicken, whereby the number of HH keeping backyard chicken was higher ($\chi^2$ = 13.6, p<0.01) than the number of commercial chicken keepers (broilers or layers); the latter represented 38%, 20%, and 12% of the chicken keepers in Sikasso, Bobo Dioulasso, and Kano. Between the three cities, no significant differences were determined for the average number of chicken in backyard holdings (18 ±12.5 across cities), and average number of chicken on commercial farms (654 ±1476.1 across cities), respectively.

Table 3: Species kept and herd sizes in livestock keeping households (HH) across the three West African cities of Kano, Nigeria (84 HH), Bobo Dioulasso, Burkina Faso (63 HH), and Sikasso, Mali (63 HH).

| Variable | Kano | | Bobo Dioulasso | | Sikasso | | $\chi^2$ | [1]P< |
|---|---|---|---|---|---|---|---|---|
| HH keeping: | n | % | n | % | n | % | | |
| Cattle | 24 | 29 | 52 | 82 | 41 | 65 | 45.7 | 0.001 |
| Small ruminants | 75 | 95 | 39 | 60 | 36 | 59 | 33.6 | 0.001 |
| Donkeys | 6 | 7 | 29 | 46 | 31 | 49 | 38.5 | 0.001 |
| Chicken | 17 | 20 | 44 | 69 | 50 | 79 | 60.9 | 0.001 |
| | Mean | SD | Mean | SD | Mean | SD | | [2]P< |
| Species kept (n) | 2.1[b] | 1.04 | 2.9[a] | 1.33 | 2.6[a] | 1.14 | | 0.001 |
| Cattle (TLU)[3] | 22.0 | 29.94 | 18.5 | 28.93 | 15.0 | 18.16 | | n.s. |
| Small ruminants (TLU) [3] | 1.7 | 1.67 | 1.2 | 1.10 | 1.4 | 1.31 | | n.s. |
| Donkeys (TLU) [3] | 1.7[a] | 1.04 | 0.6[c] | 0.29 | 0.8[b] | 0.45 | | 0.05 |
| Chicken (TLU) [3] | 0.2[a] | 0.26 | 0.4[ab] | 0.69 | 3.7[b] | 11.76 | | 0.05 |
| Total livestock (TLU) [3] | 8.2[a] | 19.55 | 22.0[c] | 27.59 | 13.9[bc] | 20.91 | | 0.05 |

[1] Upper part of table: significant differences between cities; Chi-square test.

[2] Lower part of table: significant differences between means with different superscripts; Kruskal-Wallis test;

n.s.: not significant.

[3] TLU: Tropical Livestock Unit, hypothetical animal of 250 kg live weight. Conversion factors used: cattle = 0.80, sheep and goats = 0.10, donkey =0.5; chicken = 0.01

### *2.3.2. Livestock feeding strategies*

In addition to year-round daily pasturing in open city spaces and on fallows and rangelands at the cities' peripheries, supplement feeds were offered to ruminant livestock, whereby feeding strategies differed with type of animal and orientation of production, such as draught animals, lactating cows, beef cattle, and small ruminants. Similarly, different feeding strategies were used for broilers and layers. Households who kept cattle and those keeping small ruminants and chicken, respectively, differed in the types of supplement feeds used.

In Kano, 29% and 13% of all cattle herds (n=24) were purely relying on grazing in the rainy and the dry season, respectively. In the dry season, 10% and 32% were purely relying on grazing in Bobo Dioulasso and Sikasso. During the rainy season, at least one type of supplement feed was given to 71%, 88%, and 88% of the cattle herds in Kano, Bobo Dioulasso, and Sikasso, while respective dry season values were 87%, 90%, and 68%.

Supplementation of cattle was mainly based on four types of feeds: fresh grasses, crop residues, cereal brans, and cotton seed cake (Figure 1). The proportion of farmers who fed crop residues to their animals was slightly higher ( $\chi^2$ = 25.3, p<0.001) in Bobo Dioulasso than in the two other cities. While significantly higher during the dry season ( $\chi^2$ = 62.7, p<0.001), the proportion of farmers who fed fresh grasses to their cattle was significantly lower ( $\chi^2$ = 3.8, p>0.05) in Kano than in Sikasso, and Bobo Dioulasso during the rainy season. Fresh grasses were mostly purchased in Kano, but were self-produced by the farmers in Bobo Dioulasso. Feeding cotton seed cake and cotton grain to cattle was more commonly observed in Bobo Dioulasso than in Kano, and Sikasso. Other types of feeds offered to cattle included bush hay, cowpea hay, and groundnut hay, vegetable residues, brewery wastes, and salt. Legume hay was offered in Bobo Dioulasso by about 20% of cattle farmers during the dry season, whereas in Sikasso it was about 40%. Brewery wastes were offered only in Bobo Dioulasso, and vitamins were only supplied to 15% and 17% of the cattle herds in Bobo Dioulasso and Sikasso, respectively.

At least one type of supplement feed was offered to 95%, 100%, and 72% of the small ruminant herds in Kano, Bobo Dioulasso and Sikasso in the dry season, while in the rainy season this proportion was >94% in all cities. Similarly to cattle, fresh grasses, crop residues, cereal brans and cottonseed cake were the main feeds for small ruminants (Figure 2). Purchased cotton seed cake was mainly distributed in Bobo Dioulasso, while brans from maize, millet, sorghum, and rice were used by a higher proportion of HH in Kano than in Bobo Dioulasso and Sikasso ($\chi^2$ =8.7, p<0.05).

During the rainy season fewer HH in Bobo Dioulasso ( $\chi^2$ = 78.4, p<0.001) than in Kano and Sikasso offered purchased fresh grasses to their sheep and goats. Other types of feed distributed to small ruminants included purchased vegetable residues and self-produced hay in Kano, cotton seed grain in Bobo Dioulasso, and leguminous leaves in Sikasso. Few HH regularly offered salt to their small ruminants.

There was a remarkable preference for self-compounded feeds among poultry farmers in all cities; the use of commercial feed mash was uncommon and was only observed among a few egg and broiler producers in Sikasso and Kano. With insignificant differences between cities and seasons, respectively, cereal grains and brans were the main ingredients of poultry feeds, whereby the proportion of HH who purchased cereal brans was higher in Bobo Dioulasso than in Kano and Sikasso ( $\chi^2$ =17.9, p<0.05).

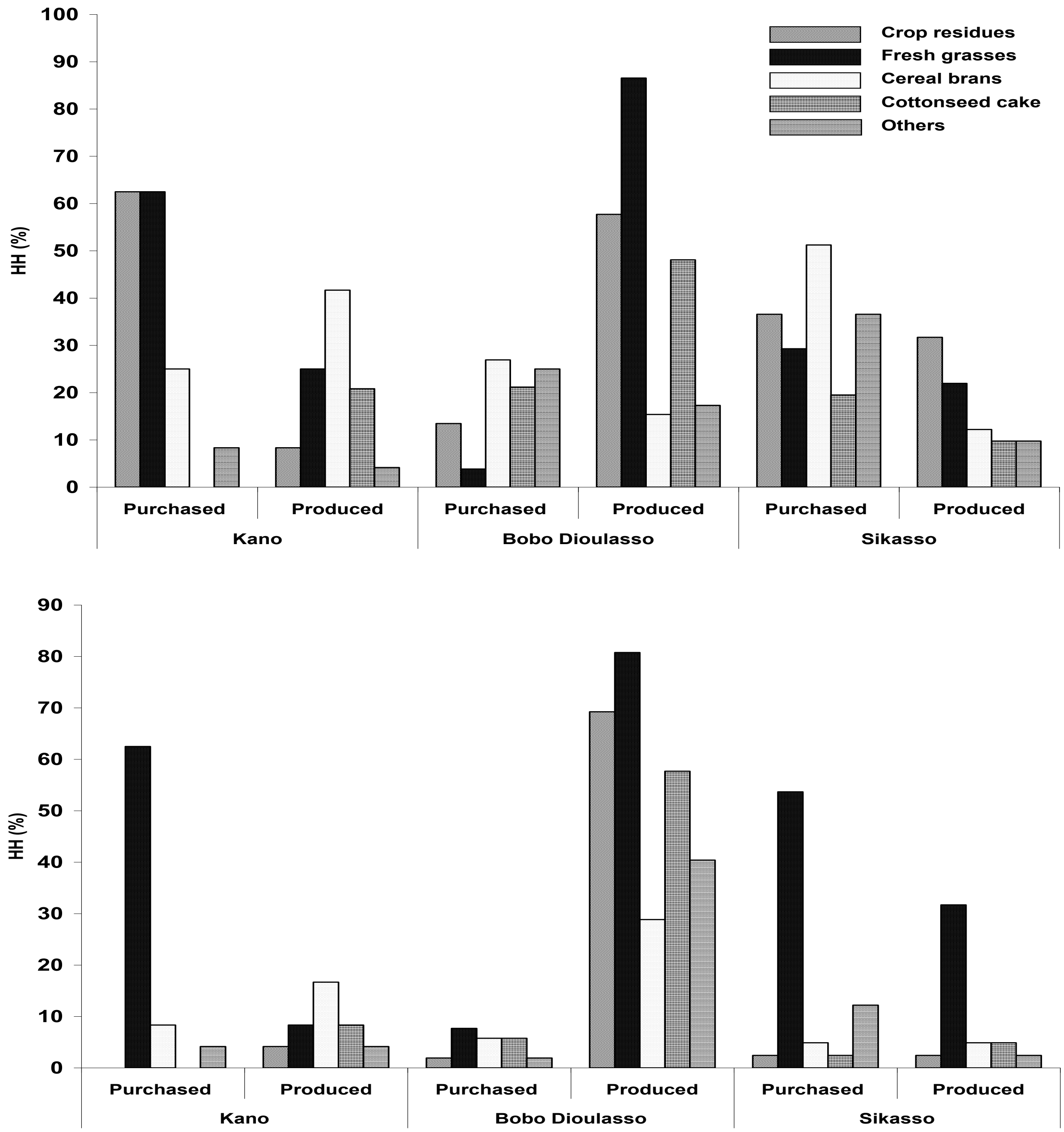


Figure 1: Number of cattle keeping households (HH) offering different types of purchased or produced feed in the dry season (above) and rainy season (below) in the West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso), and Sikasso (Mali).

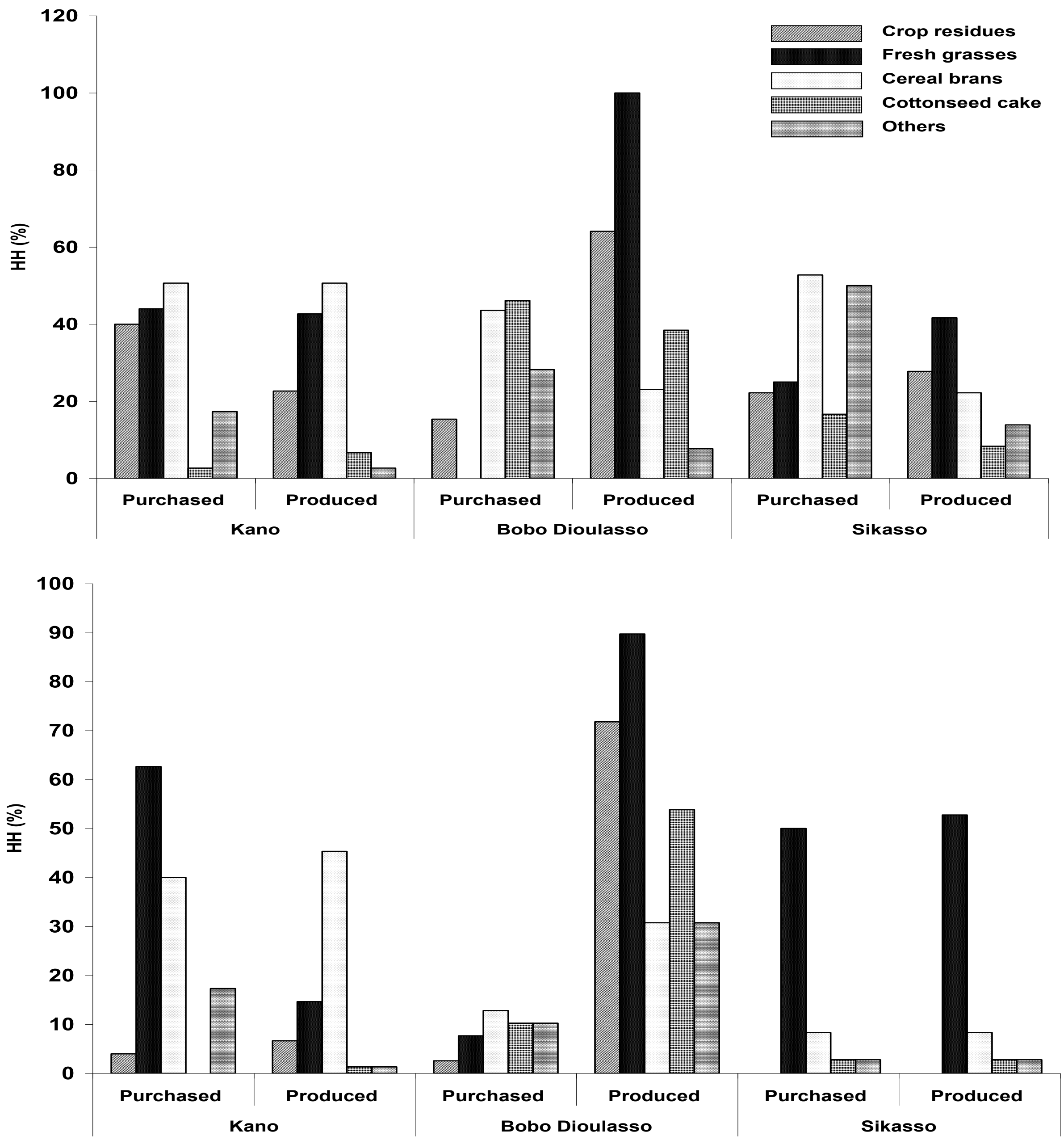


Figure 2: Number of small ruminant keeping households (HH) offering different types of purchased or self-produced feed in the dry season (above) and rainy season (below) in the West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso), and Sikasso (Mali).

At the same time a higher proportion of HH in Bobo Dioulasso than in Kano and Sikasso ($\chi^2$=17.9, $p<0.05$) produced the cereal grains offered to their poultry on their own farm. Additional types of chicken feeds included fresh grasses in Bobo Dioulasso and Sikasso, cotton seed cake in Bobo Dioulasso, commercial feed mash in Kano and home-made feed mash in Sikasso. Twenty percent of the poultry units in Sikasso could be classified as semi-commercial – here growing broilers and layers were regularly offered minerals and vitamins.

Table 4: Parameters of the logistic regression analysis for variables predicting the adoption of supplementary feeding, use of veterinary services, vaccination and curative medical treatments across 210 urban and peri-urban farm households (HH) in the West African cities of Kano, Nigeria (84 HH), Bobo Dioulasso, Burkina Faso (63 HH), and Sikasso, Mali (63 HH). For explanation of parameters see section 2.3.

| Predictors | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | β | SE β | Wald's $\chi^2$ | df | P< | Odds ratio |
| **Adoption of supplementary feeding** | | | | | | |
| Constant | -3.242 | 1.054 | 9.452 | 1 | 0.002 | n.a.[1] |
| Site | | | 6.278 | 2 | 0.043 | |
| Site 1 (= Kano) | 0.087 | 1.069 | 0.007 | 1 | 0.935 | 1.091 |
| Site 2 (= Bobo Dioulasso) | 1.787 | 0.885 | 4.709 | 1 | 0.043 | 5.970 |
| Species 1 (= cattle) | 1.527 | 0.704 | 4.709 | 1 | 0.030 | 4.603 |
| Species 2 (= small ruminant) | -1.072 | 0.704 | 2.322 | 1 | 0.128 | 0.342 |
| Species 3 (= chicken) | -0.672 | 0.681 | 0.976 | 1 | 0.323 | 0.510 |
| Overall model evaluation (Model $\chi^2$) | | | 15.858 | 5 | 0.007 | |
| Goodness-of-fit test (Homers & Lemeshow) | | | 10.222 | 7 | 0.176 | |
| **Use of veterinary services** | | | | | | |
| Constant | -4.216 | 0.746 | 31.976 | 1 | 0.000 | n.a.[1] |
| Site | | | 17.140 | 2 | 0.000 | |
| Site 1 (= Kano) | 1.164 | 0.669 | 3.021 | 1 | 0.082 | 3.201 |
| Site 2 (= Bobo Dioulasso) | 2.937 | 0.747 | 15.444 | 1 | 0.000 | 18.854 |
| Species 1 (= cattle) | 2.117 | 0.555 | 14.577 | 1 | 0.000 | 8.310 |
| Overall model evaluation (Model $\chi^2$) | | | 34.925 | 3 | 0.000 | |
| Goodness-of-fit test (Hosmer & Lemeshow) | | | 5.577 | 4 | 0.233 | |
| **Curative medical treatment** | | | | | | |
| Constant | -1.735 | 0.362 | 23.018 | 1 | 0.000 | n.a.[1] |
| Site | | | 46.039 | 2 | 0.000 | |
| Site 1 (= Kano) | -2.440 | 1.071 | 5.194 | 1 | 0.023 | 0.087 |
| Site 2 (= Bobo Dioulasso) | 2.833 | 0.502 | 31.862 | 1 | 0.000 | 17.000 |
| Overall model evaluation (Model $\chi^2$) | | | 81.710 | 2 | 0.000 | |
| Goodness-of-fit test (Hosmer & Lemeshow) | | | 0.000 | 1 | 1.000 | |
| **Prophylactic vaccinations** | | | | | | |
| Constant | 0.067 | 0.258 | 0.067 | 1 | 0.796 | n.a.[1] |
| Site | | | 35.146 | 2 | 0.000 | |
| Site 1 (= Kano) | 4.108 | 1.040 | 15.593 | 1 | 0.000 | 60.806 |
| Site 2 (= Bobo Dioulasso) | -2.121 | 0.541 | 15.384 | 1 | 0.000 | 0.120 |
| Overall model evaluation (Model $\chi^2$) | | | 104.979 | 2 | 0.000 | |
| Goodness-of-fit test (Hosmer & Lemeshow) | | | 0.000 | 1 | 1.000 | |

[1] n.a. = not applicable

The results of the logistic regression (Table 4) indicated that livestock keepers' decision to offer supplementary feed was significantly affected by the city and the animal species kept. Cattle were more likely to receive supplement feed (odds ratio = 4.6) than small ruminants and chicken, and supplementation was more likely to be practiced in Bobo Dioulasso (odds ratio = 5.9) than in the two other cities.

### *2.3.3. Health care practices*

Overall, and regardless of the livestock species kept, 85% of all livestock keeping HH stated to provide prophylactic vaccination or treatments to their animals. Across cities, the majority (68%) of HH keeping more than one animal species only provided health care to species that they considered of economic importance and wherever cattle were kept these were given priority over all other species.

With no significant differences between farm types, the large majority of livestock keepers in Sikasso (95%), Kano (78%), and Bobo Dioulasso (70%) acknowledged to have access to veterinary services. Prophylactic vaccinations of cattle and small ruminants were provided by a significantly higher ($\chi^2$ = 41.9, p<0.001) proportion of HH in Sikasso (85%) and Kano (98%) than in Bobo Dioulasso (25%). In contrast, a significantly higher ($\chi^2$ = 42.2, p<0.001) proportion of HH in Bobo Dioulasso (89%) than in Sikasso (48%) and Kano (2%) reported to provide curative treatments to their ruminant animals (Table 4). The semi-commercial poultry keepers particularly in Sikasso (18%) were observing a time table for prophylactic vaccinations against the major poultry diseases such as Newcastle disease, infectious bursal disease, and infectious bronchitis, including also treatments against internal and external parasites. Almost all livestock keepers had their animals confined to closed barns or sheds during the night in the courtyard or in the vicinity of their houses.

Similar to the practice of feed supplementation, the results of the logistic regression (Table 4) showed that the city and the type of animal species kept were the most important factors determining use of veterinary services. The likelihood of using veterinary services was much greater in Bobo Dioulasso (odds ratio = 18.8) than in Kano and Sikasso. City was the single factor that significantly predicted the use of curative medical treatments and prophylactic vaccinations. Regardless of the species kept, livestock keepers in Bobo Dioulasso was more likely (odds ratio = 17.0) to provide curative medication to their animals than those in Kano and Sikasso. In contrast, livestock keepers in Kano were more likely (odds ratio = 60.8) than those in Bobo Dioulasso and Sikasso to prevent occurrence of diseases in their herds through prophylactic vaccinations.

### *2.3.4. Manure production and uses*

Livestock faeces and urine, sometimes mixed with bedding material and feed leftovers, were commonly heaped without any cover in the courtyard close to the barn or around the house. From there the dung was removed after a long period of exposure to high temperatures during the hot dry season and considerable rainfall during the rainy season. Across the three cities, livestock dung was either burnt together with other household wastes (30% of HH) or used as fertilizer in crop fields and/or gardens (39% of HH). Burning occurred mainly in Kano and was reported by 71% of HH that kept only a few heads of small ruminants. In contrast to Kano, the large majority of HH in Bobo Dioulasso (97%) and Sikasso (95%) reported the use of manure as fertilizer. In Bobo Dioulasso manure was only used on crop fields, whereas in Sikasso it was applied both to crop fields and gardens. Only a few HH in Sikasso (5%) reported the sale of manure. There were also differences between farm types with respect to manure uses: manure was burnt in almost half of the cGCL farms, whereas in 85% of the cLsC farms it was applied to crop fields or gardens. For the latter farm type, manure use as fertilizer was more frequent in Sikasso (94%) and in Bobo Dioulasso (95%) than in Kano (15%).

### *2.3.5. Marketing of livestock*

Overall, sales were the main reason for animal offtakes, and a significantly higher proportion of animals was sold (70%) than purchased (39%) by the livestock keepers involved in this study. Purchases were more common in Sikasso than in the other two cities, whereas sales were more frequent in Kano and Bobo Dioulasso than in Sikasso. Usually both types of livestock transactions were taking place in the dry season. Cattle and sheep fetched higher prices (211 € ±84.5 and 42 € ±24.2, respectively) in Kano than in Bobo Dioulasso (153 € ±81.2 and 32 € ±30.1, respectively) and in Sikasso (160 € ±73.3 and 36 € ±14.4, respectively). In contrast, prices for one goat and one unit of poultry were not significantly different between Sikasso (33 € and 2 €, respectively), Kano (19 € and 2 €, respectively) and Bobo Dioulasso (12 € and 2 €, respectively). The TLU unit price of sheep was higher than that of the other animal species (Figure 3).

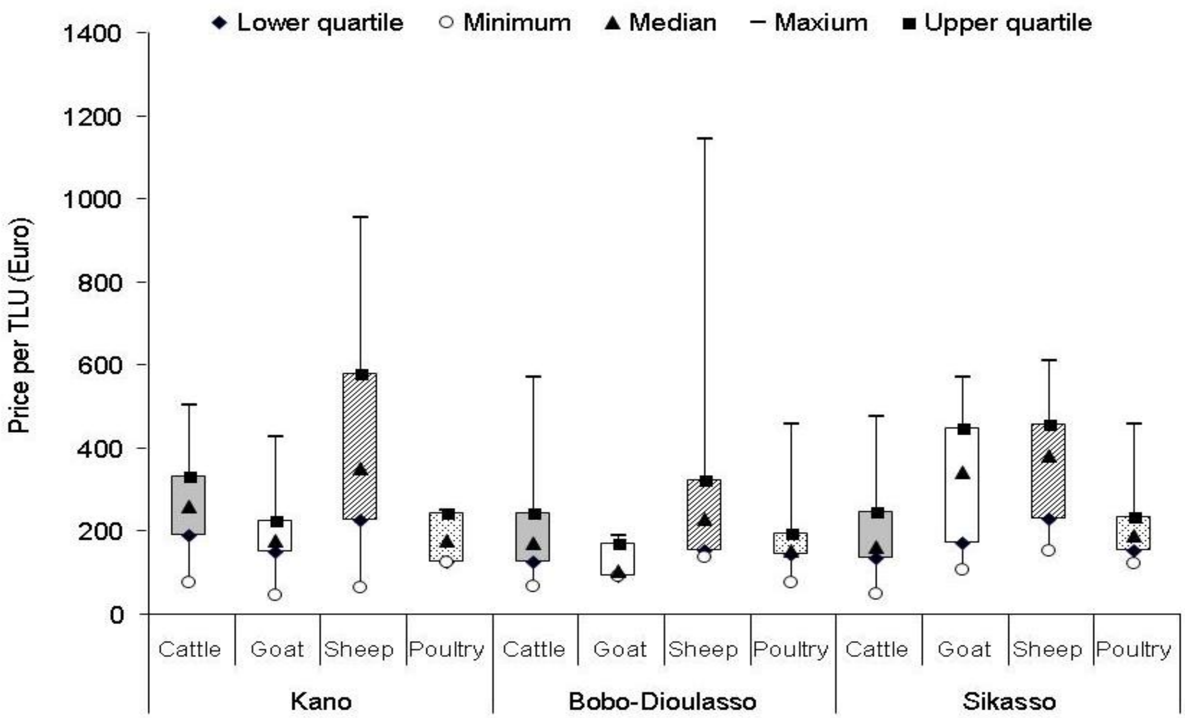


Figure 3: Average (2006-2007; n=279) sales prices of different livestock species in the West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso), and Sikasso (Mali).

## 2.4. Discussion

### *2.4.1. Households' socio-economic characteristics*

The high proportion (63%) of HH that were keeping livestock across the three cities highlighted that livestock production was a popular activity of urban dwellers in the surveyed locations. This proportion was higher than the 26.3% reported for Ouagadougou where a random sampling of urban households was used (Thys et al. 2005) but lower than the 82% observed in Niamey where a systematic sampling of urban households had been adopted (Graefe et al. 2008). The relatively young age of the large majority of heads of HH across the cities compared well to earlier findings from Kano (random sampling of households; Muhammad 2008) and Niamey (systematic sampling of households; Belli et al. 2008), and indicated that livestock keeping will continue to flourish in West African cities in the recent future. In Kano and Bobo Dioulasso, households involved in livestock husbandry had more years of experience in UPA than their counterparts in Sikasso. Muhammad (2008) indicated that this factor can be determinant for the management of (peri-) urban livestock. However, the results of our logistic regressions indicated that there was no impact of years of experience on innovation uptake. Comparable to our findings, Siegmund-Schultze and Rischkowsky (2001), who used a systematic sampling approach, and Thys et al. (2005) also observed a high rate of illiteracy among livestock keepers in Bobo Dioulasso and Ouagadougou, respectively.

Most of the surveyed HH kept more than one livestock species, which was in agreement with findings of previous studies conducted in various cities of sub-Saharan Africa (Ali et al. 2003; Lebbie 2004; Rischkowsky et al. 2006; Graefe et al. 2008). Powell et al. (2004) argued that this commonly observed species diversification was a risk reduction strategy. Higher annual rainfall and lower population density in Bobo Dioulasso and Sikasso as compared to Kano implied a higher availability of feed for animals. This was probably the reason for the lower total number of ruminants and lower proportion of households keeping cattle in Kano compared to Bobo Dioulasso and Sikasso (Harris and Yusuf 2001; Muhammad 2008). With respect to the average size of cattle herds, no significant differences were observed between cities. However, the values obtained in our study were higher than the average of 1.4 - 2.4 TLU of cattle reported by Diogo et al. (2010) for Niamey and of 12.4 heads of cattle observed by Thys et al. (2005) in Ouagadougou. Mali and Burkina Faso are the major cattle producing countries in West Africa, and most of their cattle are found in the area of Sikasso and Bobo Dioulasso, respectively (Igue and Schumacher 2003).

Similar to cattle, the average size of small ruminant herds in our study was higher than the 8.6 heads per HH reported by Thys et al. (2005) for Ouagadougou, but comparable to the values reported by Diogo et al. (2010) for Niamey. In Kano, cLsC farms possessed more TLU than their counterparts in Bobo Dioulasso and Sikasso. They were mainly involved in buying, fattening, and selling small ruminants, and some of them also practiced intensive poultry farming. As reported previously (Siegmund-Schultze and Rischkowsky 2001; Ali et al. 2003; Fall and Cissé 2005; Thys et al. 2005; Graefe et al. 2008; Hamadou et al. 2008; Muhammad 2008) small ruminants were commonly kept in and around West African cities, mainly for generating cash income, and for ceremonies and other social purposes. Urbanization has a positive effect on the demand for animal products (Rae 1998; van der Zijpp 1999), and degree of urbanization as well as population density was higher in Kano than in the two other cities.

### *2.4.2. Livestock feeding*

Regardless of the city, small ruminants were mostly zero-grazed and all HH provided their cattle with additional feeds to complement the lack of grazing area in open inner-city spaces as well as on fallows and rangelands located at the outskirts of the towns. These findings were consistent with those of previous studies (Ali et al. 2003; Wambugu and Franzel 2004; Fall and Cissé 2005; Coulibaly et al. 2007; Graefe et al. 2008; Hamadou et al. 2008; Legesse et al. 2008; Duku et al. 2010) which indicated that most (peri-) urban livestock keepers respond to declining grazing areas by shifting from the traditionally extensive towards more intensive feeding practices. Land is the fundamental resource required for farming, and access and tenure are critical (Ellis and Sumberg 1998). Since more than 90% of livestock keeping HH in all three cities were also involved in field cropping, crop residues were mostly produced on the farms. The use of cotton seed cake, particularly at the end of the dry season, was more pronounced in Bobo Dioulasso and Sikasso than in Kano. These differences were mainly due to the presence of cotton processing factories in Bobo Dioulasso and Sikasso, which are located in West Africa's cotton zone. Generally, farmers provided supplement feeds to their animals to enhance their weight gain, milk yield and ability to reproduce (Wambugu and Franzel 2004; Coulibaly et al. 2007; Sidibé-Anago et al. 2008; Legesse et al. 2008; Duku et al. 2010; Mapato et al. 2010). The difference between Bobo Dioulasso and the two other cities in supplementation practices can partly be explained by the dissemination of some of these technologies by a dairy development project in the 1990s (Hamadou and Kiendrebeogo 2004). However, in a recent study of the (peri-) urban livestock production in Niamey, Diogo et al. (2010) observed that the quantity of feed and nutrients offered to the animals by far exceeded their requirements and finally ended up in the dung heap in the form of faeces, urine, and feed refusals.

The high costs of commercial poultry feeds and negative experiences of poultry farmers with respect to the quality of these feeds (Apantaku et al. 2006) were probably the main reasons for the preference of self-compounded feeds. These findings agreed with observations made by Centrès (1996) in Bobo Dioulasso and Bamako and suggested that although commercial poultry production was increasing in the urban and peri-urban areas of West Africa (Traoré 2006; Kondombo 2007), extensive backyard production systems were still prevailing.

### *2.4.3. Health care practices*

The high proportion of HH that reported to vaccinate or medically treat their animals indicated the increased importance of health care among urban livestock keepers (Hamadou et al. 2008). However, few HH took care of all animals, reflecting a species prioritization. This prioritization was probably associated with production objectives: small ruminants were given high priority in Kano because they were imperative for religious celebrations (Ali et al. 2003). As indicated by the logistic regression, livestock keepers in Bobo Dioulasso and Sikasso were less likely than those in Kano to vaccinate their animals against infectious diseases. Consequently, one might expect a higher occurrence of infectious diseases among livestock herds in these two cities, and the higher likelihood of using a curative medical treatment in Bobo Dioulasso compared to Kano indicated that zoonotic as well as other infectious diseases were more prevalent in Bobo Dioulasso. Thys et al. (2005) reported that the first constraint of animal husbandry in Ouagadougou was animal health problems including disease occurrence and drug and treatment delivery. Delafosse et al. (1995) and Vekemans et al. (1999) identified bovine tuberculosis as the major cause of meat rejection at the slaughterhouse of Bobo Dioulasso, while Sidibé et al. (2004) reported a high prevalence of foot-and-mouth disease, brucellosis, trypanosomiasis, contagious bovine pleuropneumonia, anthrax, pasteurellosis, and dermatosis among cattle herds in the same city. A very high prevalence (94.4%) of tuberculosis was also reported for peri-urban dairy herds of Bamako (Sidibé et al. 2003). Differences in the adoption of curative medical treatments between cities might also be related to cultural differences as well as differences in types of livestock production systems, environmental factors and husbandry methods (Muchaal 2002). Mantovani (2005) emphasized the need for collaboration between public health sectors (veterinary and human) and the other services involved in urban policy planning and management to achieve satisfactory urban hygiene.

#### *2.4.4. Manure utilization*

Manure production was influenced mainly by the objectives of livestock production, herd size, and management strategies (Lekasi et al. 2001; Powell et al. 2006, 2008). Many HH in Kano that burnt livestock manure kept only a few small ruminants. Ali et al. (2003) also observed that small ruminant manure was very often swept in the backyard and burnt with household waste. The frequent use of animal dung for vegetable gardens and crop fields in Bobo Dioulasso and Sikasso contradicted earlier observations in Bamako and Bobo Dioulasso (Centrès 1996), but agreed with recent findings in Niamey (Graefe et al. 2008). This seemed to reflect an increasing awareness of urban and peri-urban farmers of the importance of manure for maintaining soil fertility.

The majority of the HH in our study locations used to heap livestock dung in the courtyard, a practice that Diogo et al. (2010) previously described for livestock units in Niamey. Unprotected dung storage potentially affects dung quality by providing favorable conditions for pathogens and parasites, and in consequence bears contamination risks for manured vegetables (Diogo et al. 2010). The exposure of the dung heap to high temperatures during the hot dry season and to rainfall during the rainy season also leads to nutrient losses through gaseous emissions, leaching, and runoff (Harris 2002; Gupta et al. 2007; Cornejo and Wilkie 2010; Predotova et al. 2010). There seems a need to raise farmers’ awareness of the importance of dung management in view of efficient nutrient recycling and minimized risks for human and environmental health.

### *2.4.5. Livestock marketing*

The higher proportion of animals sold than purchased by the livestock keepers involved in this study indicated that (peri-) urban livestock keeping was strongly market oriented. Cohen and Garrett (2010) reported that with the food crisis in 2007 - 2008 the vulnerability of poor urban dwellers increased and food purchases accounted for the bulk of their expenditures. Tefera (2010) stated that in Central Ethiopia urban agriculture plays an important role in attaining household food security. He argued that households owning a higher quantity and quality of livestock are less likely affected by food insecurity. The more frequent purchase of live animals in Sikasso than the two others cities can be explained by the presence of a few farms that were specialized in cattle and sheep fattening and regularly bought lean animals, a practice currently gaining momentum in West African cities (Ministère des Ressources Animales 2005). The higher prices fetched by cattle and sheep in Kano was probably due to the city's high degree of urbanization as well as high population density; moreover, the majority of Kano's population is Muslim and request for sheep was high with religious ceremonies such as “Eid al Kabir”. However, across the region the livestock sector still receives little public financial support in processing and packaging infrastructure and lacks policies that stimulate regional trade in animal products (SWAC-OECD/ECOWAS 2008).

### *2.4.6. Implications for the design of programs to improve management practices and animal performances*

In northern Namibia high school education was positively related to the adoption of new cattle management technologies, leading to the postulate that educated farmers can better realize the importance and benefits of adopting new technologies than uneducated ones (Musaba 2010). Our study in contrast showed that the education level of HH heads and the number of years of experience in (peri-) urban agriculture did not affect the decision of adopting improved livestock management, such as supplementation and vaccination. This suggested that the high rate of illiteracy among livestock keepers in Kano, Bobo Dioulasso, and Sikasso was not restricting the implementation of improved feeding and health care practices, and will therefore not negatively affect the adoption of new technologies as suspected by Marenya and Barrett (2007) and Musaba (2010). Similar to our results, Onemolease and Alakpa (2009) found no relationship between level of education and adoption of improved livestock management practices such as animal vaccination, nutrition, deworming, isolation of sick animals, and improved breeding practices in the Niger delta region of Nigeria.

However, our results suggest that the adoption of improved technologies depends on the livestock species, and higher adoption rates can be expected among cattle farmers. Previous studies (Sidibé et al. 2004; Fall and Cissé 2005; Wymann 2005; Coulibaly et al. 2007; SWAC-OECD/ECOWAS 2008) reported the use of artificial insemination and crossbreeding by (peri-)urban dairy farmers to improve milk yield and body weight gain in cattle. In contrast to rural areas where cattle are still kept to accumulate wealth and prestige (Belli et al. 2008), cattle keeping in cities is mainly market-oriented (Centrès 1996; Hamadou and Kiendrebeogo 2004; Bonfoh et al. 2005; Graefe et al. 2008; Hamadou et al. 2008) with meat and milk sale being the major objectives of farmers (Hamadou et al. 2008). Because grazing areas are shrinking due to urbanization, cattle farmers increasingly turn to semi-intensive production systems such as zero-grazing and supplementary feeding with concentrate feeds, and better veterinary care. Small ruminants and local chicken have lower feed requirements and fulfill more non-commercial functions (Boly et al. 2001; Ali et al. 2003; Thys et al. 2005; Rischkowsky et al. 2006; Chukwuka et al. 2010) than cattle; they will continue therefore to be raised with less capital investment and technology use.

### 2.5. Conclusions

Urban livestock keeping has a strong market orientation as evidenced by the relative higher number of animals sold than purchased by the livestock keepers in this study. The rapidly growing market demand will likely promote the intensification and modernization of the commercially valuable production branches (cattle, poultry). However, efficient resource use will determine the economic profitability, environmental safety, and risks to human health of these production systems. This will require wide dissemination of research results through government and private-public partnership and adoption by livestock keepers of improved feeding, health care and dung management. Our results suggest that this adoption may not be hindered by the illiteracy of livestock managers. Further market analysis is also necessary for the improvement of the marketing and pricing systems.

### Acknowledgements

We are grateful to the urban farmers in Sikasso, Bobo Dioulasso and Kano for their time and willingness to participate in our survey. We thank our colleagues S. Sangaré and N. Abdu for continued support with field work. The administrative support by Dr. A. Berthé from IER at Bamako/Mali, Dr. E. Compaoré from INERA at Bobo Dioulasso /Burkina Faso, and Prof. J.O. Agbenin from Ahmadu Bello University, Zaria/Nigeria, are greatly appreciated. The authors are grateful to the Volkswagen Stiftung, Hannover, Germany, for supporting this research financially under the “UrbanFood” project within the collaborative program ‘Resources, their dynamics, and sustainability–capacity–development in comparative and integrated approaches’ (No. I/82 189).

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## Chapter 3

# Energy and nutrient supply to unsupplemented and supplemented herds of (peri-) urban lactating cowsand sheep in Sikasso

**Abstract**

Urban livestock husbandry is an important activity for many urban dwellers in Africa who try to serve the increasing urban demand for milk, meat, and eggs. During 18 months, data on demographic events, types, and amounts of supplement feeds given, milk and manure produced, and live weight changes were collected in 9 dairy herds and 13 sheep herds in Sikasso, second largest city in Mali. Herds were either grazing only (Go; 4 cattle, 5 sheep herds) or grazing and supplemented at the homestead (Gsf; 5 cattle, 8 sheep herds). Regularly collected samples of supplement feeds and manure were analyzed for their nutrient and energy contents.

Herd growth was significantly higher ($P$<0.05) in Gsf than in Go cattle, while no differences were observed between the two sheep groups. Live weight gains of cattle and sheep were significantly higher ($P$<0.05) in the rainy than in the dry season, but in both seasons Go cattle performed better than Gsf cattle ($P$<0.05), due to periodic short-distance transhumance of the former. Since on a yearly basis the energy supply to Gsf cattle and sheep would have enabled higher productivities than measured, the unrealized production points to a non-negligible impact of parasitic infestations. From our results we conclude that the ruminant production systems in Sikasso are still of very rural rather than urban character. A shift towards more efficient production systems would require stronger market incentives from the urban population and supportive extension and veterinary services of public or private partners.

**Key words**: efficiency, grazing, live weight gain, milk yield, mortality.

**L'approvisionnement en énergie et en nutriments des troupeaux de vaches laitières et de moutons supplémentés et non supplémentés en agriculture urbaine et périurbaine à Sikasso**

**Résumé**

L'élevage urbain et périurbain est une importante activité pour de nombreux citadins en Afrique qui tentent de répondre à la demande croissante du milieu urbain en lait, en viande et en œufs. Durant 18 mois, les données sur les événements démographiques, types et quantités de complément d'aliment donnés, le lait et le fumier produits et les changements de poids vif ont été collectés dans neuf troupeaux de vaches laitières et 13 troupeaux de moutons à Sikasso, deuxième ville du Mali. Les troupeaux étaient alimentés soit par pâturages seulement (Go, 4 troupeaux bovins, 5 troupeaux de moutons) soit par pâturages plus complément à la ferme (Gsf; 5 troupeaux bovins, 8 troupeaux de moutons). Des échantillons de complément d'aliments et de fumier prélevés régulièrement ont été analysés pour leur contenu en nutriments et énergies.

La croissance des troupeaux bovins a été significativement plus élevée (P<0,05) dans Gsf que dans Go, alors qu'aucune différence significative n'a été observée entre les deux systèmes de gestion des troupeaux de moutons. Les gains moyens poids vif des bovins et des ovins ont été significativement plus élevée (P<0,05) en saison des pluies qu'en saison sèche, mais pour les deux saisons, les troupeaux Go ont donné de meilleurs résultats que ceux de Gsf (P<0,05) cela était du aux transhumances périodiques de courte distance effectuées par les troupeaux du premier group. Dès lors que, sur une base annuelle, l'approvisionnement énergétique pour les bovins et les ovins de Gsf aurait permis des productivités plus élevées que mesurées, les productions non réalisées pointent un impact non négligeable des infestations parasitaires. De nos résultats, il ressort que les systèmes de production des ruminants à Sikasso ont toujours un caractère très rurale plutôt qu'urbain et pour une évolution vers des systèmes de production plus efficaces, il faudrait des incitations plus forte du marché de la part des populations urbaines et le soutien des services vétérinaires d'extension et des partenaires publics ou privés.

**Mots clés:** Efficacité, pâturage, gain de poids vif, rendement en lait, mortalité.

### 3.1. Introduction

Although significant, 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). Statistics indicate that the imbalance between supply and demand will persist and even worsen in the 2020s (SWAC-OECD/ECOWAS 2008). This is illustrated by the region's continued strong dependency on extra-African imports for products such as beef, milk, and poultry meat. With estimated numbers of 8.3 million cattle, 9.5 million sheep, 10.2 million goats, and 34.0 million poultry in 2008 (FAO 2011), 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). Like in most sub-Saharan countries of Africa, 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. Urban and peri-urban livestock husbandry has become a very important activity for a considerable proportion of African urban dwellers (Hamadou et al. 2004; Thys et al. 2005) to whom this activity provides food, income, employment, and social security (Thys et al. 2005; PAM et al. 2006; Cohen and Garrett 2010). In Bamako, capital of Mali, for example, three types of (peri-) urban milk production systems were identified: a traditional system with local breeds and fairly low milk extraction (1 - 2 liters per cow and day), a semi-modern system established with local and crossbreed cattle grazing natural pasture and yielding 2 - 5 liters per cow and day, and a modern system with crossbreed cattle, a high input of feed supplements and a saleable yield of 5 - 12 liters per cow and day (Debrah et al. 1995; Bonfoh et al. 2005). However, very often feed resources available in the vicinity of cities cannot satisfy the high feed demand of (peri-)urban livestock production systems and must be complemented by forages and crop residues from the rural hinterland (Coulibaly et al. 2007; Graefe et al. 2008) and by agro-industrial by-products (Hamadou et al. 2008). Although scarcity of feed resources, especially in the dry season, was identified by several authors a major factor limiting the productivity of (peri-) urban livestock systems (Thys et al. 2005; Diogo et al. 2010; Teklu et al. 2011), information on the use efficiency of inputs into such systems is still sparse. This information is, however, needed if strategies are to be developed that can improve the productivity of (peri-) urban livestock holdings. This study therefore aimed at the determination of the supply and conversion of feed, nutrients and energy to (peri-) urban sheep, and cattle herds by quantifying inflows, conversion into products, and outflows of these components in a typical West African city.

## 3.2. Materials and methods

### 3.2.1. Location and climate

The city of Sikasso, second largest in Mali, is situated in the southern part of the country, the southern Sudanian savanna. It 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 two major seasons: a rainy season from May to October and a dry season from November to April. Average annual rainfall ranges from 800 to 1100 mm. Sikasso is of high agricultural and pastoral potential because of its landscape that embraces many lowlands; these hold significant residual moisture during the first months of the dry season (Coulibaly et al. 2007). Feed resources for ruminant livestock consist of the vegetation of natural pastures and crop residues from rotational or associative cropping systems based on cereals (maize, rice, millet, and sorghum), legumes (groundnut and cowpea) as well as cotton.

### 3.2.2. Livestock herds and management

At total of 9 dairy herds and 13 sheep units were included in this study; they were located inside a 15 km radius around the centre of the town and are further referred to (peri-) urban units (Figure 1). The herds were selected according to their owners' livestock management practices and production objectives out of 125 livestock enterprises characterized in a previous study (Dossa et al. 2011). All cattle were of the local N'Dama and Méré (Zebu x N'Dama) breeds that are not as productive as exotic breeds but are characterised by their heat tolerance, tolerance against trypanosomiasis, and ability to survive on poor quality feeds (Bosso et al. 2009). All cattle and sheep herds were grazed on natural pastures at the city fringes and open spaces within the built-up quarters, whereby daily grazing time averaged 10 hours in the dry season and less than 8 hours in the rainy season. Overnight, all herds were confined near the house in kraals made from tree branches. For the purpose of this study, cattle herds were classified into grazing only (Go, n=4), and mainly grazing plus some stall feeding, primarily based on maize bran and cottonseed expeller (Gsf, n=5). From April to June as well as from August to October, a short distance transhumance of less than 30 km around the city was practiced by all Go herds. During lactation, milking cows were kept separate from their calves after hand milking; the latter occurred only once a day, early in the morning. Prior to milking, calves suckled their mothers for a few minutes to stimulate milk ejection. Overnight calves were staying in the kraal with their mothers, but were separated from them about 2 to 3 hours prior to morning milking. Feed supplementation was generally limited to lactating cows in the dry season, but sometimes included sick animals. Six out of the nine cattle-keeping households were also keeping sheep herds included in this study.

The Djallonke sheep, which is of relatively small body size but quite productive under the conditions of the Sudanian savanna, was the only breed kept in the studied sheep herds. Eight herds were mainly grazing but received feed supplements at the homestead (Gsf), while the other five herds were only grazing (Go). Sheep were confined in closed pens near the homestead overnight. Lactating ewes were not milked and lambs younger than 3 months were grazed close to the homestead after the morning departure of their mothers to pasture. Feed supplementation was based on cereal brans and was available to all animals in the Gsf herds.

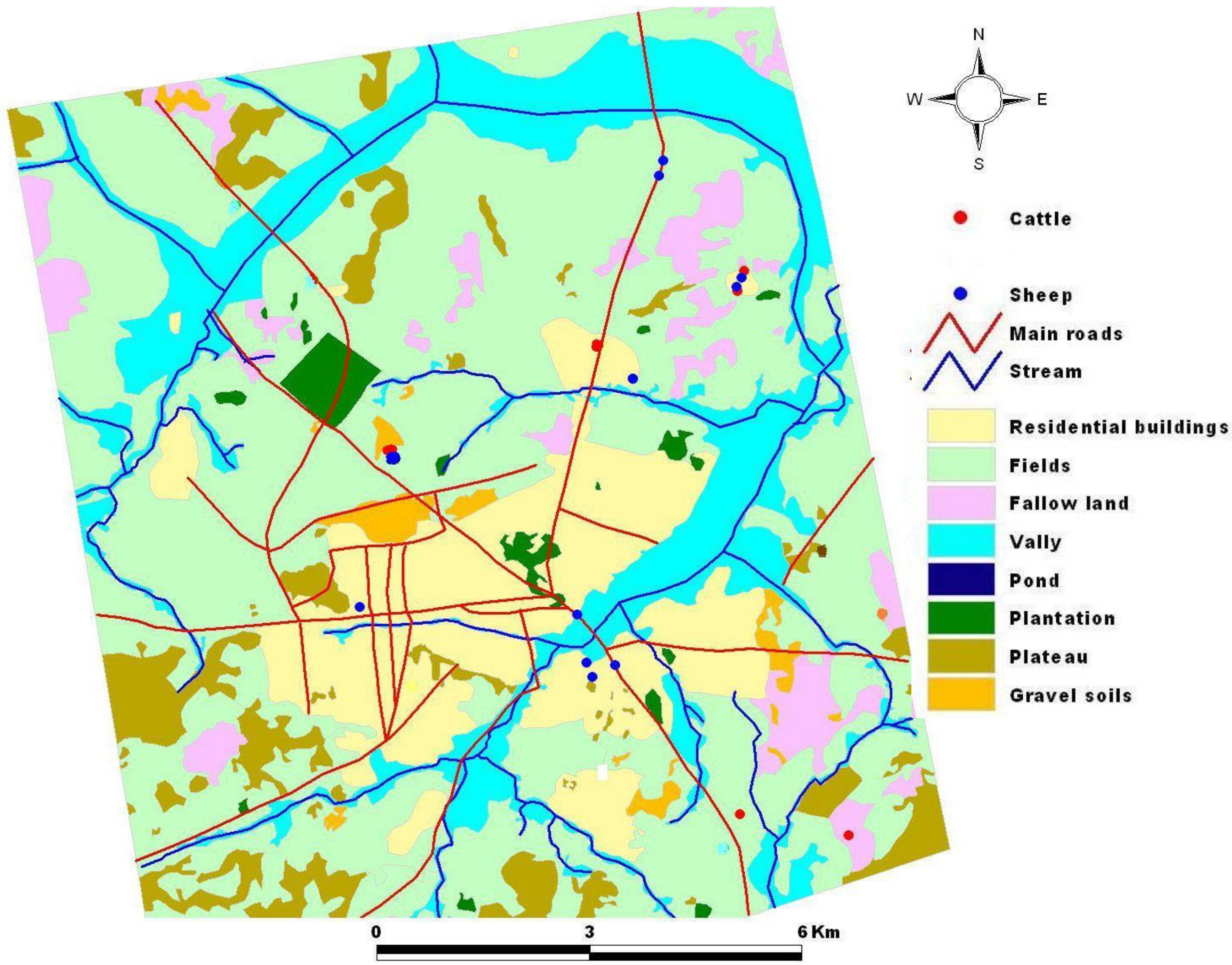


Figure1: Map of Sikasso with indication of 9 dairy farms (red dots) and 13 sheep units (blue dots) investigated in the present study

### *3.2.3. Data collection*

Monitoring of feed and nutrient inflows and manure outflows in the 9 dairy herds and 13 sheep units covered a period of 18 months (July 2007 to December 2009). At the initial visit to each farm, all animals present in the cattle and sheep herd, respectively, were individually ear-tagged and physically described for future identification. Details of the history of each individual were collected from the owners of the herds or from the herdsmen. Sheep and young calves were weighed with a suspended weighing scale (0 to 100 kg, accuracy 0.5 kg) while the life weight (LW) of cattle above 100 kg was estimated from body measurements using the formula [Eq. 1] developed by Dodo et al. (2001) the for the zebu Azawak breed:

$$Y = 0.0281\ x^2 - 3.294\ x + 125.217 \qquad \text{[Eq. 1]}$$

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

At each subsequent visit spaced 6 to 8 weeks, a semi-structured questionnaire was used to collect information on all demographic events (animal exits for any reason, and entries through purchases, births, gifts and loans) that had occurred in the herds since the previous visit. Types and amounts of feeds offered at the homestead, of feed additives (i.e. minerals, vitamins) and of veterinary products used as well as the production, sale and/or auto-consumption of milk, meat and manure were recorded. The interviews were accompanied by the quantification of the daily amount of feedstuffs offered at the homestead using a portable electronic weighing scale of 50 kg capacity and 0.02 kg accuracy, and of the LW of all animals present following the procedure described above. In order to minimize possible variations in LW due to grazing and watering, animals were weighed in the early morning. Quantities of manure produced by each herd were determined every 8 weeks for sheep herds and every 6 months (onset and end of rainy and dry season, respectively) for dairy herds. Samples (250 g dry matter, DM) of all feeds offered and of manure were taken bi-monthly and air-dried before storage; samples of a given type of feedstuff and manure, respectively, were pooled per herd (cattle or sheep), household, and season.

### *3.2.4. Chemical analyses*

Samples of feed offered (maize bran, cottonseed cake, and rice straw) and of manure were analyzed for dry matter (DM) concentration by drying 5 g of air-dry sample material at 105ºC for 5 h. Organic matter (OM) concentration was then derived by ashing the sample at 550ºC for 4 h (Naumann et al. 2004). A CN analyzer (vario MAX) 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 with rumen liquor *in vitro* for 24 h (Menke et al. 1979) using the formula of Close and Menke (1986) and Menke and Steingass (1987). Sample analyses were conducted by the laboratories of the ICRISAT Sahelian Center at Niamey, Niger, and of the Faculty of Organic Agriculture at Kassel University, respectively.

### *3.2.5. Calculation of nutrient and energy use*

To assess resource use efficiencies in the livestock units, the ME provided by the offered feeds 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 LWG) 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 for maintenance (0.45 MJ/$kg^{0.75}$ LW), adult live weight gain (34 MJ/kg LWG), and milk production (5.3 MJ/kg milk with 4% fat), were taken from Menke and Huss (1987).

Lamb: ME req. (MJ/d) = $0.43 \times LW^{0.75} + ((14.6 + 0.131 \times LW + 23.9 \times LWG) \times LWG)$ [Eq. 2]

Calf: ME req. (MJ/d) = $0.53 \times LW^{0.75} + (15 \times LWG)$ [Eq. 3]

where LW is live weight in kg and LWG is daily live weight changes in kg.

Feed dry matter intake during grazing was estimated from daily time on pasture (yearly average, cattle: 6.6 h for Go, 5.7 h for Gsf) and an intake rate of 8 g DM/h per $kg^{0.75}$ LW for cattle (Ayantunde et al. 2002), while a daily intake of 55 g DM per $kg^{0.75}$ LW was assumed for sheep (Fernández-Rivera et al. 2005). Average energy contents of forage DM ingested on pasture throughout the year was assumed to 8.0 MJ ME $kg^{-1}$ (Schlecht et al. 1999). Collection efficiencies were defined as the ratio of the collected quantity of DM and nutrients, respectively, over the quantity of feces and nutrients recovered in the dung heap (Powell et al. 2008).

### *3.2.6. Statistical analyses*

Data were analysed with SPSS/PASW version 18.0 (SPSS Inc. 2010). Descriptive statistics were performed for all variables. Differences between the two systems (Go, Gsf) and between the two seasons (rainy, dry) were explored using the independent samples t-test for all continuous variables that were normally distributed. 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. Significance was determined at $P<0.05$.

## 3.3. Results

### *3.3.1. Herd structure and dynamics*

The average total number of animals across the nine dairy farms during 18 months was 286 cattle; average initial herd sizes were 36 animals (28.6 TLU[2]) and 29 animals (23.2 TLU) for Go and Gsf herds, respectively (Table 1). Although mature cows (aged >40 months) represented 40% and 65% of the initial herd in Go and Gsf groups, 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 the Gsf than for the Go group. Regardless of group, births and purchases were the only sources of cattle inflow, whereby inflows 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.

The structure of Go and Gsf sheep herds at the beginning and at the end of the study was similar, as well as the numbers of incoming and outgoing animals during the study period were similar (Table 1). However at the end of the study, there was a slight increase in the proportion of lambs ≤6 months, while the proportion of adults >21 months was decreasing in both groups. Except for a few cases of gifting and exchange of male animals in Gsf herds, the main incoming routes were births (38%) and purchases (58%). The average age of purchased sheep was 10 and 7 months in Go and Gsf herds, respectively, but no significant differences existed between the two groups in the weight of these animals ($P$>0.05). 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 and 18% were sold, 8% were stolen and 3% were gifted to relatives or friends. The average weight of outgoing sheep was higher in the Go than in the Gsf herds ($P$<0.01), whereas there was no significant difference in their average age at the moment they left the herds ($P$>0.05).

[2] 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 of cattle and sheep herds in (peri-) urban livestock holdings at Sikasso, Mali, from 07/2008 to 12/2009.

| Parameter | Feeding management | Cattle Herds (n) | Cattle Mean[&] | Cattle SD | Cattle Females [α] (%) | Cattle Calves [α] ≤6 mo (%) | Cattle Adults [α] >40 mo (%) | Sheep Herds (n) | Sheep Mean[&] | Sheep SD | Sheep Females [α] (%) | Sheep Lambs [α] ≤6 mo (%) | Sheep Adults [α] >21mo (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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*≤ | | | | *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*≤ | | | | *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*≤ | | | | *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*≤ | | | | *n.s.* | *n.s.* | *n.s.* | | | | *n.s.* | *n.s.* | *n.s.* |

[&] animal number

[α] significant differences between cities; Chi-square test.
mo: months.

### *3.3.2. 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; Go) and 15 g (±158.5; Gsf), whereby daily LW 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). The number of lactating cows per herd and year averaged 8.5 (±3.69; Go) and 12.6 (±4.33; Gsf). Averaged for our study period of 540 days, the daily amount of milk extracted from Go and Gsf cows was around 0.9 kg (Table 3), whereby in Gsf herds amounts extracted per day were higher in the rainy season than in the dry season (Table 4). However, milk extraction across the two groups was normally limited to a lactation period 354 days (±31) with an average daily milk yield of 0.9 kg.

No significant differences were found between the two groups in the age at first calving and the calving interval, respectively. However, the prolificacy rate was lower and the overall mortality rate was higher in the Go than in the Gsf herds (Table 5).

Table 2: Effect of the season on daily weight gain (g/animal) of lactating cows in two (peri-) urban dairy production systems at Sikasso, Mali, during 07/2008 - 12/2009.

| | Daily weight gain | | | | | |
|---|---|---|---|---|---|---|
| | Grazing only | | | Grazing + stall feeding | | |
| Season | n | Mean | SD | n | Mean | SD |
| 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 |

[a, b] significant differences (*P<0.05*) between seasons, t-test.

At one and two months of age, respectively, the average LW of a Go calf was slightly higher than that of a Gsf calf (Figure 2). During the entire study period, only one calf from the Gsf group died. At 6 months of age, the animals' LW averaged 70 kg (±19.3; Go) and 60 kg (±13.6; Gsf), pointing to an average daily LWG of 217 g (±202.9) and 185 g (±143.5), respectively. Although 3 months old (*P*<0.05) and 5 months old (*P*<0.05) calves of the Go group had a higher LW than calves of the Gsf group, the average daily LWG of calves during the six first months of age was neither affected by season nor sex of calves (*P*>0.05).

Table 3: Daily intake (g/animal) of feed dry matter and nutrients, live weight (LW) and daily live weight changes (LWC), daily milk extraction (above) as well as daily energy intake and requirement (MJ ME/animal; below) of two differently managed groups of (peri-)urban dairy cows and sheep in Sikasso, Mali, from 07/2008 to 12/2009.

| Parameter (daily values, 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/d) | | | | | | | | |
| Dry matter | 1506 | 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 | 1326 | 557.6 | n.a. | | 255 | 130.5 | n.a. | |
| Digestible organic matter | 1037 | 474.3 | n.a. | | 200 | 92.9 | n.a. | |
| Crude protein | 389 | 419.0 | n.a. | | 32 | 16.4 | n.a. | |
| Intake of dry matter at pasture* | 4460 | | 5472 | | 719 | | 750 | |
| Total intake of dry matter | 5966 | | 5472 | | 1012 | | 750 | |
| Performance per animal | | | | | | | | |
| LW adults (kg) | 228.0 | 20.05 | 246.0 | 10.76 | 30.3 | 8.20 | 31.4 | 2.37 |
| LWG adults (g/d) | 15.4 | 158.49 | 63.4 | 126.14 | 6.8 | 51.33 | 14.5 | 35.97 |
| Milk extraction (g/d) | 914 | 255.7 | 849 | 306.4 | n.a. | | n.a. | |
| LW newborn (kg) | 29.1 | 12.73 | 31.4 | 9.24 | 4.5 | 2.11 | 3.3 | 1.40 |
| LWG suckling offspring (g/d) during: :1-6 mo (calf) and 1-3 mo (lamb)** | 62.6 | | 72.6 | | 12.0 | | 16.8 | 52.48 |
| Energy intake per animal (MJ ME/d) | | | | | | | | |
| ME from supplement feed | 12.9 | | 0.0 | | 2.4 | | 0.0 | |
| ME from grazing* | 35.7 | | 43.8 | | 5.8 | | 6.0 | |
| Total ME intake | 48.6 | | 43.8 | | 8.2 | | 6.0 | |
| Energy requirements per animal (MJ ME/d) | | | | | | | | |
| Maintenance, adult | 26.40 | | 27.95 | | 5.6 | | 5.86 | |
| Extracted milk | 4.84 | | 4.50 | | 0 | | 0 | |
| LW gain adult | 0.52 | | 2.16 | | 0.20 | | 0.44 | |
| LW gain suckling offspring | 7.56 | | 8.05 | | 1.51 | | 1.31 | |
| Total energy requirements | 39.33 | | 42.66 | | 7.34 | | 7.61. | |
| ME balance (intake minus requirement; MJ/animal/d) | 9.3 | | 1.1 | | 0.9 | | -1.6 | |

n.a. not applicable;
* estimated as outlined in section 2.5.
**calculated as a weighted average for 12 months from LWG of suckling offspring, and average number of offspring per female and year.

The average LW of a one month old lambs was 3.3 kg (±1.40) and 4.5 kg (±2.11) for the Go and Gsf group, respectively. However, lambs of the two groups aged >1 month did not differ significantly in their growth rates (Figure 3). Average daily LWG during the first six months of age were 62.5 g (Go) and 48.5 g (Gsf), resulting in an average LW of 20.3 kg (±5.11; Go) and 15.6 kg (±6.79; Gsf) for a six months old sheep. Without any difference between the two groups, the daily weight gain increased during the first three months of life and decreased thereafter. Although no significant differences were observed between the growth of Go and Gsf lambs in each season (Table 6), the average LWG of both Gsf and Go lambs was significantly higher in the dry season than in rainy season ($P$<0.05).

Table 4: Daily milk yield of lactating cows in two (peri-) urban dairy production systems at Sikasso, Mali, from 07/2008 to 12/2009.

| Season | Daily milk yield (g/animal) | | | | | |
|---|---|---|---|---|---|---|
| | Grazing only | | | Grazing + stall feeding | | |
| | n | Mean | SD | n | Mean | SD |
| Dry season | 38 | 777 | 286.9 | 63 | 791 $^{b}$ | 211.9 |
| Rainy season | 41 | 903 | 328.2 | 70 | 1036 $^{a}$ | 245.4 |

$^{a, b}$ significant differences ($P<0.05$) between seasons, t-test.
no significant differences ($P>0.05$) between systems.

As far as the sheep are concerned, 98 lambs were born in the 13 herds during the study period, 75% thereof in the 8 Gsf and 25% in the 5 Go herds, leading to only insignificant differences between the average number of newborn lambs in the two groups ($P$>0.05). There was also no significant difference in the average age at first lambing and the lambing interval between the two groups (Table 5). Prolificacy rates were 1.22 and 1.13 for the Go and Gsf group, respectively. The overall mortality rate was higher in Go than in Gsf herds; most incidences of deaths occurred during the rainy season.

Table 5: Reproductive parameters and overall mortality rates in two types of (peri-) urban herds of dairy cows and sheep in Sikasso, Mali, from 07/2008 to 12/2009.

| Species and management | Adults (n) | Newborn (n) | Yearly calving / lambing rate* | Prolifi-cacy** | 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 | 0.25 | 1.00 | 3.0 | 29 | 51.0 | 9.89 | 10 | 20.7 | 2.79 |
| Sheep | | | | | | | | | | | |
| Grazing only | 51 | 25$ | 0.33 | 1.22 | 35.5 | 4 | 12.2 | 2.75 | 9 | 12.1 | 2.26 |
| Grazing + stall feeding | 96 | 73# | 0.51 | 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 / 100 birth (Amegee 1983)
§ 19 calves born alive plus 1 born dead
$ 25 lambs born alive plus 9 born dead
# 73 lambs born alive plus 17 born dead

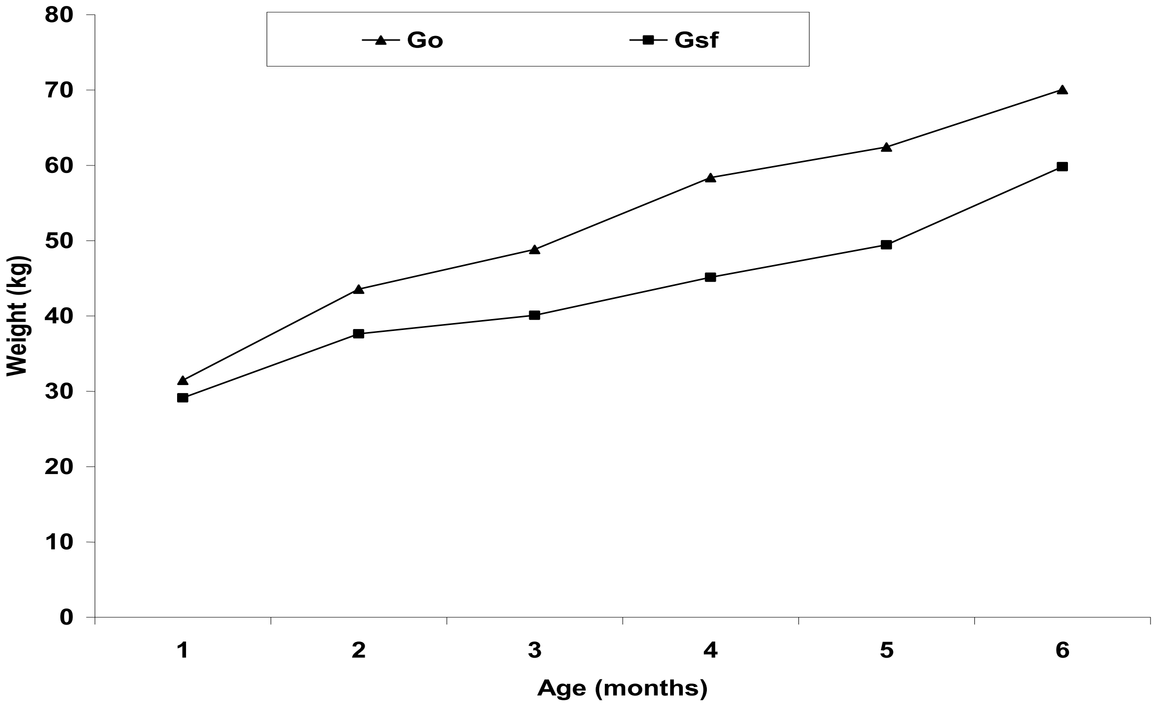


Figure 2: Live weight development of calves aged between 1 and 6 months in two differently managed groups of (peri-) urban dairy herds in Sikasso, Mali.

Go: grazing only; Gsf: grazing plus stall feeding.

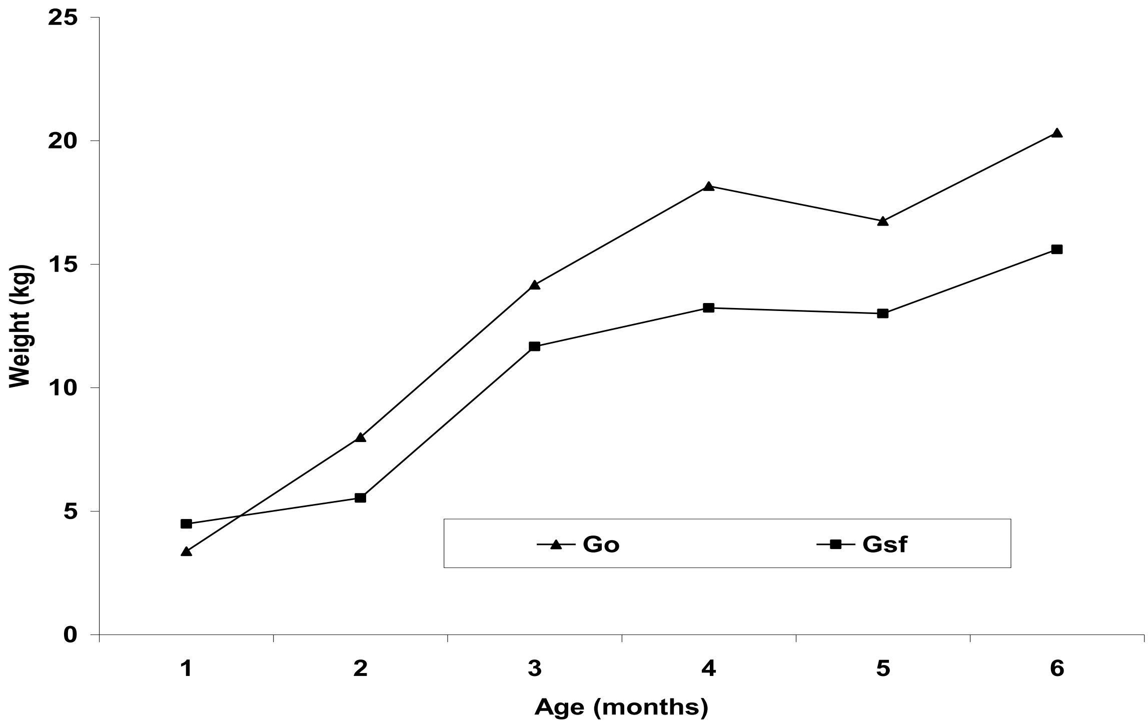


Figure 3: Live weight development of lambs aged between 1 and 6 months in two differently managed groups of peri-urban sheep herds in Sikasso, Mali.

Go: grazing only; Gsf: grazing plus stall feeding.

Table 6: Live weight (LW; kg) and live weight gain (LWG; g/d) of lambs and adult sheep in two types of (peri-) urban livestock holdings at Sikasso, Mali, from 07/2008 to 12/2009.

| | Grazing only | | | Grazing + stall feeding | | |
|---|---|---|---|---|---|---|
| Animal category and season | n | Mean | SD | n | Mean | SD |
| Lambs (1-6 months) | | | | | | |
| LWG, rainy season | 6 | 27.7 [a] | 34.88 | 13 | 28.7 [a] | 28.61 |
| LWG, dry season | 9 | 72.5 [b] | 37.28 | 20 | 67.4 [b] | 34.52 |
| Pre-weaning (1-6 months) | 8 | 62.5 | 32.77 | 57 | 48.5 | 27.77 |
| Post weaning (7-8 months) | 6 | 26.9 | 25.01 | 43 | 15.6 | 13.57 |
| Adult sheep (>21 months) | | | | | | |
| LW in 07/2008 (kg) | 35 | 33.7 | 5.84 | 71 | 31.3 | 6.72 |
| LW in 12/2009 (kg) | 34 | 31.4 | 2.37 | 71 | 30.3 | 8.20 |
| LWG, rainy season | 15 | -12.0 [a] | 42.57 | 40 | - 25.3 [a] | 41.65 |
| LWG, dry season | 24 | 27.8 [b] | 26.66 | 90 | 24.2 [b] | 48.71 |

[a, b] significant differences (*P<0.05*) between seasons.
no significant differences (*P>0.05*) between systems.

### *3.3.3. Feed ingestion, manure output and resource use efficiencies*

Supplements feeds for lactating cows in Gsf herds during the dry season consisted mainly of maize bran and cotton seed expeller. Rice straw, *Acacia albida* (Del.) A. Chew. pods and powder made of fruits from *Parkia biglobosa* (Jacq.) R. Br. ex G. Don were sometimes also used. All Go herds went on transhumance to the countryside within a circle of 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 DM intake from supplement feeds averaged 1.51 kg/d for a lactating Gsf cow and provided 389 g/d of crude protein (CP), 1.0 kg/d of digestible OM, and 12.9 MJ/d of ME. In addition, the calculated daily intake of forage DM during grazing (section 3.2.5) was 4.5 kg and 5.5 kg, which provided about 35.7 MJ and 43.8 MJ ME to Gsf and Go dairy cows, respectively (Table 3). Taking into account the energy requirements for maintenance, milk synthesis and LW gain or loss of the adult animal and its suckling offspring, the energy balance was strongly positive for a Gsf cow and slightly positive for a Go cow.

Maize bran, fresh grasses, and cowpea pods were the supplement feeds offered to Gsf sheep, which were on average supplied in a ratio (on DM basis) of 0.37:0.27:0.23. To each sheep, this mixture provided, on a daily basis, an average of 0.29 kg DM, 32 g CP, 200 g DOM and 2.4 MJ ME (Table 3). The estimated daily forage DM intake from pasture was 0.72 kg for Gsf sheep and 0.75 kg for the Go group, providing 5.8 MJ and 6.0 MJ ME, respectively. The yearly energy balance was close to zero for a supplemented and slightly negative for an unsupplemented sheep.

Feces and urine excreted overnight were commonly mixed with feed leftovers in the Gsf groups. This dung was heaped without any cover in the courtyard; from there it was removed usually at the beginning and end of the rainy season. No measures were taken to protect the dung heap against rainfall during the rainy season and exposure to high temperatures during the dry season. With no significant differences between groups, the quantity of dung DM produced per TLU and night was close to 600 g in cattle, and between 60 g and 125 g in sheep. For both livestock species, no significant differences were observed between groups and seasons in dung dry matter quantity and nutrient concentrations in the dung (Table 7). Of the DM and nutrients provided through supplement feeds, 15% to 58% were recovered in the manure (Table 8).

## 3.4. Discussion

### *3.4.1. 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 herd size and breed diversity, the dairy herds in Sikasso also differed from those of 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 increase in Gsf herd sizes of 25% over the time of study points to the willingness of dairy farmers to expand their production (Amadou et al. 2011). Since the average age of Gsf cows was higher than of Go cows, the number of calves born in the first group was also higher. In addition, higher animal inflow through purchases and reduced culling, limited to adult animals, can be considered as important strategies by farmers in both groups to fully exploit the production potential of their herds as far as animal numbers are concerned.

Table 7: 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 at Sikasso, Mali, from 07/2008 to 12/2009.

| Species and management | Season | Herds (n) | Duration of night kraaling (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 ±SD |
|---|---|---|---|---|---|---|---|---|
| Dairy cows | | | | | | | | |
| Grazing only | Dry | 4 | 12 | 618 ±326.0 | 1.5 ±0.30 | 0.4 ±0.07 | 35.1 ± 4.66 | 23.3 ± 2.38 |
| | Rainy | 4 | 14 | 543 ±244.6 | 1.3 ±0.34 | 0.3 ±0.06 | 30.8 ± 2.34 | 23.7 ± 4.30 |
| Grazing | Dry | 5 | 13 | 586 ±277.3 | 1.6 ±0.12 | 0.5 ±0.20 | 37.9 ± 7.65 | 23.1 ± 3.72 |
| + stall feeding | Rainy | 5 | 16 | 880 ± 34.4 | 1.3 ±0.31 | 0.3 ±0.06 | 35.3 ± 8.60 | 26.8 ± 0.16 |
| Sheep | | | | | | | | |
| Grazing only | Dry | 5 | 13 | 72 ± 37.89 | 1.0 ±0.76 | 0.3 ±0.20 | 22.1 ±12.62 | 38.4 ±43.48 |
| | Rainy | 5 | 14 | 48 ± 31.44 | 1.1 ±0.79 | 0.2 ±0.14 | 13.4 ± 4.84 | 51.6 ±55.78 |
| Grazing | Dry | 8 | 14 | 135 ± 96.60 | 1.9 ±1.32 | 1.2 ±1.52 | 53.9 ±43.66 | 26.8 ± 6.80 |
| + stall feeding | Rainy | 8 | 16 | 108 ± 94.42 | 1.5 ±1.39 | 0.4 ±0.42 | 35.7 ±35.02 | 23.1 ± 7.83 |

Table 8: Daily amount of dry matter (DM), nitrogen (N), phosphorus (P), and carbon (C) ingested with feed at the homestead, and recovered in the manure at the night kraal of dairy cows and sheep in the (peri-) urban grazing +stall feeding systems at Sikasso, Mali, from 07/2008 to 12/2009. Values are means (g/animal) ±SD.

| Variable | DM | N | P | C |
|---|---|---|---|---|
| Dairy cow herds (n=5) | | | | |
| Feed intake at homestead | 1506 ± 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* | 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* | 0.33 | 0.26 | 0.58 | 0.34 |

* ratio between intake and manure.

In contrast to the observed increase in dairy herd sizes, sheep herd sizes remained almost constant in both management groups during the study period. This probably 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 (Amadou et al. 2011; Dossa et al. 2011). Similar reasons for keeping sheep in and around other West African cities were reported in previous studies (Siegmund-Schultze and Rischkowsky 2001; Thys et al. 2005; Graefe et al. 2008). The high sheep mortality of up to 20% observed in Sikasso might be due to incidences of 'Peste des Petits Ruminants' (PPR) and trypanosomiasis. Osaer et al. (1999) reported increasing trypanosomiasis prevalence in Djallonke sheep due to loss of tolerance against this disease and particularly against *Trypanosoma congolense* and *T. vivax* (Geerts et al. 2008), given on-going crossbreeding with susceptible Sahelian sheep breeds.

### 3.4.2. Live weight development and reproduction

The insignificant difference between the two lactating cowsgroups in LWG observed during the rainy season indicates that feeding management during this period was similar and based on the same pasture feeds. The calculated LWG are higher than the 37 g/d and 8 g/d reported for adult cattle in high and low input systems at Niamey (Diogo et al. 2010). Differences might be due to differences in quality and quality of pasture vegetation between Sikasso (Sudanian savanna; $C_4$ grasses, high mass) and Niamey (Sahelian zone; $C_3$ grasses and forbs, low mass). For the dry season, the daily weight losses of 22 and 91 g/d observed in the Gsf and Go group, are in line with losses of up to 22% of body weight observed by Schlecht et al. (1999) in unsupplemented cattle during the dry season in Central Mali, but are much lower than the losses of 300 g/d reported by Fernández-Rivera et al. (2005) for night grazing and supplemented village cattle herds close to Niamey, Niger. The dry season LW loss of Gsf cows suggests that supplement feeding did not adequately balance the - insufficient - feed intake from pasture. The cows in the Go herds, on the other hand, apparently were nearly able to maintain their LW during the dry season due to the two transhumance periods to areas where grazing resources were apparently adequate to supply maintenance requirements (Fernández-Rivera et al. 2003; Ayantunde et al. 2011). Although the practice of transhumance requires investment in labour and travel, this seems to be economically advantageous (Turner 2000) over the restricted purchase of expensive (Debrah et al. 1995) crop residues and agro-industrial by-products in (peri-)urban areas.

The live weights and growth rates of Go and Gsf calves observed during the first six months of life were lower than the values reported by Baiden and Duncan (2008) for indigenous beef cattle breeds under traditional management at Pokuase Station, Accra, Ghana. This might be due to differences in feeding management of calves: the restricted suckling practiced in the region of Sikasso and beyond deprives calves of cow milk (Coulibaly and Nialibouly 1998; Sidibe-Anago et al. 2008) in order to extract more milk for home consumption or sale (Bonfoh et al. 2005; Coulibaly et al. 2007); this lowers LWG in calves.

The age at first calving of heifers observed in our study was slightly lower than that values reported for Méré cows under traditional management at Koutiala (Sanogo 2010), 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 calving interval recorded in our study was longer than values reported by Sanogo (2011) and Sokouri et al. (2010). This difference may be due to the older age of cows in our study but also to poor feeding management (section 3.4.3), which affects cow fertility (Oyedipe et al. 1982). However, the calving rate observed in our study 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.

Live weight gains of sheep observed in this study were far lower than reported for a low input sheep system in Niamey (Diogo et al. 2010). This could be due to the high prevalence of gastrointestinal diseases observed during the rainy season, and also to the quantity and quality of forage intake at pasture. 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 in southern Mali. However, rainy season LW losses observed in both management groups could also in part have been due to incidences of trypanosomiasis (Tembely et al. 1986; Goossens et al. 1999; Sangare et al. 2010), which is an endemic disease in this tropical humid region. The live weight losses observed for four months old lambs might on the other hand have been due to the transition from a mainly milk-based diet to a regime of roughages (Gbangboche et al. 2005).

The average age at first lambing observed in our study was lower than the values reported for the agro-pastoral Sudano-Sahelian zone of Mali (Niaré 1996), traditionally managed sheep in central Mali (Wilson and Durkin 1983), and agro-pastoral systems in Senegal (Lesnoff and Lancelot 2010). This suggests that the (peri-) urban sheep husbandry systems in Sikasso are at present in transition from a traditional to an intensive management. This is, however, not confirmed by the lambing interval which was higher than that reported by Niaré (1996) for the agro-pastoralist Sudano-Sahelian zone of Mali. The lengthy lambing interval may be related to the slow growth rate of weaned lambs and thus to the poor feeding system (Gbangboche et al. 2006) as well as diseases pressure.

### *3.4.3 Feed intake, manure production and energy and nutrient use efficiency*

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 rice and maize cultivation and challenges livestock feeding (Coulibaly et al. 2007). Similarly, farmers from the region of Koutiala (Mali, 120 km north of Sikasso), reported that the quantity of forages is decreasing in their communal grazing areas due to cropland extension and increased grazing pressure on the remaining pastures (Sanogo 2010). Since the major constraint to (peri-)urban livestock productivity is feed (Decruyenaere et al. 2009), the owners of Go cattle herds in Sikasso opted for short periodic transhumance while those of Gsf herds provided supplement feeds during the dry season. However, the amounts of supplement feeds offered to Gsf cattle herds was much lower than the quantities of supplement feeds given to cattle in Niamey, Niger (Diogo et al. 2010), and also not match the recommendations drawn from experiments for increasing cattle milk yield near Koutiala (Sanogo 2010) and Bobo Dioulasso (Ouédraogo et al. 2008). The energy balances calculated for Sikasso indicate that with the actual feeding practices, 93% of the ME ingested above maintenance requirements was converted into products (LWG of adult and suckling animal, extracted milk) in Go cattle, while supplemented dairy cows converted only 58% of the ME ingested above maintenance into these products. As already stated above (section 3.4.2), diseases might in parts explain the low energy use efficiency in Gsf animals. However, our estimates of feed intake on pasture as well as the assessment of LW changes in adult cattle bear errors as well and energy balances should thus only be taken as an indication, not as absolute values. By comparing the average cost of 100 Francs CFA (approx. 0.15 Euro) for the daily feed supplement (1.5 kg DM of maize bran plus cotton seed expeller) offered to a Gsf animal and the average amount of 65 g/d of extra milk extracted from Gsf as compared to Go cows which yields 20 FCFA at sale, the l supplementation practice of Gsf cows is currently not economic. The practice of sending herds (Go) on short-term transhumance in order to compensate decreasing feed intake and quality seems thus to be much easier and more economic for the dairy farmers around Sikasso.

As far as sheep are concerned, the insignificant differences between the Go and the Gsf herds for LW changes, in spite of daily supplement provision to the latter, might be explained by their reduced grazing time and thus lower feed intake on pasture. Similar to supplemented cattle, the slightly positive energy balance and the low use efficiency of 67% of the metabolizable energy supplied above maintenance requirements by Gsf sheep can certainly be related to the rough approximation of daily feed intake on pasture. However, Sangare et al. (2010) reported that trypanosomiasis infection reduced weight gain of Djallonke sheep; the low energy use efficiency in sheep could thus at least in parts have also been due to disease pressure, especially in the rainy season.

As stated by Paul et al. (2009), nutrient excretion and manure quality are highly affected by feed quality and intake. Hence, the absence of significant differences in the amounts of dung produced and dung quality between the two management groups of cattle and sheep, throughout the study period, may have primarily been the result of indifferent manure handling. At present, about 24% of N and 25% of P imported into livestock holdings through purchased supplement feeds are ending up at the dung heap. From there nutrients losses continuously occur due to handling and storage practices. Studies by Predotova et al. (2010) from Niamey (Niger) have shown that without protection of dung heaps from nutrient leaching in the rainy season and gaseous emissions due to the typically high temperatures throughout the year, annual amounts of N and P lost from dung heaps can reach 0.3 kg and 1.2 kg per 100 kg of dung dry matter. Covering the storage heap and judicious use of bedding material in animal kraals can prevent such losses (Camara 1995, Predotova et al. 2010), and could be a key for sustainable agricultural practices (Rufino et al. 2007; Tittonell et al. 2009), especially since manure is often the only (cheap) nutrient source available to smallholder farmers.

#### *3.4.4. Milk production*

In our study, there was no significant difference between the two management groups in the average milk yield per cow during the study period and across seasons, although cows in the Gsf groups received supplement feed during the dry season. The recorded milk yields are similar to those reported by Sanogo (2010) from the city of Koutiala for the same crossbreeds of N'Dama x Zebu cattle which were also grazing and supplemented during the dry season. Values also compare well to those of indigenous Malian zebus (Maure and Sudanese Fulani) kept under controlled conditions at Niono in central Mali (Coulibaly and Nialibouly 1998). However, present milk offtake is lower than the daily yield of 1 - 2 liters per cow reported by Sanogo (2010) for stall-fed crossbreed N'Dama x Zebu cattle, by Bonfoh et al. (2005) for local breeds in traditional grazing-based production systems in Mali, and by Millogo et al. (2008) for the (peri-) urban dairy holdings of Ouagadougou and Bobo Dioulasso in Burkina Faso. Olafadehan and Adewumi (2008) argued that inadequate nutrition of lactating cows, especially during the dry season, is a major limitation to the productivity of dairy herds. Although the low milk yields might in part be explained by a relatively low milk production potential of the N'Dama crossbreeds, the poor management observed during the study period, especially insufficient supply of feed nutrients and energy during lactation (chapter 3.4.3) has a negative effect, not only on milk yield and calf development but, through the use of body reserves for milk production, also on live weight development and reproductive performance of the cows (Remppis et al. 2011). Since milk yield is also affected by diseases (Nilforooshan and Edriss 2004; Ouédraogo et al. 2008), and given the fact that the Sudanian Savanna is an endemic zone of trypanosomiasis infection, milk yield could also have been affected by this disease.

### 3.5. Conclusions

The study showed that (peri-) urban dairy production and sheep husbandry in Sikasso are characterized by an overall low productivity that likely reflects inadequate feeding practices in the still mainly pasture-based systems, reinforced by insufficient health care practices especially in sheep. Under such conditions, the small amounts of supplement feeds offered to lactating cowsseem a waste of resources compared to the practice of periodic short-distance transhumance at times when grazing resources near the city are exhausted. We therefore conclude that feeding and general management of (peri-) urban ruminant stock, and thus the systems' productivity, will only increase if market incentives from a growing (and at least partly well-off) urban population and supportive extension and veterinary services emerge. In small secondary West African cities such as in Sikasso where these incentives are lacking, the ruminant livestock production systems are therefore still of rural rather than urban character.

### Acknowledgements

We are grateful to the urban 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. The authors are grateful to the Volkswagen Stiftung, Hannover, Germany, for supporting this research financially under the “UrbanFood” project within the collaborative program ‘Resources, their dynamics, and sustainability–capacity–development in comparative and integrated approaches’ (No. I/82 189).

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## Chapter 4

# Safety of horticultural and livestock products from urban and (peri-) urban enterprises in two West African cities

Modified version submitted to Environmental Monitoring and Assessment.

**Abstract**

Despite their contribution to food security, animal products and vegetables originating from urban and peri-urban agriculture (UPA) often raise public health and environmental concerns, given high use of agro-chemicals, organic fertilizers and wastewater. The present study aimed to characterize contamination sources of irrigated lettuce and milk with microbiological contaminants, and of tomato and cabbage with pesticide residues in UPA systems of Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). At three occasions in 2009, samples of irrigation water, organic fertilizer, and lettuce were collected in 6 gardens, and samples of cabbage and tomato in 12 gardens; raw and curdled milk were sampled in 6 dairy herds. Information on health risks for consumers of such foodstuffs was obtained from 11 health centers in Sikasso. Thermo-tolerant coliforms and *Escherichia coli* contamination levels of irrigation water significantly exceeded WHO recommendations for unrestricted irrigation of vegetables consumed raw. Microbial contamination levels of lettuce at the farm gate and the market place in Bobo Dioulasso and at the farm gate in Sikasso were higher than at the market place in Sikasso ($P<0.05$). Pesticide residues were detected in only one cabbage and one tomato sample and were below the maximum residue limit for consumption. Counts of thermo-tolerant coliforms and *Escherichia coli* were higher in curdled than in raw milk ($P<0.05$). From 2006 to 2009, cases of diarrhea/vomiting and typhoid fever had increased by 11% and 48%, respectively, in Sikasso. To reduce risks linked to the consumption of UPA vegetables and milk, a comprehensive approach is needed to establish and effectively control hygienic management practices along the production, processing and marketing chain.

**Key words:** Bobo Dioulasso, *Escherichia coli*, milk, pesticide residues, thermo-tolerant coliforms, Sikasso, vegetables.

## Sécurité sanitaire des produits d'origines horticulturale et animales des entreprises en zone urbaine et périurbaine de deux villes Ouest Africaines


### Résumé

Malgré leur contribution à la sécurité alimentaire, les produits animaux et les légumes provenant des zones urbaines et périurbaines soulèvent souvent des préoccupations en santé publique et environnementales, étant donné l'utilisation abusive des produits agro-chimiques, des engrais organiques et des eaux usées. La présente étude visait à caractériser les sources de contamination de la laitue irriguée et le lait avec les contaminants microbiologiques, et de la tomate et le chou avec des résidus de pesticides dans les systèmes d'agriculture urbaine et périurbaine de Bobo Dioulasso (Burkina Faso) et de Sikasso (Mali). A trois périodes, en 2009, des échantillons d'eaux d'irrigation, d'engrais organiques et de la laitue ont été collectés dans six jardins, et des échantillons de choux et de tomates prélevés dans 12 jardins; le lait caillé et cru ont été échantillonnés dans six troupeaux laitiers. Des informations sur les risques sanitaires liés à la consommation de tels produits alimentaires pour les consommateurs ont été notées dans 11 centres de santé à Sikasso.

Les niveaux de contamination des eaux d'irrigation par les coliformes thermotolérants et Escherichia coli ont largement dépassé les recommandations de l'OMS pour l'irrigation de légumes consommés crus sans restriction. Les niveaux de la contamination microbienne de la laitue au jardin et au marché à Bobo-Dioulasso et au jardin à Sikasso étaient supérieurs à ceux du marché de Sikasso ($P<0,05$), tandis que les résidus de pesticides qui étaient au-dessous de la limite maximale de résidus pour la consommation, ont été détectés seulement dans un échantillon de chou et un échantillon de tomate. Les taux de coliformes thermotolérants et de Escherichia coli étaient élevés dans le lait caillé que dans le lait cru ($P<0,05$). De 2006 à 2009, les cas de diarrhée/vomissement et de fièvre typhoïde ont augmenté respectivement de 11% et 48%, à Sikasso.

Pour réduire les risques liés à la consommation de légumes et du lait en provenance de l'agriculture urbaine et périurbaine, une approche holistique est nécessaire afin d'établir et de contrôler efficacement les pratiques de gestion hygiénique le long de la chaîne de production, de transformation et de commercialisation.


**Mots clés:** Bobo Dioulasso, Escherichia coli, lait, résidus de pesticides, coliformes thermotolérants, Sikasso, légumes.

## 4.1. Introduction

During the last two decades, interest in food production in and around West African cities has increased together with the urban population that is growing at 5-7% per annum (FAO 2003). To satisfy the food demand of the urban population, there has been a shift from extensive to very intensive urban and peri-urban livestock and vegetable production systems that are heavily depending on purchased feeds and intensive use of manure, irrigation water, and pesticides. Besides contribution to food security, household income, job creation, and environmental benefits (Faye and Alary 2001; Cissé et al. 2005; Graefe et al. 2008; De Zeeuw et al. 2011), urban and peri-urban agriculture (UPA) practices have raised numerous concerns about public health and environmental aspects (Keraita and Drechsel 2002; Binns et al. 2003; Amoah et al. 2005, 2006; Ndiaye et al. 2006), due to intensive use of agro-chemicals and wastewater in vegetable production, as well as the inappropriate management of feedstuffs, medicine and manure in livestock production systems.

Recent work underlines the importance of livestock health care and management for the quantity and quality of food of animal origin produced in UPA systems (Coulon and Priolo 2002; Montel 2003), since consumers' health greatly depends on the biological and chemical quality of the plant and animal products included in their diets. Biological contaminants in the food chain are viruses, bacteria, funguses, and parasites (Bourgeade et al. 1992; FAO/WHO 2008), which may come from a multitude of sources. With regard to livestock and livestock products, zoonotic agents are of major concern. Several studies showed that fresh milk and milk products are highly contaminated with zoonotic pathogens in many West African cities (Bonfoh et al. 2002, 2003; Millogo et al. 2008; Pistocchini et al. 2009), and contamination of dairy products with contagious non-zoonotic pathogens was also reported (Bonfoh et al. 2003, 2005; Harouna et al. 2009; Wullschleger 2009).

Vegetable pollution at the farm gate is generally linked to the use of contaminated organic fertilizer such as human faeces (in manure or household wastes) and animal manure, and of wastewater for irrigation (Keraita et al. 2003; Jablasone et al. 2004; Cofie et al. 2005; Amoah et al. 2006; Carr et al. 2010; Forslund et al. 2010; Qadir et al. 2010). In many cities of sub-Sahara Africa, vegetables and their irrigation water, frequently fetched from ponds, shallow wells, drains, domestic channels, and industrial wastewaters, host coliform bacteria and parasites in numbers exceeding recommended standards (Drechsel et al. 2000; Sonou 2001; Keraita and Drechsel 2002; Binns et al. 2003; Keraita et al. 2003; Amoah et al. 2005; Ndiaye et al. 2006; Chigor et al. 2010; Diogo et al. 2010). Many of these vegetables are eaten raw, raising concerns about public health (Amoah et al. 2007; Seidu et al. 2008; Mara and Sleigh 2009).

Abusive use of pesticides leading to high concentrations of their residues in fresh vegetables constitute another serious public health and environmental threat in West African UPA (Manirakiza et al. 2003; Oluwole and Cheke 2009; Rosendahl et al. 2009). The use of pesticides in urban vegetable farming in the region has considerably increased over the last decade and many highly toxic pesticides are being indiscriminately used without adequate control (Ntow et al. 2006; Lund et al. 2010). Studies conducted in Ghana (Amoah et al. 2006) and in Benin (Assogba-Komlan et al. 2007) reported residual pesticide concentrations in vegetables above the published limits tolerable for consumption. In the cotton zone of Southern Mali and Western Burkina Faso, UPA vegetable producers purchased cotton pesticides and used them on vegetables without any consideration of food safety, public and environmental health (Cissé et al. 2005; Bassole and Ouedraogo 2007). Pesticide use and handling practices might expose farmers to chemical hazards (Dinham 2003; Ajayi and Aknnifesi 2007; Keida and Palis 2008; Oluwole and Cheke 2009; Issa et al. 2010) leading to chronic health diseases such as hypertension (Saldana et al. 2009), ophthalmic disorders (Jaga and Dharmani 2006), myocardial infarction (Mills et al. 2009), respiratory dysfunctions (Fieten et al. 2009; Soomro et al. 2010), cancer (Alavanja et al. 2004; Ejaz et al. 2004; Kokouva et al. 2011), and neurotoxicity (Alavanja et al. 2004; Baldi et al. 2011).

Consumption of foods containing significant amounts of pesticide residues and/or biological pollutants can also lead to gastrointestinal and other foodborne infections. Although no statistical data on illness linked to food consumption is available for West African cities, sporadic cases are regularly reported (Faruqui et al. 2002; Adedoyin et al. 2008; Oluwole and Cheke 2009). However, many of the lesser developed countries lack resources to assure food security, and issues of food safety therefore have a very low priority even if accredited control systems are already in place or being worked out (Cannavan 2004).

Against this background, the present study aimed at characterizing the sources of contamination and contamination levels, respectively, of irrigation water, lettuce and milk with pathogens, and of tomato and cabbage with pesticide residues in the UPA systems of two West African cities.

## 4.2. Materials and methods

### *4.2.1. Sampling sites*

The study was carried in the cities of Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). Bobo Dioulasso is the second largest city of Burkina Faso with approximately 400,000 inhabitants (Commune de Bobo Dioulasso 2007). It is situated in the south-western part of the country (11º16'N, 4º31'W, 460 m a.s.l), on the crossroads between Ivory Coast and Mali. The climate is characterized by a rainy season (May-October), and a dry season

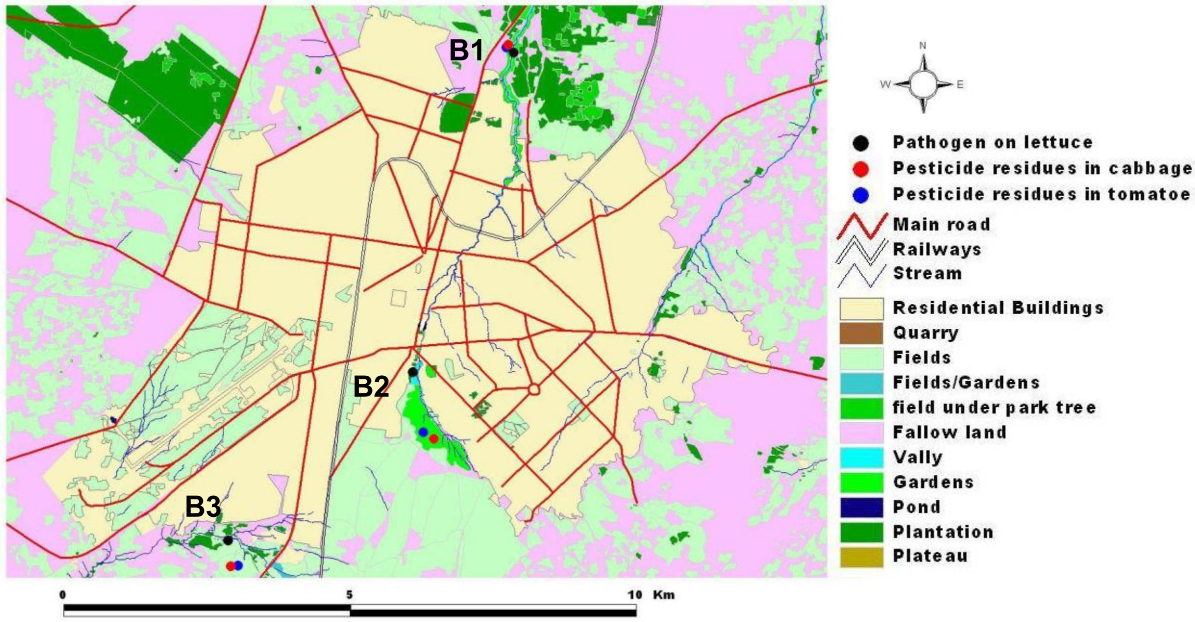
(November-May); annual rainfall varies between 900 and 1200 mm (Millogo et al. 2008). Gardening activities are well developed in the vicinity of the four major rivers that cross the city. Sources of irrigation water include the rivers, smaller streams, and shallow wells. Within the city, untreated sewage drains aliment the rivers. Sikasso, the second largest city of Mali (11º19'N, 5º40'W, 410 m a.s.l.), hosts 135,500 inhabitants and is characterized by a subhumid climate with a rainy season from May to October and a dry season from November to April. The annual average temperature is 26ºC (Coulibaly et al. 2007) and annual rainfall varies from 900 to 1100 mm. The Lotio River that floods the city's lower laying areas (160 ha) during the rainy season, leaves these with significant residual soil moisture in the first months of the dry season (PROMISAM 2007), enabling a well-developed production of vegetables. In addition, many shallow lakes, shallow wells, and streams exist in and around the city and constitute major sources of irrigation water. Again, untreated sewage, stormwater, and drains flow into the Lotio River.

### *4.2.2. Sampling for pathogen analysis*

#### *4.2.2.1. Sampling of manure, irrigation water and lettuce*

Three gardens were selected in three different quarters of Sikasso (S1: Kaboila; S2: Sanoubougou_1; S3: Mancourani), and three in Bobo Dioulasso (B1: Dogona; B2: Bolomakote; B3: Lafiabougou). While gardeners in S2 used shallow well water for irrigation, gardeners in S1, S3, B1, B2 and B3 used open creek water alimented by the city canalization (Figure 1). Water from the Lotio River and its affluent Kotoroni was used to irrigate S1 and S3, while the Houet River was used to irrigate B1 and B2 and water from the Kodeni River was used in garden B3. Whereas gardeners S1, S2, B1 and B3 applied only livestock manure to their lettuce crop, gardeners S3 and B2 used mineral fertilizers only. For each potentially pathogen-containing resource (manure where applicable, irrigation water and lettuce) one pooled sample composed of five independent samples per garden was taken at three different periods, namely in February, May and November 2009. In each garden, the five independent samples of lettuce plants (200 g of fresh matter, FM, as a mix of elderly and young leaves) were taken just before harvest at the corners and in the centre of the two diagonals of the plot. Each lettuce harvest was then traced from the garden to the market place where additional lettuce subsamples (n=5) were taken and pooled into a second sample. All samples were placed in labeled sterile plastic bags. Five independent subsamples (100 ml) of irrigation water per garden were taken where the farmers drew water for irrigating vegetables; these were pooled into one sample (500 ml) and stored in labeled sterile glass bottles. Five manure subsamples (100 g FM) per garden were collected from the dung heap just before dung was spread on the plot. They were pooled into one sample

(500 g FM) and placed in labeled sterile plastic bag. All samples were transported to the laboratory in an iced cooling box.



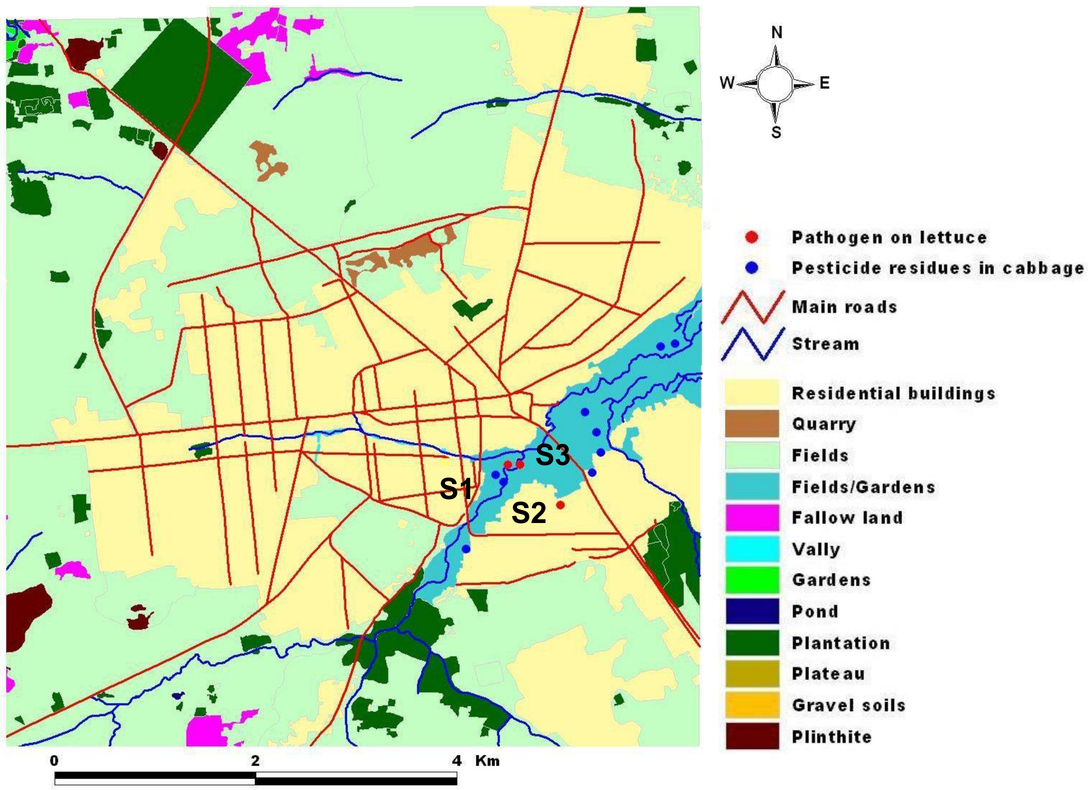




Figure 1. Gardens locations (above) in Bobo Dioulasso (Burkina Faso) and (below) in Sikasso (Mali) for sampling of irrigation water, lettuce, tomato, and cabbage

*4.2.2.2. Sampling of milk*

Six milk producing households (M1 - M6) were selected in Sikasso. The households M1, M2, and M3 owned less than 20 milking cows and M4, M5, and M6 more than 20. Four of them (M3, M4, M5, and M6) were producing curdled milk and the other two (M1 and M2) raw milk. After mixing the milk gained from all cows milked in the household in the morning, 5 samples of 100 ml each were taken from the milk can. These were pooled into one sample per household, transferred into labeled sterile bottles, and transported to the laboratory in an iced cooling box. Sampling of milk occurred in February, May, and November 2009, leading to a total of 12 samples of raw milk and 6 samples of curdled milk.

*4.2.2.3. Sampling of cabbage and tomatoes for pesticide residues analysis*

Nine gardens growing cabbage in Sikasso as well as three gardens growing tomatoes and three gardens growing cabbage in Bobo Dioulasso were selected to determine whether the respective vegetables contained pesticide residues (Figure 1). The owners of these gardens applied pesticides containing mainly pyrethroids, organo-phosphates and organo-chlorine compounds to protect their cabbage and tomato harvest against insect attacks. Per garden ten plants of cabbage and ten tomato fruits, respectively, were taken along each of the two diagonals of the field in February, May, and November 2009. Each sample was immediately wrapped in aluminium foil and placed separately into labeled sterile plastics bags; immediate sample transport to the laboratory was done using an iced cooling box.

### *4.2.3. Microbiological examination and pesticide residue analysis*

Microbiological analyses were done at the Medical Biology Analysis Laboratory (EXALAB) in Bobo Dioulasso, whereas pesticide residue analysis was performed at the Environmental Toxicology and Quality Control Laboratory (ETQCL) of the Central Veterinary Laboratory (LCV) in Bamako, Mali.

Ten grams of fresh manure and lettuce, respectively, and 100 ml of irrigation water and milk were sampled and homogenized. Serial dilutions were performed with sterile distilled water to obtain sample dilutions ranging from $10^1$ to $10^7$.

Coliform counts were performed using Violet Red Bile Agar with Lactose (Speck 1976). One ml of each diluted sample was transferred to a sterile Petri dish. Ten ml of medium were added (at 48°C) to the content of each Petri dish. The inoculated solution was gently rotated by hand. After solidification, a second layer of the medium was poured on to the depth of 5 mm. The solidified solution was then incubated during 24 hours at 35°C and 44°C, respectively, for the enumeration of total and faecal coliforms.

For coliform identification, the solution was inoculated in Eosine Methylene Blue, incubated at 37°C for 24 hours and the suspected colonies were identified using the micro-method identification gallery API Staph of bioMerieux® SA. *Staphylococcus* germs were cultivated on Chapman agar-agar hyperchlorinated media and their identification was based on their biochemical and bacteriological characters. *Streptococci* were identified after 24 hours of incubation under $CO_2$ on Mueller Hinton medium used for isolation. Tryptose agar medium enriched with sheep serum was used for the isolation of Brucella from milk. The inoculated milk samples were incubated at 34°C in $CO_2$ for 48 hours. For all samples, colonies were isolated and counted using the Most Probable Number (MPN) technique. The samples of manure, irrigation water and lettuce leaves (farm gate and at market) were analyzed for helminth eggs using the concentration method (Schwartzbrod 1998). For the identities of specific helminth eggs, color charts for the diagnosis of intestinal parasites (WHO 1994) were used.

To determine pesticide residues in cabbage leaves and tomato fruits, 10 g FM of sample were homogenized with a blender, extracted with ethyl acetate, partitioned with a mixture of magnesium sulfate ($MgSO_4$) and sodium chloride (NaCl), and cleaned by dispersive solid-phase extraction (dispersive-SPE) cleanup (Food and Drug Administration 1994). A 6890 HP chromatograph equipped with an electron capture detector and a capillary column (30 m length, 0.32 mm internal diameter) coated with HP-5, 0.25 µm film thickness was used for the analysis of (residues of) chlorpyrifos methyl, chlorpyrifos ethyl, profenofos, dimethoate, endosulfan, lambda-cyhalothrin, cypermethrin, deltamethrin, p,p'-DDT and its breakdown products endosulfan I and II, and endosulfan sulfate.

The temperature program was as follows: 80°C held for 2 minutes, followed by 25°C $min^{-1}$ increase to 150°C, 3°C $min^{-1}$ increase to 200°C, 8°C $min^{-1}$ increase to 280°C; this temperature was kept stable for 10 min. Nitrogen (N) was used as a carrier gas at a flow rate of 2.0 ml $min^{-1}$. The make-up gas was N at a flow rate of 60 ml $min^{-1}$. The injection volume was 1 µl in splitless mode, the injector temperature was 250°C and the detector temperature was 300°C. Chemical compounds in samples were identified by their retention times compared to the retention times of the corresponding certified pesticides standard.

### *4.2.4. Consumer health risks*

Information on health risks for consumers of foodstuffs contaminated with pathogens or pesticide residues were gathered through individual interviews of the directors of ten public health centers in Sikasso. This was complemented by the collection of data on the number of cases of toxi-infections and diarrhea linked to consumption of vegetable and animal products in one hospital (Hopital Régional de Sikasso), one health reference center (CSRef de Sikasso), and eight community health centers "Centre de Santé Communautaire (CSCOM)". Semi-structured questionnaires containing also open-ended questions on the use of pesticides and veterinary drugs were administered to the owners of the sampled gardens and dairy herds.

### 4.2.5. Data analysis

Laboratory and survey data were analyzed using SPSS/PASW version 18.0 (SPSS Inc. 2010). Total and faecal coliform counts and Escherichia coli counts, expressed as most probable number (MPN), were $\log_{10}$ transformed, and one way randomized analysis of variance (ANOVA) was used to analyze the transformed data. Independent variables considered were city (n=2), garden within city (n=3; nested), period (n=3), and their interactions; for milk only the two products (fresh versus curdled) were compared. Independent samples t-test and least significant difference (LSD) were used to determine differences between group means; significance was examined at P<0.05.

## 4.3. Results

### 4.3.1. Microbiological contamination of lettuce at garden and market level

All of the 36 lettuce samples (18 from Bobo Dioulasso, 18 from Sikasso) contained total and faecal coliforms. Across the two cities, the geometric mean ($\log_{10}$) of thermo-tolerant coliforms ranged from 3.48 to 7.95 MPN 100 $g^{-1}$ FM (Table 1). Significant differences between samples from farm gate and market place were neither (P>0.05) detected in Sikasso nor in Bobo Dioulasso (Figure 2).

Table 1: Faecal coliform contamination levels of lettuce sampled at harvest (farm gate) as well as at market level in Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). Values present means of three gardens per city and three harvests[1] per garden, and are expressed as $\log_{10}$ of the geometric mean MPN[2] per 100 g of fresh lettuce.

| | | | Faecal coliform counts | |
|---|---|---|---|---|
| Location | City | n | Geometric mean (S.D.) | Range |
| Farm | Bobo Dioulasso | 9 | 5.17 (1.66) $^{a}$ | 3.74 - 7.88 |
| | Sikasso | 9 | 5.03 (1.66) $^{a}$ | 3.60 - 7.95 |
| Market | Bobo Dioulasso | 9 | 5.45 (1.43) $^{a}$ | 4.18 - 7.60 |
| | Sikasso | 9 | 4.31 (0.66) $^{ab}$ | 3.48 - 5.60 |

[1] Harvest took place in February, May and November 2009.

[2] MPN: Most Probable Number.

[a,b] Significant differences between means with different superscripts; t-test, P<0.05.

As far as seasonal and yearly variations were concerned, the contamination levels did not differ significantly between the cold dry season (February) and the hot dry season (May; Table 2) in Sikasso and in Bobo Dioulasso (Figure 3). Likewise there were no significant differences between contamination levels at the farm gate and the market place in Bobo Dioulasso and Sikasso (Figure 4). *Escherichia coli* were found in 21% and 24% of the lettuce samples from Bobo Dioulasso and Sikasso, respectively. However, no significant difference was observed between cities for *E. coli* contamination levels ($\log_{10}$), which ranged from 3.60 to 4.68 MPN 100 $g^{-1}$ FM. Furthermore, *Enterobacter* sp., *Klebsiella pneumonia*, *Proteus* sp., *Levinia* sp., *Morganella* sp., and *Citrobacter* sp. were found in some samples, while *Salmonella* sp. and *Shigella* sp. were not found in any of the 36 samples. The proportion of samples from Bobo Dioulasso that contained bacteria was significantly higher ($P<0.05$) than that from Sikasso. As far as parasites are concerned, Ankylostomes eggs were found in both cities, whereas *Balantidium coli*, *Entamoeba* sp., *Strongyloides* sp., *Shistosoma* sp. and *Trichocephalus* sp. were encountered on lettuce from Bobo Dioulasso and *Trichomonas* sp., *Miracidium* sp., and *Anguillulea* sp. occurred in Sikasso. Most parasites were encountered in the hot dry season (May).

Table 2: Faecal coliform contamination levels of lettuce harvested and sold at the market place in three subsequent production cycles in Bobo Dioulasso, Burkina Faso, and Sikasso, Mali. Values are presented as $\log_{10}$ of the geometric mean MPN[1] per 100 g of fresh lettuce and (S.D.).

| | | Faecal coliform counts | | | | |
|---|---|---|---|---|---|---|
| Period | | Bobo Dioulasso | | | Sikasso | |
| (2009) | n | Farm | Market | n | Farm | Market |
| February | 3 | 4.17 (0.13) | 4.64 (0.43) | 3 | 4.39 (0.43) | 4.23 (0.60) |
| May | 3 | 6.02 (1.81) | 6.19 (1.95) | 3 | 5.99 (1.64) | 4.46 (0.32) |
| November | 3 | 5.51 (2.06) | 5.62 (1.37) | 3 | 4.83 (2.41) | 4.25 (1.11) |

[1]MPN: Most Probable Number.

Regardless of the city, the number of thermo-tolerant coliforms ($\log_{10}$) in lettuce sampled at market places ranged from 3.48 to 7.60 MPN 100 $g^{-1}$ FM (Table 1). Counts were significantly lower in samples from Sikasso than in those from Bobo Dioulasso, where vendors washed lettuce with (contaminated) irrigation water before selling it at different market places. In Sikasso, all lettuce samples that showed contamination at harvest remained contaminated until the market place. However, values of thermo-tolerant coliforms in lettuce sampled at market place were 15% lower ($P<0.05$) than at the farm gate, since tap water or water from residential wells was used by vendors in Sikasso to wash the lettuce. No significant difference was observed between the two sites for *E. coli* contamination.

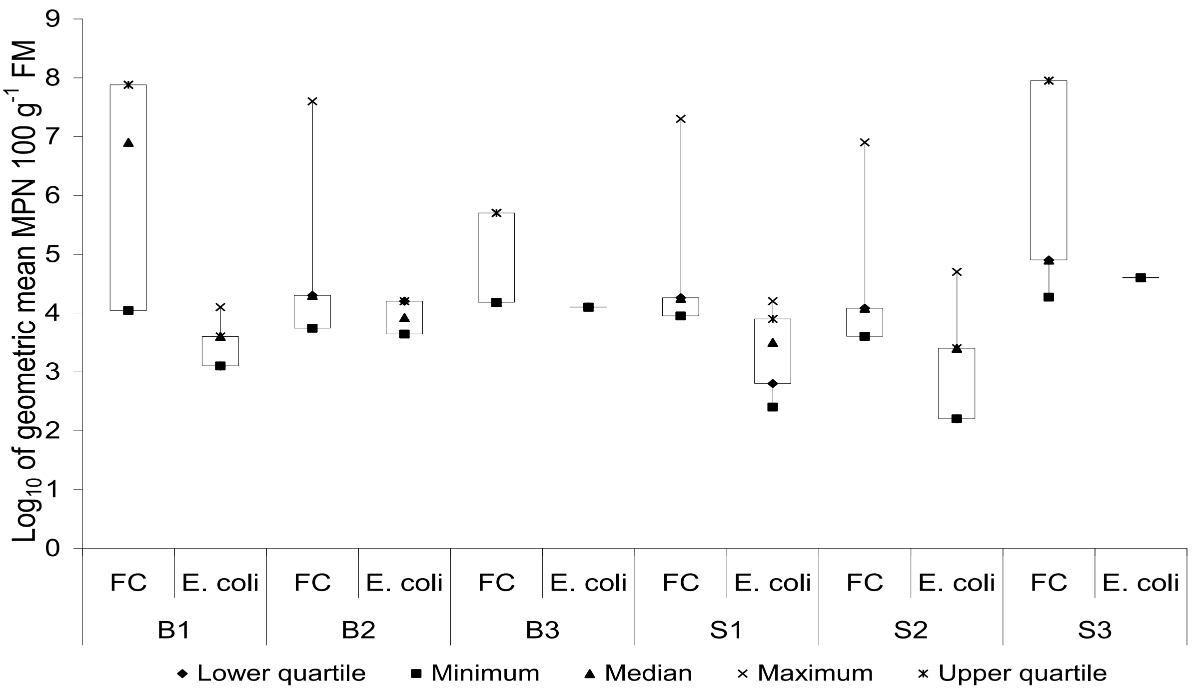



Figure 2: Average yearly variation of faecal coliform (FC) and *Escherichia coli* (*E. coli*) contamination levels of lettuce at harvest in six different garden localities in Bobo Dioulasso, Burkina Faso (B1, B2, B3) and in Sikasso, Mali (S1, S2, S3). MPN: Most Probable Number; FM: fresh matter.

#### *4.3.2. Microbiological contamination of irrigation water and manure*

Lacking significant differences across cities and water sources, geometric means ($log_{10}$) of thermo-tolerant coliforms in irrigation water ranged from 2.00 to 7.48 MPN 100 $ml^{-1}$ (Table 3). No significant differences between stream and well water were observed for thermo-tolerant coliform counts in Sikasso and in Bobo Dioulasso at any of the sampling periods. Overall, *Escherichia coli* were detected in 28% of all water samples, with a greater proportion of samples contaminated at a higher level in Bobo Dioulasso than in Sikasso. The pollution ($log_{10}$) ranged from 2.20 to 3.51 MPN 100 $ml^{-1}$. In addition, *Enterobacter* sp. and *Pseudomonas* sp. were determined in a few irrigation water samples from both cities during all collection periods.

Table 3: Faecal coliform contamination levels of irrigation water sources used in lettuce production at Bobo Dioulasso, Burkina Faso, and Sikasso, Mali. Values are presented as $log_{10}$ of the geometric mean MPN[1] per 100 ml of water.

| | | | Faecal coliform counts | |
|---|---|---|---|---|
| Water source | City | n | Geometric mean (S.D.) | Range |
| Stream water | Bobo Dioulasso | 9 | 4.35 (1.39) | 3.00 - 7.48 |
| | Sikasso | 6 | 3.31 (1.10) | 2.00 - 4.80 |
| Shallow well water | Sikasso | 3 | 2.88 (0.54) | 2.00 - 3.30 |

[1]MPN: Most Probable Number.

There was no significant difference between the two cities in the average counts of thermo-tolerant coliforms in animal manure (Table 4). At a range ($log_{10}$) of 5.30 to 8.26 MPN 100 $g^{-1}$ FM of thermo-tolerant coliforms in Sikasso, the contamination of manure in this locality was more important than in Bobo Dioulasso. *Levinea* sp. was found in only three samples of organic fertilizer and two samples of irrigation water used in vegetable gardens, whereas *Enterobacter* sp. was found in all types of samples (irrigation water, organic fertilizer, and lettuce).

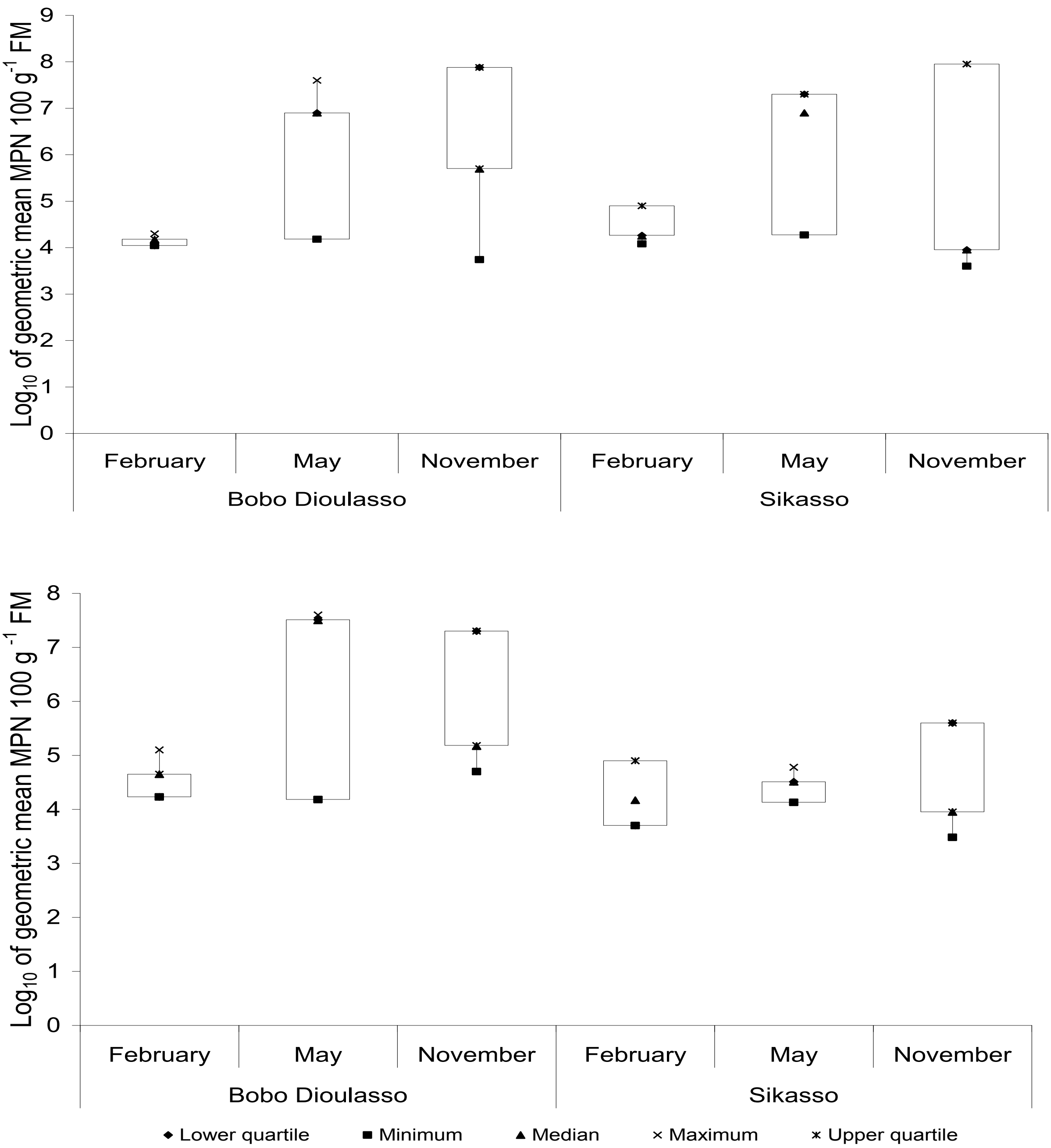



Figure 3: Changes in faecal coliform contamination levels of lettuce at the farm gate (above) and at the market place (below) in Bobo Dioulasso (Burkina Faso) and Sikasso (Mali) as determined in February, May and November 2009. MPN: Most Probable Number; FM: fresh matter.

### *4.3.3. Microbiological contamination of milk*

The most important health problems for which dairy cows were treated by their owners were trypanosomosis, bacterial diseases, including pasteurellosis, and parasites. Trypanosomosis, which is the most widespread endemic disease in the zone, was targeted by 59% of the curative treatments, while parasites, pasteurellosis and other bacterial diseases, respectively, were the target of 19%, 13%, and 10% of all curative treatments of dairy cows. No prophylactic treatment of any of the problems was reported.

Table 4: Faecal coliform contamination levels of livestock manure used in lettuce production in Bobo Dioulasso, Burkina Faso, and Sikasso, Mali. Values are presented as $log_{10}$ of the geometric mean MPN[1] per 100 g of fresh manure.

| | | Faecal coliform counts | |
|---|---|---|---|
| City | n | Geometric mean (S.D.) | Range |
| Bobo Dioulasso | 6 | 4.35 (1.81) | 3.78 - 8.68 |
| Sikasso | 6 | 7.19 (1.14) | 5.30 - 8.26 |

[1]MPN: Most Probable Number.

The commonly consumed dairy products in Sikasso were raw, boiled, and curdled milk. Overall, six bacterial groups were identified in the milk samples, namely *Escherichia coli*, *Streptococcus* sp., *Proteus* sp., *Klebsiella* sp., *Pseudomonas* sp., and *Enterobacter* sp. Out of the total 12 raw and 6 traditionally curdled milk samples, respectively, 5 and 4 were contaminated with thermo-tolerant coliforms and 2 and 4 with *Escherichia coli*. *Salmonella*, *Shigella*, *Staphylococcus*, and *Brucella* bacteria as well as parasites were not detected in any sample. *Streptococcus* was found in one curdled milk sample during the cool dry season. Lacking significant differences between raw and curdled milk, ranges ($log_{10}$) of thermo-tolerant coliforms and *Escherichia coli* were 6.30 to 7.88 MPN 100 $ml^{-1}$ and 6.20 to 7.78 MPN 100 $ml^{-1}$, respectively (Table 5). No bacteria were found in the curdled milk produced by two out of the six farms during any sampling period, and on one farm producing raw milk total and faecal coliform contamination levels decreased to zero from the first to the third collection period.

### *4.3.4. Pesticide contamination in cabbage and tomato*

All gardeners in Bobo Dioulasso and Sikasso who grew cabbage and tomato used pesticides to protect their production. In both cities Rocky 500EC, Lambda Super 2,5EC and Decis were used. In addition, Cypercal P230EC and Calfos 500EC were used in Bobo Dioulasso, while Cypalm 200EC, Conquest C176EC and Pyrical 48EC were used in Sikasso. Rocky 500EC contains endosulfan which is an organo-chlorine compound, while Calfos 500EC, Cypercal P230EC and Pyrical 480EC contain organo-phosphates. Lambda Super 2,5EC, Decis, Conquest C176EC and Cypalm 200EC are classified as pyrethroids. A biopesticide from *Azadirachta indica* and a neonicotinoid (acetamiprid) were also used in one garden at Sikasso.

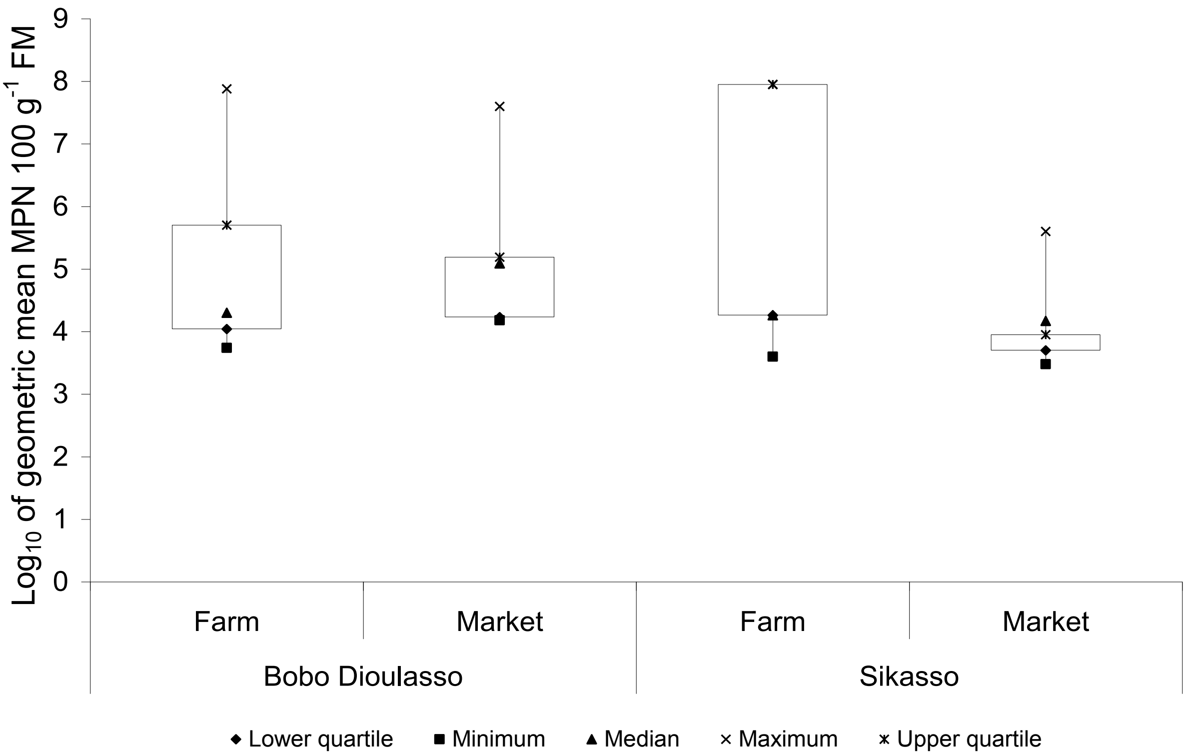



Figure 4: Average yearly contamination levels of lettuce with faecal coliforms at the farm gate and the market place in Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). MPN: Most Probable Number; FM: fresh matter.

The period between the latest use (fifth or sixth application in a cropping cycle) of all those pesticides and harvest (and sampling) of cabbage and tomato varied from five to fourteen days. All gardeners used knapsack or hand sprayers for applying the pesticides. The person spraying was little or not protected against exposure, only some gardeners wore rubber boots and a face mask.

During the two sampling periods out of the total of 30 samples (24 of cabbage and 6 of tomatoes) investigated, residues of nine pesticides of the organo-phosphate group (profenofos, chlorpyrifos, chlorpyrifos methyl, dimethoate), pyrethroids (cypermethrin, deltamethrin, lamda-cyhalothrin), and organo-chlorines (endosulfan, DDT mix) were searched for in cabbage leaves and tomato fruits. The residues of cypermetrin were detected in only two samples (one cabbage from Sikasso and one tomato from Bobo-Dioulasso) at a concentration of 0.05 mg $kg^{-1}$ and 0.21 mg $kg^{-1}$ FM, respectively. No residues of other pesticides were detected.

Table 5: Thermo-tolerant coliform contamination levels in raw and curdled milk produced in Sikasso, Mali. Values are presented as $\log_{10}$ of the geometric mean MPN[1] per 100 ml of produce.

| | | Faecal coliform counts | | | | |
|---|---|---|---|---|---|---|
| | | ___Thermo-tolerant coliforms___ | | | ___Escherichia coli___ | |
| Milk | n | Geometric mean (S.D.) | Range | n | Geometric mean (S.D.) | Range |
| Raw | 5 | 4.21 (1.86) | 1.88 - 6.18 | 2 | 5.99 (0.12) | 5.90 - 6.08 |
| Curdled | 4 | 6.76 (0.74) | 6.30 - 7.88 | 4 | 6.66 (0.74) | 6.20 - 7.78 |

[1]MPN: Most Probable Number.

#### *4.3.5. Consumer health risks*

According to the health care specialists interviewed, less than 20% of the population in Sikasso visits hospitals or health centers. Cases of illness and disease due to consumption of contaminated animal products and vegetables were not systematically recorded at the different medical centers surveyed. Nevertheless, the total number of cases of diarrhea/vomiting and typhoid fever recorded across these centers increased from 2006 to 2009 by 11% and 48%, respectively. With respect to the total number of annual consultations, the cases of diarrhea/vomiting and typhoid fever together increased by 0.28% from 2006 to 2007 and decreased by 0.45% and 2.04% between 2007 - 2008 and 2008 - 2009, respectively (Table 6).

Table 6: Number of recorded cases of health problems possibly linked to food consumption in eleven health centers of Sikasso between 2006 and 2009.

| Health problems | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|
| Diarrhea and vomiting | 1378 | 1972 | 2657 | 1535 |
| Typhoid fever | 1298 | 2124 | 2085 | 1919 |
| Total medical consultations | 40836 | 59943 | 74332 | 79624 |
| Diarrhea/vomiting and typhoid fever (% of total) | 6.55 | 6.83 | 6.37 | 4.33 |

### 4.4. Discussion

#### *4.4.1. Microbiological contamination of irrigation water and lettuce*

Irrespective of period and city, irrigation water and lettuce leaves sampled during the study showed thermo-tolerant coliform levels exceeding a geometric mean count of $1 \times 10^3$ MNP 100 $ml^{-1}$ (water) and $1 \times 10^3$ MNP 100 $g^{-1}$ lettuce (wet weight) recommended by the World Health Organization (WHO 2006) for unrestricted irrigation and lettuce, respectively. The high contamination of stream water with thermo-tolerant coliform bacteria in both cities is primarily due to the direct discharge of untreated domestic sewage into streams as they pass through residential areas. The contamination levels are similar to those previously reported from Ouagadougou, Burkina Faso (Cissé 1997), Accra, Ghana (Amoah et al. 2005, 2006, 2007; Amponsah-Doku et al. 2010), and Niamey, Niger (Diogo et al. 2010). The high contamination levels of lettuce in Bobo Dioulasso can be explained by the fact that 2 out of the 3 gardens investigated there irrigate with water from the Houet River all year round. Upstream, clothes are washed in the Houet and while flowing through the city, the river receives solid and liquid wastes from riverside households and from the main slaughterhouse of the city. Before reaching Dogona quarter, where gardens line the river bank, the water is thus highly contaminated, which explains the high coliform contamination of lettuce sampled in garden B1.

The pollution of shallow wells in Sikasso, on the other hand, can be explained by surface runoff and a rising groundwater table during the rainy season. Ogden et al. (2002), Ndiaye et al. (2006) and Amponsah-Doku et al. (2010) highlighted the role of surface runoff and the mobility of pathogens across the soil for contamination of irrigation water. In Ghana, Amoah et al. (2005) and Amponsah-Doku et al. (2010) found that runoff from residential areas and from pastures, latrines, markets, and household waste dumps contributed to coliform contamination of irrigation water. Guber et al. (2007) reported that suspended manure colloids decreased bacterial attachment to soil, clay, and silt fractions, and to coated sand fractions, but did not decrease the attachment to sand fractions without coating of organic matter. The low attachment of bacteria to silt and clay particles in the presence of manure colloids may lead to predominantly free-cell transport of manure-borne faecal coliforms in runoff. The high concentration of thermo-tolerant coliforms determined in organic fertilizer in both cities suggests that this material represents a major contamination source for vegetables and irrigation water. Several studies pointed to the primordial role of organic fertilizers (manure, human excreta and household waste) in the contamination processes of soils and vegetables (Drechsel et al. 2000; Amoah et al. 2005, 2006; Diogo et al. 2010). This indicates that health risk assessments should not be limited to irrigation water, but also address alternative pathways of vegetable contamination through animal manure and soil splash. Although Unc and Goss (2004) suggested that the survival conditions for enteric bacteria are unfavorable once they are voided from the animal organism, Nicholson et al. (2005), Ferguson et al. (2007) and Guber et al. (2007) argued that some germs can survive for extended periods in even as an hospitable environments as on fabrics and plastics (Robine et al. 2000). *Escherichia coli* and *Enteroccocus* sp. from pig manure may survive in the soil for periods of 40 - 68 days after application (Cools 2001). However, studies in Kumasi showed that in the dry season the avoidance of lettuce irrigation with wastewater six days before harvest effectively reduced microbial contamination (Keraita et al. 2007). However, this might adversely affect the yield and freshness of vegetables, and thus decrease farmers' profits under semi-arid vegetable growing conditions (Diogo et al. 2010).

In contrast to Sikasso, the contamination of lettuce with pathogenic micro-organisms was not significantly decreased by postharvest handling in Bobo Dioulasso. This was mainly due to the fact that harvested lettuce was washed with the already contaminated river water before sale. Amoah et al. (2007) reported similar findings from Kumasi, Ghana, where use of irrigation water to wash harvested lettuce before sale was a common practice of wholesalers and retailers. The significant decrease in the number of coliforms from farm to market observed in Sikasso was mainly due to the use of clean water fetched from residential wells for washing the harvested lettuce. Nevertheless, the faecal coliform contamination level remained above the recommended threshold of WHO (2006), suggesting that washing the vegetables before marketing can decrease but not eliminate potential microbiological risk for consumer health.

#### *4.4.2. Microbiological contamination of milk*

Half of the milk samples from Sikasso were contaminated with faecal coliforms and *E. coli*. Treating only sick animals in cattle herds where bacterial diseases and parasites are endemic and widespread lowers milk quality (Noordhuizen and Metz 2005). Ogola et al. (2007) mentioned that the health status significantly influenced the somatic cell counts in dairy cows affected by intramammary infections in Rift Valley Province, a major milk production region of Kenya. Early detection of diseases in the herd, quarantine at farm level, medication, and vaccination are all very effective in controlling bacterial diseases in animals (Ahmad 2005). Treatments of lactating cows only after disease manifestation might be one of the reasons for pathogen introduction into the milk (Hayes et al. 2001), others being dirty udders teats, and tails. None of the farmers tied the cow's wash or disinfect udder, tail during milking, had an appropriate milking parlor or did wash hands before milking. Milk production practices influence bacterial contamination at the barn level, and poor hygienic standards at the farm can affect the rest of the dairy production chain, as exemplified in studies from Uganda (Grillet et al. 2005; Grimaud et al. 2007), Mali (Bonfoh et al. 2003, 2005), Ghana (Donkor et al. 2007), Morocco (Sraïri et al. 2009), Kenya (Ogola et al. 2007), South Africa (Beukes et al. 2001), Niger (Harouna et al. 2009; Pistocchini et al. 2009), and Burkina Faso (Millogo et al. 2008, 2010). In addition to the mammary gland, udder skin and milking practices, the litter quality, way of milk storage, air quality, milk transport, and milk transformation processes can be sources of contamination (Sevi et al. 2003; Menard et al. 2004; Bonfoh et al. 2005, 2006; Grimaud et al. 2007; Millogo et al. 2008; Sraïri et al. 2009).

The average counts of faecal coliforms and *E. coli* determined in Sikasso were lower than those reported for raw and traditionally fermented milk from the peri-urban areas of Bamako (Bonfoh et al. 2002, 2003) and from Burkina Faso (Savadogo et al. 2004; Millogo et al. 2010), but are still above the acceptable threshold of ≤10 colony-forming units (cfu) per ml. *Streptococcus* spp. were found in some of the curdled milk samples, probably as a result of mastitis infection. McDonald et al. (2005) isolated many streptococcal pathogens in milk from cows with clinical or subclinical mastitis, and Miranda-Morales et al. (2008) reported that *Staphylococcus aureus*, *Streptococcus agalactiae*, and *Mycoplasma* spp. were primarily responsible for clinical and subclinical mastitis at their study sites in Mexico.

Metwally et al. (2011) reported that boiling milk for 0.5 and 1 min decreased the bacterial counts from 3.6 x $10^9$ cfu $ml^{-1}$ in cow's milk to 6.3 x $10^2$ and 3.2 x $10^2$ cfu $ml^{-1}$, whereas *Listeria monocytogenes* (7.5 × $10^6$ cfu $ml^{-1}$) was completely destroyed at 100ºC. Although heat treatment effectively reduces bacterial counts in milk, traditionally curdled milk produced in Sikasso is usually not boiled before processing. For two out of the six surveyed cow herds the bacterial counts were very low, pointing to better overall herd management and cleaner milking practices, which were indeed observed. Prophylactic vaccinations against contagious bovine pleuropneumonia and earlier curative treatments in case of bovine trypanosomosis, foot and mouth disease and tuberculosis were administered regularly, and the milkers washed their hands, milk utensils and transportation equipments with soap before milking and use, respectively, on these two farms. In addition, the tail of cow was attached during milking.

#### *4.4.3. Pesticide contamination of cabbage and tomato*

The microclimate in frequently irrigated urban gardens leads to a year-round high atmospheric humidity, which favors the outbreak of insect pests and vegetables diseases that are usually controlled by the gardeners through frequent application of pesticides (Houndete et al. 2010). Since in only two vegetable samples non-hazardous concentrations of cypermethrin residues were detected, there was no potential health risk for consumers with regard to pesticide residues in Bobo Dioulasso and Sikasso. This result and the complete absence of residues from other pesticides are in contradiction with the massive use of a very wide range of pesticides as reported by the vegetable farmers themselves during our interviews. Therefore, either the pesticides applied by farmers were fake products and did not contain any active compound, or the laboratory procedures used in this study were not sensitive enough to quantify pesticide residues. Most of the surveyed farmers complained about the inefficiency and low quality of the pesticides used; however, the targeted pests might already have developed some resistance. In fact, sucking insects such as biting aphid (*Aphis gossypii*, Glover), whitefly (*Bemisia tabaci*, Gennadius) and the bollworm (*Helicoverpa armigera*, Hübner) are common polyphagous pests in West African plantations of cotton and vegetables such as tomato and cabbage, and have been reported to have developed resistance against pesticides in this region (Martin et al. 2000, 2005; Brevault et al. 2002; Ntow et al. 2006; Houndete et al. 2010).

Attempts undertaken to obtain pesticide samples from the vendors were not successful. They argued that pesticides from the stock delivered to farmers before the cropping season had finished by the time we wanted to obtain a sample of the sold product. However, it is quite common to find inappropriate packaging in registered retailer shops: a recent study from Burkina Faso revealed that insecticides with English labels were not authorized in the "Comité Inter-Etat de Lutte contre la Sécheresse au Sahel (CILSS)" states and usually came from Ghana or Nigeria (Secrétariat de la Convention de Rotterdam 2010). However, retailers declared to prefer pesticides from Ghana or Nigeria because products sold by registered plants or suppliers are far too expensive for their customers.

Although endosulfan is banned in the CILSS states, it is still found in some pesticide formulations used on vegetables in Bobo Dioulasso, such as ROCKY 500EC (endosulfan 500 g $l^{-1}$), ROCKY 386EC (cypermethrin 36 g $l^{-1}$ + endosulfan 350 g $l^{-1}$), CAIMAN SUPER (alpha-cypermethrin 18 g $l^{-1}$ + endosulfan 350 g $l^{-1}$) and CAIMAN ROUGE (endosulfan 250 g $l^{-1}$ + thiram 205 g $l^{-1}$). Similarly, in soil samples from Sikasso, high residue levels of six pesticides, including endosulfan (I and II), metabolite endosulfan sulfate, pp'-DDT, pp'-DDe and pp'-DDD were determined by Safiatou et al. (2007).

### *4.4.4. Consumer health risks*

Given the concentrations and kinds of pathogens found in lettuce at the farm gate and the market place, there is a potential health risk for consumers, whereby post-harvest contamination is less important than contamination at the farm level. Similarly, a potential health risk ensues from the consumption of raw and curdled milk directly purchased from the farmer. The observed high levels of lettuce and milk contamination with thermo-tolerant coliforms such as *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus* sp., *Staphylococcus aureus,* and *Enterobacter* sp. might be a major contributor to the increasing number of patients who did consult health centers in Sikasso for diarrhea and vomiting and typhoid fever between 2006 and 2009. The 48% increase in cases of typhoid fever demonstrates the extent of the problem, although *Salmonella* sp., the agents causing typhoid fever, were not found in any sample.

Apart from *E. coli*, of which some toxin-producing strains can affect consumers (Kivaria et al. 2006; Karmali 2004), the other pathogens identified in the milk samples hardly produce toxins, nor do they form spores. Infection with these organisms through milk can thus be fully controlled through milk pasteurization. Toxins produced by *Staphylococcus aureus* (Argudín et al. 2010), which could enter curdled milk through the udder or human skin, could also constitute a health risk (Klotz et al. 2003; Hetzel et al. 2004), especially as it is a major cause of gastroenteritis (Le Loir et al. 2003). In Africa many consumers fail to link food consumption to diseases: Bonfoh et al. (2003) found that 78% of people surveyed in Bamako and Mopti (Mali) were not aware of the role of food in diarrheal diseases. According to the directors of the public health centers, the recorded data represent less than a tenth of the suspected food poisoning cases in Sikasso, namely severe ones, and those occurring in families that can afford paying consultation fees and pharmaceuticals. According to Koné (Health Reference Center Sikasso, 18 May 2009) many people only link a disease case to food intake if it occurs immediately or only few hours after the intake of a contaminated product. The informant assumed that because of widespread poverty and illiteracy, less than 20% of the sick inhabitants consult the public health care services in Sikasso.

### 4.5. Conclusions

In Bobo Dioulasso and Sikasso, wastewater and organic fertilizers are the main sources of lettuce contamination with coliforms far beyond food safety limits. Although post-harvest contamination of lettuce may also occur through washing with untreated wastewater, risk reduction strategies should start at the farm level and target the quality of the mentioned inputs. Similarly, the major factors of microbial contamination of raw and curdled milk are unhygienic milking and storing practices at the farm level. To reduce risks linked to the consumption of UPA vegetables and milk, a holistic and participatory approach is needed in order to establish and effectively control hygienic management practices during production, and along the processing and marketing chain of these high value foodstuffs.

### Acknowledgements

We are grateful to urban vegetable and dairy farmers as well as lettuce vendors in Bobo Dioulasso and Sikasso for their time and willingness to participate in our survey and product sampling. We thank our colleague H. Dossa for substantial support with data analysis and D.J-P. Lompo and S. Sangaré for their continued help with field work. The administrative support of E. Compaoré from INERA at Bobo Dioulasso, Burkina Faso, is greatly appreciated. The authors are grateful to the Volkswagen Stiftung, Hannover, Germany, for supporting this research financially under the “UrbanFood” project within the collaborative program ‘Resources, their dynamics, and sustainability–capacity–development in comparative and integrated approaches’ (No. I/82 189).

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# Chapter 5

# General discussion and conclusions

## 5.1. Intensification of urban and peri-urban livestock production in West Africa

The results on livestock keepers' socio-economic characteristics across the three West African cities studied here (Chapter 2) underline how important livestock production is for the livelihoods of (peri-) urban farmers in the region. It is evident that livestock, through its multiple benefits, is well suited to contribute to social transformation of poor populations (Stroebel et al. 2011). Urbanization raises the demand for animal products (Rae 1998; van der Zijpp 1999). Various pathways for sustainable intensification of livestock husbandry can evolve in developing countries, depending on the magnitude and the rate of change of key factors driving the demand for livestock products and the quality of the underlying resource base that supports livestock production (McDermott et al. 2010). Livestock husbandry has become a popular activity for urban dwellers with a relative increase of the average number tropical livestock units (TLU[3]) in livestock keeping households (Muhammad 2008). Our insights into the (re-)productive performance of (peri-)urban livestock units in Sikasso (Chapter 3) point to a slow transition of the still quite traditional 'rural' ruminant production systems towards more market-oriented (peri-)urban systems similar to those in Niamey (Niger), Ouagadougou, and Bobo Dioulasso (Burkina Faso), Bamako (Mali), and Dakar (Senegal); (Fall et al. 2000; Hamadou et al. 2004; Bonfoh et al. 2005; Thys et al. 2005; Diogo et al. 2010).

There seems to be a lower threshold for the population size of urban centers below which an intensification of ruminant husbandry is of little advantage, either for ecological reasons (still enough grazing resources near the city or possibility for practicing short-distance transhumance systems), or for economic reasons (low purchasing power in secondary cities with little industry, artisanry, and tertiary sector). Small secondary cities in Sahelian and West African (SWAC) countries therefore seem to be less suited to study phenomena of (peri-)urban ruminant husbandry than larger ones (e.g. Kano, Nigeria, with close to 4 Mio. inhabitants) and SWAC capitals of >1 Mio. inhabitants such as Bamako, Dakar, Niamey, and Ouagadougou, from where reports on intense (peri)-urban ruminant production systems are available (Smith and Olaloku 1998; Fall et al. 2000; Bonfoh et al. 2005; Thys et al. 2005; Graefe et al. 2008).

However, it seems likely that within the next decade the pasture-based livestock production around Sikasso will suffer from shrinking grazing areas, due to the expansion of the city and the extension of cropland devoted to staple and cash crops (Hilhorst and Coulibaly 1999; Coulibaly et al. 2007). In consequence, overgrazing of the remaining pasture areas around the city will lead to a substantial reduction of pasture productivity both in

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

qualitative and quantitative terms (Abebe et al. 2011). This will increasingly force livestock keepers to shift to semi-intensive feeding systems by offering crop residues or agro-industrial crop by-products as supplement feeds to their animals (Chapters 1 and 2), and might allow animals to express their productive potential in terms of weight gain, milk yield, and ability to reproduce (Sidibé-Anago et al. 2008; Mapato et al. 2010).

Like production analysis of the dairy farms and sheep herds in Sikasso revealed poor management practices (Table 1); the daily amounts of supplement feeds offered, especially in the dry season, were insufficient to meet the animals' requirement for production (Chapter 3). Although feeding strategies that meet the animals' requirements for maintenance, production and reproduction throughout the year and its various seasons have been developed for the region (Ouédraogo et al. 2008; Sanogo 2011), these need to be explained to farmers and adopted by them. Currently even the manner of supplement distribution at the farm (group feeding) causes fights between animals for access to the feed, benefiting thus mostly the strongest animals, and a good part of feeds is spoiled and ends up as feed refusal on the dung heap. The actual practices thus need to be improved towards intensified, resource efficient, market-oriented ruminant production systems by adopting improved technologies (Stroebel et al. 2011) such as careful choice of breeds, skillful allocation of feedstuffs, appropriate use of veterinary drugs, and improved hygiene throughout the production processes (Chapter 4).

The few studies on crossbreeding of local cattle with exotic breeds such as Montbeliard, Rouge des Steppes, and Holstein to improve dairy production (Bonfoh et al. 2005; Diack et al. 2005) targeted only a small number of (peri-) urban dairy farms in West Africa. Such crossbreeds were not found in Sikasso (Chapters 2 and 3) where milk production is still based on the local taurine cattle and their crossbreeds with local zebus which are all known for their low milk yield (Debrah et al. 1995; Sanogo 2011). At this stage, the improvement of the milk production potential through crossbreeding with high yielding exotic breeds could make an important contribution to improving productivity; at the same time a very careful supervision of such strategies is needed to prevent the loss of the trypanotolerant purebred local N'Dama and West African Shorthorn breeds (Murray et al. 1990; Hanotte et al. 2003; Geerts et al. 2008). Crossbreeding strategies should be supported by the introduction of forage legume cropping to increase the availability and the quality of feedstuffs especially to lactating cows (Sanogo 2011). Despite the labour involved, the periodic transhumance observed with 'grazing only' dairy herds (Chapter 3) at present still seems to be less expensive than supplement feeding, assuring maintenance energy intake plus a bit of surplus milk extraction for (peri-) urban smallholder dairies.

Table 1: Problem analysis and strategy selection for improving efficiency and safety of (peri-) urban ruminant production systems in Sikasso, Mali

| Parameter | Cattle herds | Sheep herds |
|---|---|---|
| Problems | • Lack of pasture<br>• Low input of supplemental feeds<br>• Poor feed quality<br>• Low health care<br>• Poor dung management | • Poor feed quality<br>• Low input of supplemented feeds<br>• Low use of veterinary drugs<br>• Poor dung management |
| Consequences | • Paucity of nutrients<br>• Low growth rates<br>• Low milk yields<br>• Endemic disease prevalence<br>• Low reproductive performance | • Paucity of nutrients<br>• Low growth rates<br>• Low reproductive performance<br>• Endemic disease prevalence<br>• High mortality rates |
| Possible actions | • Appropriate feed supply<br>• Increased feed quality<br>• Strategic feeding (individual, requirement-based)<br>• Appropriate heath care<br>• Appropriate dung management<br>• Improved safety of animal products<br>• Concerted action (government) for controlling diseases and parasitism | • Appropriate feed supply<br>• Increased feed quality<br>• Strategic feeding (individual, requirement-based)<br>• Appropriate heath care<br>• Appropriate dung management<br>• Concerted action (government) for controlling diseases and parasitism |

As far as sheep husbandry is concerned, special emphasis should be placed on health management as indicated by the poor growth performance in spite of a positive energy balance (Chapter 3). Despite the increased importance of animal health care for urban livestock keepers who reported to vaccinate or medically treat their animals (Chapter 2), diseases still are limiting livestock productivity across SWAC (SWAC-OECD/ECOWAS, 2008). The direct effects of diseases on livestock productivity include reduced feed intake, changes in digestion and metabolism, increased morbidity and mortality, and decreased rates of reproduction, weight gain, and milk production; they also restrict trade in livestock and livestock products (FAO 2002). The milk contamination with microbiological pathogens reflected poor health status and poor hygienic standards (Chapter 4) as a consequence of non-investment in health care. The privatization of animal health services, the costs of service delivery and veterinary products, the minimal support of livestock keepers through public investments and lacking policies for urban production systems (SWAC-OECD/ECOWAS 2008) are aspects that affect disease control and can constrain smallholder production. The high rate of illiteracy among livestock keepers in Kano (Chapter 2) was not identified as a hindrance to the implementation of improved feeding and health care practices in (peri-) urban livestock systems, and may therefore not negatively affect the adoption of new technologies as suspected by Marenya and Barrett (2007). The interactions between animal genetics, nutrition, and diseases emphasize the need to control the effects of epidemic and endemic diseases before enhanced nutrition and genetic programmes can make an impact (FAO 2002).

**5.2. Safety of dairy products and vegetables from urban agriculture in West Africa**

Concern about food safety in urban centers currently increases given the sometimes worrisome practices of (peri-) urban agriculture (Hetzel et al. 2004; Bonfoh et al. 2006; Diogo et al. 2010; Amponsah-Doku et al. 2010). As shown in this study, the prevalence of infectious diseases and zoonoses in livestock herds across various West African cities (Chapter 1) and the microbial contamination of milk (Chapter 4) indicate that livestock and its products are potential threats for the health of consumers and the environment. Animal health including disease occurrence and drug and treatment delivery has always been one of the first constraints to animal husbandry in sub-Saharan countries of Africa (Thys et al. 2005). However, there is need for reducing these threats by giving priority to vaccination against diseases over curative treatments, and by creating a sustainable relationship between all actors involved in livestock husbandry and livestock health. Yet, responsibilities for (peri-) urban agriculture still remain unclear given the many actors involved, their lack of collaboration (Coulibaly and Yameogo 2000), and, as far as animal health is concerned, the prohibitive costs of private or state veterinary services, and the unawareness of producers and consumers about public health risks. The current ways of livestock health management (Chapter 2) increase the threat of zoonotic diseases for household labor close to animals (Vekemans et al. 1999) and deteriorate the quality of animal products (Chapter 4; Bonfoh et al. 2006; Sraïri et al. 2009). However, the misuse of veterinary drugs can also cause pathogen resistance with serious health consequences when transmitted to humans (McDonald et al. 1997; van den Bogaard and Stobberingh 2000). Since food safety starts at the farm (Olson and Slack 2006), the depreciation of products causes losses to farms and consumers. To avoid such losses, measures have to start with good animal hygiene, scrupulous observance of vaccination periods, and permanent health monitoring. Given the role of animal excreta in contamination of foodstuffs (Chapter 4; Amoah et al. 2005; Rogers and Haines 2005), the compliance with hygienic standards could help to minimize contamination of milk and vegetables from (peri-) urban agriculture. Since proper manure composting destroys most pathogens that are harmful to humans (Grewal et al. 2006; Spiehs and Goyal 2007), composting of manure could be an easy and inexpensive means to reduce vegetable contamination with faecal pathogens of animal origin.

Together with manure and sewage application, wastewater irrigation of (peri-) urban vegetables is common and economically beneficial (Scott et al. 2004), but is another main source of vegetable contamination with pathogens (Chapter 4; Jablasone et al. 2004; Amoah et al. 2005; Cofie et al. 2005; Diogo et al. 2010). Since all irrigation water sources studied in Sikasso and Bobo Dioulasso were polluted (Chapter 4), the use of groundwater, a combination of water source control and an integrated wastewater management via improved policies, institutional dialogue, and financial mechanisms may reduce the risk for (peri-)urban agriculture (Qadir et al. 2010). Generally, wastewater treatment in developing countries is impeded by low municipal/governmental resources (Drechsel et al. 2002). Lagoon sewage treatment with macrophytes (*Psitia stratiotes* L.) was shown to reduce the contamination level of faecal pathogens and parasites, but is not recommended according to the FAO and WHO directives on the quality of irrigation water for uncooked vegetables (Irénikatché et al. 2011). Furrow or flood irrigation instead of water application by cans can lower vegetable contamination levels due to reduced direct contact of the vegetables with water. However, post-harvest handling of vegetables by retailers also influences the contamination levels at market places (Chapter 4). The practice of washing vegetables before eating, which is common in urban SWAC households, could decrease or eliminate much of the microbiological agents (Amponsah-Doku et al. 2010), especially if combined with disinfectants such as sodium hypochlorite or citric acid (Raicevic et al. 2010). Along with measures to take at the field level, such practices at the household level would need to be broadly communicated to lower the incidence of diarrhea, especially in young children and elderly people, across the SWAC region (Drechsel et al. 2010).

Although the concentrations of pesticide residues found on vegetables in Bobo Dioulasso and Sikasso (Chapter 4) present no health risk for consumers, the frequent use of pesticides in (peri-) urban gardens, and especially the use of officially banned substances or chemicals not allowed on vegetables still constitute a challenge for (peri-) urban vegetable production. Amoah et al. (2006) identified pesticide residues above maximum residue limits (MRLs) for consumption in lettuce leaves on markets in Accra, Kumasi, and Tamale (Ghana); more than 60% of those lettuce samples had concentrations equal to or more than twice as high as the MRL values. Policy makers and extension services should thus focus on the massive use of a very wide range of pesticides as reported by the vegetable farmers themselves (Chapter 2), their probably fake nature, and the communication of rules and guidelines to enhance safety of pesticide use for producers and of thus treated foodstuffs for consumers. In addition, a decided enforcement and control of regulations already in place is highly indicated.

# Chapter 6

## Recommendations

### 6.1. Recommendations

For ensuring economically successful and ecologically viable (peri-)urban livestock husbandry and food safety of (peri-) urban foodstuffs of animal and plant origin, the following specific recommendations for policy makers (P), extension agencies (E), and farmers (F) are emerging from the present study:

- Dissemination (E) and adoption (F) of improved livestock feeding practices, health care, and dung management through government services and private-public partnerships.
- Concerted action involving private and public veterinary services for controlling diseases and parasitism (P, E, F).
- Dissemination (E) and adoption (F) of measures fostering the safety of animal products and vegetables at farm level, at harvest, and in post-harvesting processes. This includes the composting of manures used in vegetable cropping systems to reduce infectiousness of pathogens contained therein.
- Control of the provision (P) and appropriate use (E) of approved vegetable pesticides and the respect of their latency periods (F).
- Passing and control of laws (P) on the treatment and appropriate use (E, F) of wastewater in (peri-) urban agriculture, especially vegetable farming.
- Incorporation of (the requirements of) environmentally sound (peri-) urban agriculture in urban planning (P, (E)).

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