Horizontal nutrient fluxes and production efficiencies in urban and peri-urban crop and livestock husbandry of Niamey, Niger

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Dedication

To

the memory of my late mum Yvonne Zannou,
my dad Blaise Diogo,

my wife Diane Egounlety,
our daughter Ahouéfa Solène R. Diogo

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Summary

Horizontal nutrient fluxes and production efficiencies in urban and peri-urban crop and livestock husbandry of Niamey, Niger

Urban and peri-urban agriculture (UPA) increasingly supplies food and non-food values to the rapidly growing West African cities. However, little is known about the resource use efficiencies in West African small-scale UPA crop and livestock production systems, and about the benefits that urban producers and retailers obtain from the cultivation and sale of UPA products. To contribute to filling this gap of knowledge, the studies comprising this doctoral thesis determined nutrient use efficiencies in representative urban crop and livestock production system in Niamey, Niger, and investigated potential health risks for consumers. Also assessed was the economic efficiency of urban farming activities.

The field study, which was conducted during November 2005 to January 2008, quantified management-related horizontal nutrient flows in 10 vegetable gardens, 9 millet fields and 13 cattle and small ruminant production units. These farms, selected on the basis of a preceding study, represented the diversity of UPA crop and livestock production systems in Niamey. Based on the management intensity, the market orientation and especially the nutrient input to individual gardens and fields, these were categorized as high or low input systems.

In the livestock study, high and low input cattle and small ruminant units were differentiated based on the amounts of total feed dry matter offered daily to the animals at the homestead. Additionally, economic returns to gardeners and market retailers cultivating and selling amaranth, lettuce, cabbage and tomato - four highly appreciated vegetables in Niamey were determined during a 6-months survey in forty gardens and five markets.

For vegetable gardens and millet fields, significant differences in partial horizontal nutrient balances were determined for both management intensities. Per hectare, average annual partial balances for carbon (C), nitrogen (N), phosphorus (P) and potassium (K) amounted to 9936 kg C, 1133 kg N, 223 kg P and 312 kg K in high input vegetable gardens as opposed to 9580 kg C, 290 kg N, 125 kg P and 351 kg K in low input gardens. These surpluses were mainly explained by heavy use of mineral fertilizers and animal manure to which irrigation with nutrient rich wastewater added. In high input millet fields, annual surpluses of 259 kg C ha^{-1}, 126 kg N ha^{-1}, 20 kg P ha^{-1} and 0.4 kg K ha^{-1} were determined. Surpluses of 12 kg C ha^{-1}, 17 kg N ha^{-1}, and deficits of -3 kg P ha^{-1} and -3 kg K ha^{-1} were determined for low input millet fields. Here, carbon and nutrient inputs predominantly originated from livestock manure application through corralling of sheep, goats and cattle.

In the livestock enterprises, N, P and K supplied by forages offered at the farm exceeded the animals' requirements for maintenance and growth in high and low input sheep/goat as well as cattle units. The highest average growth rate determined in high input sheep/goat units was 104 g d^{-1} during the cool dry season, while a maximum average gain of 70 g d^{-1} was determined for low input sheep/goat units during the hot dry season. In low as well as in high input cattle units, animals lost weight during the hot dry season, and gained weight during the cool dry season. In all livestock units, conversion efficiencies for feeds offered at the homestead were rather poor, ranging from 13 to 42 kg dry matter (DM) per kg live weight gain (LWG) in cattle and from 16 to 43 kg DM kg^{-1} LWG in sheep/goats, pointing to a substantial waste of feeds and nutrients.

The economic assessment of the production of four high value vegetables pointed to a low efficiency of N and P use in amaranth and lettuce production, causing low economic returns for these crops compared to tomato and cabbage to which inexpensive animal manure was applied. The net profit of market retailers depended on the type of vegetable marketed. In addition it depended on marketplace for amaranth and lettuce, and on season and marketplace for cabbage and tomato.

Analysis of faecal pathogens in lettuce irrigated with river water and fertilized with animal manure indicated a substantial contamination by *Salmonella* spp. with 7.2 x 10^4 colony forming units (CFU) per 25 g of produce fresh matter, while counts of *Escherichia coli* averaged 3.9 x 10^4 CFU g^{-1}. In lettuce irrigated with wastewater, *Salmonella* counts averaged 9.8 x 10^4 CFU 25 g^{-1} and *E. coli* counts were 0.6 x 10^4 CFU g^{-1}; these values exceeded the tolerable contamination levels in vegetables of 10 CFU g^{-1} for *E. coli* and of 0 CFU 25 g^{-1} for *Salmonella*.

Taken together, the results of this study indicate that Niamey's UPA enterprises put environmental safety at risk since excess inputs of N, P and K to crop and livestock production units favour N volatilisation and groundwater pollution by nutrient leaching. However, more detailed studies are needed to corroborate these indications. Farmers' revenues could be significantly increased if nutrient use efficiency in the different production (sub)systems was improved by better matching nutrient supply through fertilizers and feeds with the actual nutrient demands of plants and animals.

Deutsche Zusammenfassung

Horizontale Nährstoffflüsse und Produktionseffizienzen im urbanen und peri-urbanen Pflanzenbau und Tierhaltung von Niamey, Niger

Die urbane und peri-urbane Landwirtschaft (UPL) liefert in zunehmendem Maße Nahrung und ’non-food’ Produkte für die schnell wachsende Bevölkerung westafrikanischer Städte. Bisher ist die Ressourcennutzungseffizienz in den kleinen Tierhaltungs- und Pflanzenbaubetrieben der UPL Westafrikas jedoch nur wenig untersucht, und der Nutzen, den Produzenten und Händler aus dem Anbau und Verkauf der UPL Produkte ziehen ist nicht bekannt. Daher untersuchte die vorliegende Dissertation die Ressourcennutzungseffizienz in repräsentativen städtischen Pflanzenbau- und Tierhaltungsbetrieben in Niamey, Niger, wobei Aspekte der Wirtschaftlichkeit der urbanen Landwirtschaft und möglicher Gesundheitsrisiken für die Verbraucher der erzeugten Produkte mit berücksichtigt wurden.

Die von November 2005 bis Januar 2008 durchgeführte Studie quantifizierte die durch das Management bedingten horizontalen Nährstoffflüsse in 10 Gemüsegärten, 9 Hirsefeldern und 13 Rinder-, Schaf- und Ziegenbetrieben. Die Untersuchungseinheiten wurden anhand einer Vorstudie ausgewählt und spiegelten die Vielfalt der Tierhaltungs- und Pflanzenbaubetriebe in der UPL wider. Entsprechend der Intensität des Managements, der Marktorientierung und insbesondere des Nährstoffeintrages in einzelne Gärten und Felder wurden diese als extensive beziehungsweise intensive Einheiten klassifiziert. Entsprechend wurden anhand der im Stall vorgelegten Futtermengen Rinder- und Schaf/Ziegen-Betriebe in extensive beziehungsweise intensive Betriebe eingeteilt. Während einer sechsmonatigen Studie wurde zusätzlich in 40 Gärten und auf 5 Märkten der ökonomische Nutzen erfasst, welchen Bauern und Händler aus dem Anbau und Verkauf von Amarant, Kopfsalat, Kohl und Tomaten ziehen, vier in Niamey hoch geschätzte Gemüsearten.

Als Differenz der Nährstoffein- und -austräge in eine Produktionseinheit zeigen Nährstoffbilanzen an, ob ein System hinsichtlich dieser Nährstoffe ausgeglichen, unzulänglich versorgt oder überversorgt ist; aus ökonomischer und ökologischer Sicht sind Bilanzen daher brauchbare Indikatoren für die Bewertung der Nachhaltigkeit landwirtschaftlicher (Teil)Systeme.

Für die horizontalen Nährstoffbilanzen in Gemüsegärten und Hirsefeldern ergaben sich jeweils deutliche Unterschiede zwischen den beiden Managementintensitäten. Pro Hektar betrugen die jährlichen Teilbilanzen für Kohlenstoff (C), Stickstoff (N), Phosphor (P) und Kalium (K) betrugen 9936 kg C, 1133 kg N, 223 kg P und 312 kg K in intensiv bewirtschafteten Gemüsegärten und 9580 kg C, 290 kg N, 125 kg P und 351 kg K in extensiv bewirtschafteten Gärten. Nährstoffüberschüsse waren insbesondere durch den hohen Einsatz von Mineraldüngern und Tiermist sowie Bewässerung mit

nährstoffreichen Abwässern bedingt. In Hirsefeldern mit hohen Einträgen wurden pro Hektar jährliche Überschüsse von 259 kg C, 126 kg N, 20 kg P und 0.4 kg K ermittelt, in Hirsefelder mit niedrigen Einträgen ergaben sich Überschüsse von 12 kg C und 17 kg N und Defizite von -3 kg P und -3 kg K. Hier stammten die Einträge von Kohlenstoff und Nährstoffen überwiegend aus dem Dung der auf den Feldern gepferchten Schafe, Ziegen und Rinder.

In allen tierhaltenden Betrieben übertraf die Versorgung mit N, P und K durch das im Stall angebotene Futter den Bedarf der Schafe, Ziegen und Rinder für Erhaltung und Wachstum. Der höchste durchschnittliche Zuwachs in intensiv geführten Schaf/Ziegen-Betrieben betrug 104 g d^{-1} und wurde in der kühlen Trockenzeit erzielt; der maximale Zuwachs in extensiv geführten Schaf/Ziegen-Betriebe betrug 70 g d^{-1} und wurde in der heißen Trockenzeit ermittelt. Sowohl in den intensiv als auch in den extensiv geführten Rinderbetrieben nahmen die Tiere in der kühlen Trockenzeit an Gewicht zu, während in der heißen Trockenzeit Gewichtsverluste beobachtet wurden. Sowohl in Schaf/Ziegen-Betrieben als auch in den Rinder haltenden Betrieben war die Nutzungseffizienz des im Stall angebotenen Futters niedrig; der Futteraufwand betrug 13 - 42 kg Trockensubstanz (TS) pro kg Lebendgewichtzuwachs (LGZ) bei Rindern und 16 - 43 kg TS kg^{-1} LGZ bei Schafen und Ziegen; daraus ergeben sich erhebliche Verluste der eingesetzten Futter- und Nährstoffe durch einen nicht unerheblichen Transfer in Richtung der ebenfalls unzureichend bewirtschafteten Dunghaufen.

Die ökonomische Bewertung des Anbaus und der Vermarktung hochwertiger Gemüsearten zeigte, dass bei Amarant und Kopfsalat eine geringe Stickstoff- und Phosphornutzungseffizienz Ursache der geringen Wirtschaftlichkeit dieser Kulturpflanzen ist; im Gegensatz dazu führt der hohe Einsatz von billigem Tierdung zu hohen Erlösen der Produzenten von Tomate und Kohl. Der Reinerlös der Gemüsehändler hing von der Art des vermarkteten Gemüses ab, bei Amarant und Salat außerdem vom Marktort und bei Kohl und Tomate zusätzlich von der Jahreszeit.

Die Untersuchung des mit Flusswasser bewässerten und mit Tiermist gedüngten Kopfsalates auf Fäkalkeime zeigte eine erhebliche Belastung mit Salmonellen; gemessen wurden bis zu 7.2×10^4 kolonienbildende Einheiten (KBE) pro 25 g produzierter Frischmasse sowie durchschnittlich 3.9×10^4 KBE an *Escherichia coli* pro Gramm Produkt-Frischmasse. Bei mit Abwasser bewässertem Kopfsalat lagen die Zellzahlen für *Salmonella* bei 9.8×10^4 KBE pro 25 g und für *E. coli* bei 0.6×10^4 KBE pro Gramm Frischmasse. Diese Werte überstiegen somit die für Gemüse etablierten tolerierbaren Schwellenwerte für *E. coli* (10 KBE g^{-1}) und für *Salmonella* (0 KBE pro 25 g).

Zusammenfassend zeigen die Ergebnisse dieser Studie, dass Niameys UPL-Betriebe die Umwelt potentiell gefährden, da überschüssige N-, P- und K-Einträge in Ackerbau und Tierhaltung gasförmige Stickstoffemissionen verursachen und das Grundwasser aufgrund von Nährstoffauswaschungen belasten. Um diese Schlussfolgerungen zu erhärten sind jedoch detailliertere Untersuchungen erforderlich. Andererseits bringt der städtische Gemüseanbau unbestreitbaren Nutzen mit sich, doch könnte das Einkommen der Bauern erheblich erhöht werden wenn die Nährstoffnutzungseffizienz in den verschiedenen Produktions(Teil)Systemen verbessert würde, indem die Versorgung mit Nährstoffen aus Dünge- und Futtermitteln dem tatsächlichen Bedarf der Pflanzen und Tiere angepasst würde.

Résumé

Les flux horizontaux des nutriments et la rentabilité de production des systèmes de culture et d´élevage urbains et périurbains de Niamey, Niger

L´agriculture urbaine et péri-urbaine (AUP) contribue de plus en plus à la satisfaction des besoins alimentaires et non-alimentaires des villes d´Afrique occidentale à croissance rapide. Cependant, il existe peu de données substantielles tangibles sur l´utilisation efficiente des ressources disponibles dans les systèmes de production à petite échelle de culture et d´élevage d´Afrique occidentale ainsi que sur les bénéfices que les producteurs et les détaillants obtiennent de la culture et la vente des produits de l´AUP.

Pour combler cette double lacune, les études menées dans le cadre de la présente thèse de doctorat ont déterminé les performances d´utilisation des nutriments dans les systèmes urbains de culture et de production animale représentatifs de Niamey au Niger, et ont étudié les risques potentiels pour la santé des consommateurs. En outre, la rentabilité économique des activités agricoles urbaines a également fait l’objet d’une évaluation.

L´étude de terrain qui s´est déroulée de Novembre 2005 à Janvier 2008 a mesuré les flux nutritifs horizontaux (entrées et sorties) relatifs au système de gestion dans dix (10) jardins maraîchers, neuf (09) champs de mil et treize (13) ménages de petits ruminants et de bovins. Ces entreprises ont été sélectionnées sur la base d´une étude antérieure et sont représentatifs de la diversité des systèmes de production de culture et d´élevage à Niamey. En tenant compte de l´intensité de la production, de l´orientation vers la vente et particulièrement de l´apport en nutriments aux différents jardins et champs, ceux-ci ont été classés comme système intensif (forte entrée de nutriments) ou système extensif (faible entrée de nutriments).

Dans le système d´élevage, les entreprises intensives et extensives ont été classées sur la base des quantités totales de matière sèches offertes quotidiennement aux animaux sur les fermes. Aussi, les retombées économiques pour les jardiniers et les détaillants de marché impliqués dans la culture et la vente de l´amarante, la laitue, le chou et la tomate, quatre légumes fortement appréciés à Niamey, ont été déterminées au moyen d’une enquête de six (06) mois menée sur quarante (40) jardins et cinq (05) marchés.

En ce qui concerne les jardins de légumes et les champs de mil, des différences significatives ont été constatées pour les balances horizontales

partielles des nutriments au niveau des deux intensités de gestion considérées.

Par hectare, les balances annuelles partielles moyennes du carbone (C) de l´azote (N), du phosphore (P) et du potassium (K) déterminées s´élèvent à 9936 kg C, 1133 kg N, 223 kg P et 312 kg K dans les jardins intensifs contrairement à 9580 kg C, 290 kg N, 125 kg P et 351 kg K obtenus dans les jardins extensifs. Ces excédents sont principalement dûs à la forte utilisation des engrais minéraux et organiques (fumiers) auxquels s´ajoutent l´irrigation par les eaux usées riches en éléments nutritifs. Dans les systèmes intensifs de mil, des excédants annuels de 259 kg C ha^{-1}, 126 kg N ha^{-1}, 20 P ha^{-1}, et 0.4 kg K ha^{-1} étaient déterminés. Par contre des excédents annuels de 12 kg C ha^{-1}, 17 kg N ha^{-1}, et des déficits de -3 kg P ha^{-1} et -3 kg K ha^{-1} ont été constatés dans les systèmes extensifs de mil. Ici, il convient de souligner que les entrées de carbone et d´éléments nutritifs ont pour principale origine l´application du fumier du bétail suite au parcage des moutons, chèvres et bovins.

Dans les entreprises d´élevage, N, P et K fournis aux animaux à travers les fourrages offerts dans les étables ont dépassé les exigences alimentaires pour l´entretien et la croissance des moutons/chèvres et bovins aussi bien dans les entreprises intensives qu´extensives. Le gain moyen quotidien le plus élevé déterminé dans les unités intensives de moutons/chèvres était 104 g et ceci pendant la saison sèche froide, alors que le gain moyen quotidien maximal de 70 g était obtenu dans les unités extensives pendant la saison sèche chaude. Aussi bien dans les entreprises extensives qu´intensives de bovins, les animaux, ont perdu du poids pendant la saison sèche chaude et en ont pris pendant la saison sèche froide. Sur toutes les unités du cheptel, les coefficients d´efficacité alimentaire des aliments servis dans les ménages étaient plutôt faibles allant de 13 à 42 kg de matière sèche (MS) par kg de gain moyen quotidien (GMQ) dans les unités de bovins, et de 16 à 43 kg MS kg^{-1} GMQ chez les moutons/chèvres, indiquant un gaspillage substantiel des aliments et par ricochet des nutriments qu´ils contiennent.

L´analyse économique de la production de quatre (04) légumes fortement appréciés a indiqué une faible rentabilité d´utilisation de N et de P dans la production d´amarante et de la laitue, entraînant de faibles retombées économiques pour ces deux cultures, contrairement à celle de la tomate et du chou auxquels le fumier très peu coûteux était appliqué. Il a été établi que le bénéfice net des détaillants de marché est influencé par le type de légumes vendus. En outre, l´influence du marché s´est révélée pour les gains obtenus pour l´amarante et la laitue, pendant que la saison et le type de marché ont affecté ceux obtenus pour le chou et la tomate.

L´analyse des germes pathogènes fécaux sur la laitue irriguée avec l´eau de rivière et fertilisée avec du fumier a indiqué une contamination substantielle par les espèces de *Salmonella* spp. avec une concentration de 7.2 x 10^4 unités formant des colonies (UFC) par 25 g de matière fraîche (MF) du produit, pendant qu´une concentration moyenne de 3.9 x 10^4 UFC par gramme de MF était quantifiée pour *Escherichia coli*. Sur la laitue irriguée avec les eaux usées, les concentrations moyennes relevées sont de 9.8 x 10^4 UFC par 25 g de MF pour *Salmonella* spp. et 0.6 x 10^4 UFC par gramme de MF pour *E. coli*. Ces valeurs obtenues dépassent les normes admissibles pour les légumes consommés frais estimées à 10 UFC par gramme de MF pour *E. coli* et à 0 UFC par 25 g de MF pour *Salmonella.*

En somme, les résultats de cette étude indiquent que les activités des entreprises agricoles impliquées dans l´AUP à Niamey induiraient des risques pour la santé de l'homme et l'environnement, du fait des entrées excessives de N, P et K obtenues dans les unités de production de culture et du bétail et favoriseraient ainsi la volatilisation de l´azote et la pollution de la nappe phréatique par le lessivage de nutriments. Cependant des études détaillées sont nécessaires pour confirmer ces indications.

Les revenus des paysans pourraient être significativement augmentés si l´efficacité d´utilisation des nutriments dans les différents (sous-)systèmes de production était améliorée par une meilleure synergie entre les nutriments fournis à travers les fertilisants et les fourrages et les demandes nutritives réelles des plantes et des animaux.

Chapter 1

General introduction

1. Urbanization and urban farming

The rapid growth of cities worldwide (49% urban population in 2005 and nearly 60% by 2030, UN-Population Division 2005) has spurred urban agriculture, which is the growing of plants and the raising of animals for food and other uses within and around cities and towns (van Veenhuizen 2006). The urbanization phenomenon is most notable in the rapidly expanding economies of China and India, as well as in areas of the world where there is significant population and environmental pressure without much economic growth (Redwood 2009). Sub-Saharan Africa (SSA) represents an extreme example of massive urbanization with an average rate of 36% (UN-Habitat 2007), whereby the major challenge is to feed the population of the growing cities. Today, the high input livestock and crop production systems developing in the midst of West African cities (Thys et al. 2005; Assogba-Komlan et al. 2007; Drechsel et al. 2007; Graefe et al. 2008) raise concern about food safety and environmental contamination and the sustainability of the production systems resulting from there. Urban and peri-urban agriculture (UPA) face the challenge of access to the main agricultural inputs - fertilizers and water - and the challenge of food production in an often polluted environment (De Bon et al. 2009). The most expensive inputs in terms of direct costs are fertilizers and pesticides as well as animal feeds (Drechsel et al. 1999; Urassa and Raphael 2004). These resources should thus be used very efficiently (Chapter 1.3), which will at the same time reduce negative externalities (Chapter 1.2) such as nutrient or pesticide leaching to the groundwater. Nutrient budgeting approaches provide a basis for informed management decisions and improved farming practices (Öborn et al. 2003; Hedlung et al. 2003) and have been used to estimate the subsoil nutrient depletion in SSA (van den Bosch et al. 1998; Smaling et al. 1999). A number of studies focused on food safety and N, P and K balances in various vegetable gardens and livestock production systems characterised by high inputs of fertilizers, waste water, manure and livestock feeds, and on subsequent nutrient losses leading to eutrophication and environmental pollution (Huang 2006; Khai et al. 2007; Redding et al. 2007; Powell et al. 2008). However, urban farming is not only characterised by problems but also by substantial benefits to farmers and consumers of primary and transformed UPA products (Chapter 1.1).

1.1 Benefits of urban agriculture

Urban and peri-urban agriculture has been internationally recognised as a means to increase food supply in cities. At the same time, UPA can contribute to improved nutrition, employment and alleviates poverty among urban households (Barrage et al. 2006). According to FAO (2005), UPA already supplies food to about 700 million city dwellers worldwide and substantially contributes to the world food demand, covering about 10% thereof (Schnitzler et al. 1998). For the city of Kumasi (Ghana) it was estimated that 90% of all lettuce, cabbage and spring onions consumed are produced in the city itself, while the rest coming from peri-urban and rural areas (Cofie et al. 2001). In Kampala (Uganda), 70% of the eggs and poultry meat consumed is produced within the city boundaries (Bryld 2003), and in Dar es Salaam (Tanzania) the livestock numbers in and around the city have increased dramatically between 1985 and 1989, with poultry numbers rising from 500,000 to about 800,000 (Mosha 1991). A comprehensive study of urban agriculture in Kenya revealed that almost two-thirds of all Kenyan households grew some of their own food (maize, bean, cabbage), 29% of them did so within the boundaries of the town in which they lived (Nairobi, Kibera, Korogocho and Pumwani/Eastleigh) and 17% of the households kept animals within the boundaries of Nairobi (Dennery 1995). While poor urban households spend 50% to 90% of their income on food, urban agriculture may offer an opportunity for a better diet and a chance to shift household spending toward other needs, such as health care and housing (Rabinovitch and Schmetzer 1997).

Besides its direct nutritional benefits through consumption, urban agriculture is also viewed as a vital element in the survival strategy of household members who can generate extra income through urban farming (Tacoli 1998). In the low-income urban households of Korogocho (Kenya), 40% of the produced green maize, green bean, cowpea, pigeon pea, cabbage, amaranth and sugarcane were sold; while in the low-income areas of Pumwani/Eastleigh (Kenya) the proportion of commercialised produce was even higher (Mwangi, 1995). Likewise, for Niamey (Niger), Graefe et al. (2008) showed that urban food production represented the sole source of income for 46% of 130 surveyed households involved in UPA. Of these households, 82% kept sheep, goats and cattle, 42% were involved in the cultivation of lettuce, cabbage, tomato, roselle, amaranth, pepper and strawberry, and 58% cultivated pearl millet as a staple crop. The net monthly income (NMI) per farm in Niamey was estimated at US$ 40, while in Bamako (Mali), Ougadougou (Burkina Faso), Cotonou (Benin), Lagos (Nigeria) and Accra (Ghana) the NMI per farm varied between US$ 10 – 300, 15 – 90, 50 – 110, 53 – 1160 and 40 – 57 (Drechsel et al. 2006). In Lagos, where commercial vegetable production enterprises operate, 78% of labour was hired for the major activities land preparation, (trans-) planting, weeding, irrigation and harvesting. Mean daily wages ranged from US$ 0.31 for harvesting to US$ 1.86 for irrigation (Ezedinma and Chukuezi 1999). Similarly, in Port Harcourt, Nigeria’s third largest commercial centre after Lagos and Kano, commercial floriculture enterprises employed 82% of the annual labour on a permanent basis with higher monthly wages for men (about US$ 31 per labourer) than for hired female labourers (about US$ 24) (Ezedinma and Chukuezi 1999). At the city level, UPA provides fresh perishable products that rural agriculture cannot supply easily and provides positive environmental side-effects through waste recycling and maintenance of green spaces in town (Fleury and Ba 2005; Floquet et al. 2005).

1.2 Problems related to urban agriculture

Despite its growing importance and clear benefits, UPA has been characterised by large inefficiencies of production due to oversupply of soil amendments especially to vegetables (Eaton and Hilhorst 2003; Graefe et al. 2008). For example, from the South of Benin high inputs of organic (>40 t ha^{-1}) and mineral fertilisers (>600 kg ha^{-1}) are reported for African eggplant (Assogba-Komlan et al. 2007). In Kumasi (Ghana), the use of poultry manure in vegetable farming is very common due to its fast release of nutrients for vegetables, and its low price of US$ 0.1 per bag (Drechsel et al. 2000). Annual poultry manure application rates can be as high as 100 - 200 t ha^{-1} (Drechsel et al. 2005). In Kamboinsé and other surrounding areas of Ouagadougou (Burkina Faso) as well as in Bamako (Mali), solid organic waste is applied in urban agriculture (Eaton and Hilhorst 2003). Farmers regularly make informal arrangements with drivers of the municipal waste lorries to have solid waste dumped near their fields (Eaton and Hilhorst 2003). However, the frequencies and amounts of waste application are unknown. For the urban vegetable production at Kumasi, the potential daily availability of nutrients from solid organic wastes was estimated at 3000 kg N, 800 kg P and 4200 kg K (Nsiah-Gyabaah and Adam 2001).

In addition to negative side-effects of excess application of nutrients on the quality of groundwater by leaching (Zhang et al. 1996; Bassanino 2007), health risks for consumers may arise if pathogens, mainly faecal coliforms of human and animal origin (Keraita and Drechsel 2002; Amoah et al. 2005) and heavy metals are introduced into the food chain (Gupta et al. 2008). These contaminants may originate from the use of untreated livestock manure, agro-chemicals and organic municipal waste water as well as sewage as inputs to the cultivation of crops, vegetables and livestock feeds (Guendel 2002; Binns et al. 2003; Asano and Cortuvo 2004). For health and environmental concerns in urban food production, the case of Kano (Nigeria) is illustrative, where high concentrations of chemical pollutants in irrigation water have been reported (Binns 2003), with the consequence of accumulation of heavy metals in the irrigated plants (Mapanda et al. 2005; Kalavrouziotis et al. 2008). Limited recycling of livestock manure to cropland, poor manure management, heavy fertilization and nutrient input via wastewater were major weaknesses identified in the UPA system of the Sahelian city of Niamey, Niger (Graefe et al. 2008) and other urban faming systems of West Africa (Drechsel et al. 1999; Keraita and Drechsel 2002; Amoah et al. 2005, Assogba-Komlan et al. 2007).

1.3 Resource use efficiency of UPA

Efficient utilization of resources is an important economic component of any business operation (Linn et al. 2007) whereby the major challenge is to manage the animals, crops and other farm components such as to use available nutrients, and thereby reduce the potential losses to the environment (Rotz 2004). Input of nutrients such as N and P are essential to maintaining agricultural productivity (Tilman et al. 2002). At the same time, a supply of nutrients in excess of immediate crop needs can be a source of potential environmental damage to surface and ground water (eutrophication), air quality (acidification) and contribute to global warming (Carpenter et al. 1998; Dijkstra et al. 2007). Solutions to these problems will require significant increases in nutrient use efficiency, that is increased crop production, meat and milk output per unit of N, P, K and water applied (Titman et al. 2001). In crop production, nutrient-use efficiency is increased by closely matching temporal and spatial nutrient supply with plant demand (Cassman et al. 2002; Chen et al. 2006). A common goal in animal feeding is to provide the appropriate amount and quality of protein to maximize production at a minimum of feeding costs. As the balance between the quality and amount of protein fed and the animals' requirement improves, less nitrogen is excreted and meat and milk production may be improved (Rotz 2004). However, to ascertain long-term sustainability of the natural resource base in general and of agricultural lands in particular, proper monitoring of nutrient flows and balances is required (Gustafson et al. 2007). Sustainability of UPA basically implies its ability to continue in the future and operate at the current or increased levels of production (Nugent 2001), while at the same time affecting less environmental health and providing healthy lives as well as ecosystem services to urban dwellers. Considering all costs and benefits of a given practice, nutrient efficient management will maximise the net benefits to society (Tilman et al. 2002) whereby the equilibrium between nutrient inputs and removals has been described as a key factor (Gustafson et al. 2007).

1.4 Objectives and research hypotheses guiding the present study

Since the so-far published evaluations of matter and nutrient fluxes and balances in African (and some Asian) UPA systems are predominantly based on the extrapolation of estimated input and output values or on partial balances for specific production sectors, this study aimed at a detailed analysis of management-based horizontal nutrient flows in differently managed UPA production systems in Niamey, Niger, so as to determine the sustainability and environmental safety of the urban crop and livestock production systems.

More specifically, this PhD research aimed at:

(i) determining the horizontal fluxes (inputs and outputs) of C, N, P and K and the nutrient use efficiencies along the continuum of water, soil, plants and animals in the UPA plant (vegetable and millet) and livestock production systems;

(ii) determining the concentrations of heavy metals (copper: Cu, cadmium: Cd, lead: Pb, zinc: Zn, and Nickel: Ni) and faecal pathogens in irrigation water and on leafy vegetables (amaranth, lettuce, cabbage - pathogens only) in the urban vegetable enterprises; and

(iii) characterising the benefit of high value vegetable production in Niamey in economic terms.

To achieve these goals, the following research hypotheses were tested through a two-year (11/2005-01/2008) quantitative on-farm monitoring in representative UPA crop and livestock enterprises, accompanied by structured interviews and interview-based market surveys:

(i) The livestock production in Niamey is characterized by inefficient forage management (Figure 1a), resulting in low growth rates of animals and sub-optimal nutrient use efficiency.

(ii) The vegetable production in Niamey is characterized by high nutrient inputs through organic or inorganic fertilizers (Figure 1b) and irrigation with wastewater and sewage (Figure 1c); the high value vegetables produced in Niamey cover more than 50% of the demand in town.

(iii) The use of untreated irrigation water, livestock dung and household wastes in urban agriculture leads to a contamination (Figure 1d) of leafy vegetables with faecal pathogens and heavy metals.

Figure 1. Aspects of Niamey's UPA systems. a) Feeding management. b) Input of livestock dung (top) to okra and urea (down) to lettuce. c) Input of wastewater to lettuce. d) Lettuce fertilized with livestock manure (down) and sampled before marketing for pathogen screening (top).

1.5 Structure of the thesis

Following this introductory overview (Chapter 1) on nutrient flows in urban agriculture and on the benefits and risks ensuing from UPA, this thesis comprises an analysis of horizontal nutrient balances in urban and peri-urban gardens and fields (Chapter 2), whereby potential risks for human health linked to irrigation and fertilisation practices are also addressed. Chapter 3 characterises live weight development, horizontal nutrient fluxes and resource use efficiencies in Niamey's livestock enterprises, and Chapter 4 evaluates gardeners' and retailers' economic benefits from cultivating and marketing high demand vegetables. The thesis concludes with a comprehensive discussion (Chapter 5) on how farm nutrient management practices influence the efficiency of urban food production and determines potential risks for food safety that are often coupled with these production systems, whereby possibilities for improvement of nutrient management and consequent reduction of negative externalities are addressed.

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Horizontal nutrient fluxes and food safety in urban and peri-urban vegetable and millet cultivation of Niamey, Niger*

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Abstract

Urban and peri-urban agriculture (UPA) has often been accused of being nutrient inefficient and producing negative externalities. To investigate these problems for the West African capital Niamey (Niger), nutrient inputs through fertilizer and manure to 10 vegetable gardens and 9 millet fields and nutrient offtakes through harvests were quantified during 24 months, and contamination of irrigation water and selected vegetables with faecal pathogens and heavy metals was determined. Annual partial horizontal balances for carbon (C), nitrogen (N), phosphorus (P) and potassium (K) amounted to 9,936 kg C ha^{-1}, 1,133 kg N ha^{-1}, 223 kg P ha^{-1} and 312 kg K ha^{-1} in high input vegetable gardens as opposed to 9,580 kg C ha^{-1}, 290 kg N ha^{-1}, 125 kg P ha^{-1} and 351 kg K ha^{-1} in low input gardens. In high input millet fields, annual surpluses of 259 kg C ha^{-1}, 126 kg N ha^{-1}, 20 kg P ha^{-1} and 0.4 kg K ha^{-1} were recorded, whereas surpluses of 12 kg C ha^{-1}, 17 kg N ha^{-1}, and deficits of -3 kg P ha^{-1} and -3 kg K ha^{-1} were determined for low input fields. Counts of *Salmonella* spp. and *Escherichia coli* yielded above threshold contamination levels of 7.2 x 10^{4} CFU 25 g^{-1} and 3.9 x 10^{4} CFU g^{-1} in lettuce irrigated with river water and fertilized with animal manure. *Salmonella* counts averaged 9.8 x 10^{4} CFU 25 g^{-1} and *E. coli* 0.6 x 10^{4} CFU g^{-1} for lettuce irrigated with wastewater, while these pathogens were not detected on vegetables irrigated with pond water. These results underline the need for urban gardeners to better adjust the nutrients applied to crop requirements which might also reduce nutrient accumulations in the soil and further in the edibles parts of the vegetables. Appropriate pre-treatment of irrigation water would help improve the quality of the latter and enhance the food safety of vegetables determined for the urban markets.

Keywords: microbial contamination, nutrient balance, urban agriculture, West Africa

2. Introduction

During the last decade the use of open inner-city and peripheral spaces for urban and peri-urban agriculture (UPA) has become increasingly important in Africa to enhance the food supply to the population of the rapidly growing cities (Bryld 2003; Cofie et al. 2003). Intensively managed UPA systems can provide farmers with additional opportunities for employment, income and subsistence food (Rabinovitch and Schmetzer 1997; Lynch et al. 2001; Drechsel et al. 2006; Nguni and Mwila 2007; Thornton, 2008). Moreover, UPA can contribute positively to poverty alleviation and social integration of disadvantaged and marginalized groups such as handicapped, sick or old people, female-headed families, children and jobless uneducated young people (van Veenhuizen and Danso 2007). Furthermore, these production systems allow consumers to purchase fresh vegetables and fruits as well as eggs, fresh meat and milk, poultry and fish (Cofie et al. 2001; Niang et al. 2002; Drechsel et al. 2007) on urban and local markets. To achieve these multiple objectives, UPA makes use of typical urban resources such as wastewater, organic municipal waste, sewage and market refuse in crop production, which have often been found to cause microbial and heavy metal contamination of produce (Keraita and Drechsel 2002; Amoah et al. 2005; Akegbejo-Samsons, 2008). Besides solid organic and liquid wastes, household wastes, contaminated livestock and poultry manures were reported to be sources of pathogen contaminations mainly of faecal origin (Guendel 2002; Sonou 2001; Drechsel et al. 2006). While manure application on UPA soils may reach up to 100 t ha^{-1} yr^{-1}, mineral fertilizers are often used as an additional nutrient source for vegetables such as cabbage (*Brassica oleracea* L.; Drechsel et al. 2005). In Lomé (Togo), for example, farmers used a combination of cotton (*Gossypium hirsutum*) grain, different manures and mineral fertilizers as soil amendments (Schreurs 2001). From the South of Benin high inputs of organic (>40 t ha^{-1}) and mineral fertilisers (>600 kg ha^{-1}) were reported as inputs to African eggplant (*Solanum aethiopicum* L.*;* Assogba-Komlan et al. 2007). In the Sahelian cities of Bamako (Mali), Ouagadougou (Burkina Faso) and Niamey (Niger) where large-scale poultry farming is constrained by heat, the combined application of cattle manure and mineral fertilizers in UPA systems is common (Drechsel et al. 2006; Graefe et al. 2008). In Niamey, the intensive fertilizer application to UPA gardens (Graefe et al. 2008) suggests strongly positive horizontal nutrient balances that may result in large gaseous and leaching losses of nutrients and environmental pollution. This is obviously in strong contrast to the negative nutrient balances reported for rural West African farming systems (Stoorvogel and Smaling 1990; Van den Bosch et al. 1998). However, detailed studies are lacking that quantify the nutrient flows and balances in the UPA systems of this region.

As such nutrient balances are of interest both from an economic and environmental point of view and have been used to evaluate the sustainability of farming systems at different scales (Nielsen and Kristensen 2005; He et al. 2007; Kyllingsbæk and Hansen 2007; Khai et al. 2007; Guo et al. 2008). The difference between the sum of nutrient inputs and the sum of nutrient outputs constitutes a surplus or deficit for the system. Depending on the objectives and scales of the research, different types of nutrient balances can be used. In this study we used the soil surface nutrient budget approach (Oenema et al. 2003; Bassanino et al. 2007) to quantify management-related horizontal nutrient fluxes and balances in UPA vegetable and millet farming systems of the Sahelian city of Niamey. More specifically, our objectives were (i) to quantify the management-based horizontal fluxes and balances of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) at the level of gardens and fields, and (ii) to determine the concentrations of heavy metals and faecal pathogens in irrigation water used and the thus irrigated leafy vegetables.

2.1 Materials and methods

2.1.1 Study area and cropping systems

The study was carried out in Niamey (13.5°N, 2.2°E; 220 m asl), the capital city of the Republic of Niger, which currently has around 900,000 inhabitants who are estimated to increase to 2.5 Mio in 2025 (Maurice 2003). The region’s climate is semi-arid with a single rainy season from June to October and an 80-year average precipitation of 577 mm yr^{-1} (L´Hôte et al. 2002). During the study period (January 2006 - January 2008), annual rainfall recorded was substantially lower than this average and, equally typical for semi-arid climates, varied substantially between different experimental sites within the city (Table 1). During the cool dry season (November-February), average daily temperatures range from 16 - 32°C and are lowest in January (24°C); during the hot dry season (March-May) average daily temperatures range from 27 - 41°C and peak in April/May (34°C).

The city area under study covers 672.4 km^2 with the major built-up part located north of the Niger River that separates Niamey at a length of about 15 km. This northern part is crossed from north to south by a major riverbed (wadi) through which water drains nearly year-round into the Niger River. Most of the UPA activities, especially gardening, are located along this wadi and the Niger River. Niamey’s UPA is mainly characterized by intensive urban and peri-urban vegetable gardening and some peri-urban millet farming associated with intensive sheep and goat husbandry in the city centre and extensive cattle keeping at the outskirts of the city (Graefe et al. 2008). The input-intensive, largely market-oriented vegetable gardening is dominated by exotic crop species (Table 1), whereby in contrast to popular judgement species richness was found to increase with market orientation and partly with garden size (Bernholt et al. 2009). At the city’s outskirts millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) intercropped mainly with cowpea (*Vigna unguiculata* L.) and occasionally groundnut (*Arachis hypogea* L.) are cultivated as staple food.

For this study 10 vegetable gardens (Table 1) and 9 millet fields (Table 2) representing the diversity of UPA crop production systems were selected on the basis of a preceding study (Graefe et al. 2008) and were closely monitored to quantify the management-related nutrient inputs (INs) and outputs (OUTs) (Figure 1).

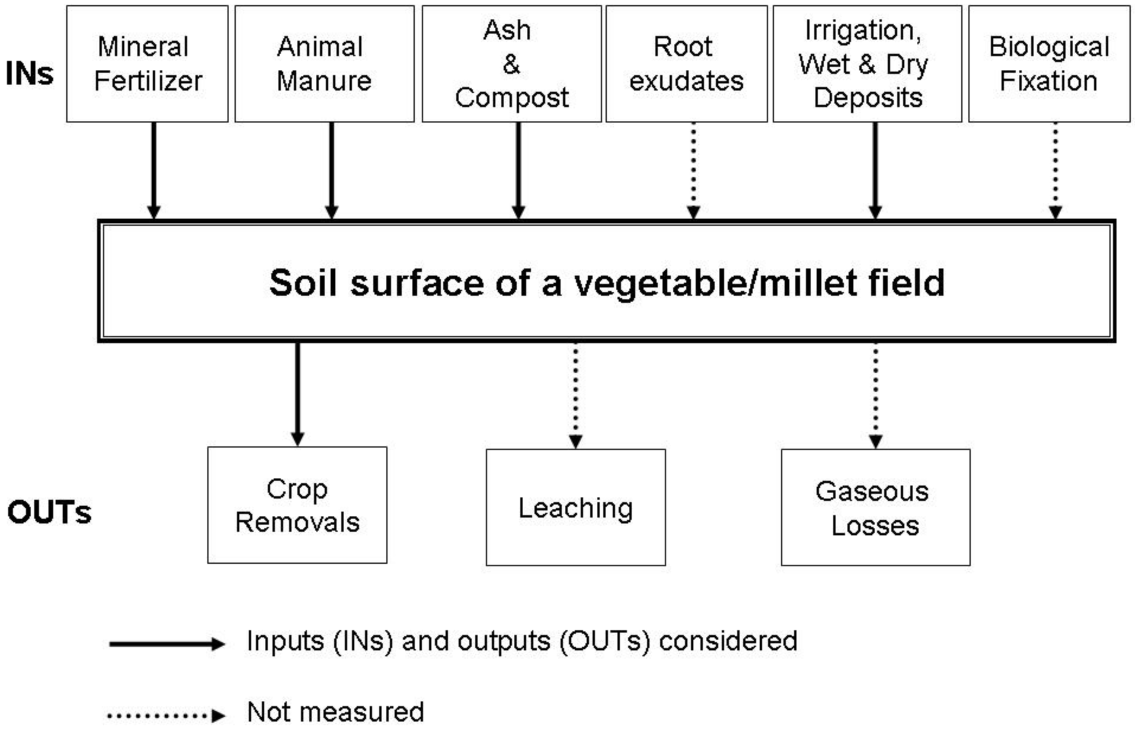

Figure 1. Diagram showing the delineations of the soil surface partial horizontal balance (SSPHB) approach. Any application outside the double boundary was considered to be an external input into the SSPHB.

Table 1. Characteristics of the selected urban gardens in Niamey (Niger) and their inputs during January 2006 to January 2008.

Garden name		Goudel	Yantala Bas 1	Yantala Bas 2	Nogare 1	Nogare 2	Saguia	Saga	Tondibia Gorou	Gountou Yena 1	Gountou Yena 2
Management type		low input	low input	high input	low input	low input	low input	high input	high input	high input	high input
Garden area (m^2)		714	738	820	1903	619	588	788	1085	686	610
Rainfall (mm)	2006	362	404	404	435	435	335	208	496	383	383
	2007	273	371	371	399	399	381	315	467	364	364
Main vegetables		lettuce, roselle, leek	lettuce, celery, amaranth	lettuce, cucumber, tomato, cabbage	lettuce, cabbage, pea, celery, amaranth	lettuce, pea, French bean	zucchini, eggplant, moringa	cabbage, okra	lettuce, tomato, cabbage	lettuce, amaranth, roselle, cabbage	amaranth, cabbage
Other crops		mint	mint	mint, maize	mint, strawberry, maize	mint		melon	cowpea	maize	maize
Season of cultivation [a]		CD, HD, R	CD, HD, R	CD, HD, R	CD, HD, R	CD, R	CD, R	CD, HD, R	CD, R	CD, HD, R	CD, HD, R
Fertilizer application (t ha^{-1} $year^{-1}$)	Urea	0.06	0.40	1.08	0.23	0.65		3.3	0.53	0.65	
	NPK[b]		0.13		0.06	0.12		1.22	0.19		
	DAP[c]					0.11		0.56			
	Manure[d]	76.9	40.0	67.53	16.72	53.11	24.09	30.13	51.52	14.07	
	Compost[d]				17.22						
	Ash[d]					6.58					
Irrigation water application (litre m^{-2} day^{-1})	Waste									46	65
	Upstream river	14	56	35							
	Downstream river				25	29		39			
	Pond								20		
	Well						115				

[a] CD= cool dry, HD= hot dry, R= rainy season; [b] NPK= 15-15-15, [c] DAP= diammonium phosphate, [d] air dry matter

Table 2. Characteristics of the selected peri-urban millet fields and their inputs near Niamey, Niger during January 2006 to January 2008.

Field name	Gabgoura 1	Gabgoura 2	Nogare	Saguia 1	Saguia 2	Tondibia Gorou 1	Tondibia Gorou 2	Tondibia Gorou 3	Tondibia Gorou 4
Management type	high input	low input	low input	high input	high input	high input	low input	low input	high input
Field area (ha)	1.6	1.6	0.5	0.2	3.0	2.4	1.1	4.6	7.7
Rainfall (mm)									
2006	362	362	435	335	335	496	496	496	496
2007	273	273	399	381	381	467	467	467	467
Main crop	pearl millet	pearl millet	pearl millet	pearl millet	pearl millet	pearl millet	pearl millet	pearl millet	pearl millet
Associated crop	cowpea	cowpea			cowpea	cowpea	cowpea	cowpea	cowpea
Fertilizer application (t ha^{-1} $year^{-1}$)									
NPK	0.02	0.01							
Manure[a]	16.3	1.4		6.2	10.8	7.7	1.6		10.4

[a] air dry matter

Based on the management intensity, and especially the nutrient input to individual gardens and fields, respectively, these were categorized as high or low input systems. While in gardens high input systems were also strongly market-oriented, low input systems were mainly managed for home consumption, this differentiation could not be made for the millet fields which all served home-consumption.

Three and five sampling plots were installed in each garden and field, respectively. Their size varied from 1 - 10 m^2 for small gardens and from 10 - 25 m^2 for large ones, while in the fields, observed plot sizes were set at 100 m^2. The total area of fields and gardens as well as the individual plot sizes were determined using a hand-held differential Global Positioning System (GPS; Trimble Pro XR, Sunnyvale, CA, USA). This data was imported into a detailed map produced from a 2005 Google Earth satellite image with 15 m resolution using ArcView 3.2. (Redlands, CA, USA).

2.1.2 Quantification of horizontal nutrient fluxes

Horizontal nutrient fluxes (inputs and outputs) related to farmers' management were measured in the selected gardens and millet fields over a period of 24 month (January 2006 - January 2008). All study sites were visited at least once a week and farmers were interviewed about all relevant resource inputs onto and removals from the selected plots. The main sources of nutrient inputs included fertilizers (animal manure, mineral fertilizers, ash, compost), and irrigation water; wet and dry deposition and biological N fixation were accounted for using transfer functions. Moreover, carbon influx from root exudates were accounted for as they constitute an input flux for the organic C pool of the soil through the process termed rhizodeposition (Nguyen 2003). However, as root exudation is very difficult to quantify under field conditions (Dilkes et al. 2004), we assumed that root C influx was equivalent to harvested shoot C.

In the gardens, fertilizer inputs were quantified throughout the cropping cycle by weighing the amounts applied. In the fields, the quantity of the predominantly used animal manure remaining on the soil after corralling of sheep, goats and/or cattle was determined before the onset of the rainy season using a frame of 1 m^2 with 10 repetitions per field. Representative samples of fertilizer and dung applied were taken at each application event (gardens) and sampling date (fields), respectively, and were kept for analysis of C, N, P and K.

Different sources of irrigation water were used, namely waste water, pond water, well water and river water collected upstream and downstream of the city, depending on the location of the garden. Inputs from irrigation water were quantified on a weekly basis in the garden plots by counting the number of watering cans (8 - 17 l; volume determined in each case) used per day. The total amount of water applied was calculated from the quantity applied per day and the length of the cropping cycle and was multiplied by the nutrient concentration in the water source. Nutrient inputs through rainwater were calculated from the amount of rainfall measured by a rain gauge at 1.5 m above ground in each garden and the nutrient concentrations therein.

To quantify the outputs throughout the 24-months measurement period, the harvested biomass of all vegetables (except for minor quantities of medicinal or ornamental plants) was determined on the selected plots of each garden by either weighing the total crop harvested per plot or by sampling and weighing all material removed from two sampling areas of 1 m^2 per plot and multiplied by the total area harvested. Samples were pooled by garden, harvest date, type of vegetable and fertilization treatment. In the fields, the grain and straw yield of millet and cowpea was quantified at harvest (October) on the selected plots, and representative samples were kept for the analysis of C, N, P, K. All samples of manure and harvested plant matter were oven-dried to constant weight at 65°C and ground to 1.5 mm particle size before chemical analysis using standard methods (see below).

Nutrient fluxes were estimated by multiplying the oven-dry mass of material by their nutrient concentrations using equation (1).

$$F = \sum_{i=1}^{n} Q_i C_i \tag{1}$$

where F is the total nutrient flow (input or output) over the period of measurement, *n* is the number of events (application of fertilizer, irrigation water, rain or crop removal, etc.), Q_i is the quantity of raw material at event i and C_i is the nutrient concentration in the raw material at event i.

2.1.3 Soil and water sampling

To assess the *status quo* of soil fertility in each garden and field, soil samples were collected at 0-20 cm (garden and field) and 20-50 cm (fields only) depths using an auger. Two subsamples each taken from two different spots within the same plot were pooled to obtain a total of 5 samples per field and 3 samples per garden, thereby differentiating samples of differently managed plots. In the gardens, the samples were collected before crop fertilization and after 12 and 24 months of intense cultivation, while in the millet fields samples were colleted before the onset of the rainy season in the first year (2006) and after the harvest in the first and in the second year (2007). Soil samples from fields were pooled by soil depth into one composite sample. All samples were air-dried on a clean paper within a few hours after sampling and analyzed for mineral N (NO_3^- and NH_4^+), Bray-P, pH, organic carbon, effective cation exchange capacity (CEC), exchangeable K and total N using standard analytical techniques (see below).

For each garden on a bi-monthly basis, 100 ml of irrigation water were collected in duplicate from the watering cans or the source point. For rain water two samples were collected at one rainfall event in the beginning (July) and the middle of the rainy season (mid-August). After sampling, one drop of

0.1n HCl was added to each water sample after which samples were kept in the refrigerator at 4°C until analysis of pH, N, P, and K.

2.1.4 Chemical analyses

In soil, irrigation water and rainwater samples pH was determined in 1 : 2.5 soil : water (w : v) and water : water (v : v). In soil samples, organic carbon was determined according to the wet oxidation method (Walkley and Black 1934) and P-Bray according to Bray and Kurtz (1945). Total N and mineral N as nitrate (NO_3^--N) and ammonium (NH_4^+-N) were determined colorimetrically with an Alpkem Rapid Flow Analyzer (RFA 1985) at 520 nm and 660 nm, respectively. Soil effective cation exchange capacity (ECEC) was determined by summation of exchangeable cations after their extraction with 1n NH_4^- acetate and analysis of the extract by atomic absorption spectroscopy or flame emission spectro-photometry and of exchangeable acidity (H^+ and Al^{3+}) according to Espiau and Peyronel (1976). In manure, water and plant samples, total N was determined colorimetrically using the Bertholet reaction (Chaney and Marbach 1962) with an N-auto-analyzer (TECHNICON AAII, Ontario, Canada). Total P was also determined colorimetrically based on the phosphomolybdate complex reduced with ascorbic acid (Lowry and Lopez 1946) and K by flame photometry (Instrument Laboratory 543, CA, USA).

2.1.5 Calculation of nutrient balances

Soil surface nutrient budgets were compared to the change in extractable nutrients over the 24-months period using equation (2) proposed by Khai et al. (2007). To this end C, N, P and K partial balances were computed at the level of an individual field and garden by subtracting the nutrient outputs (through all harvested products) from the nutrient inputs.

$$\Delta P_E = I_E - O_E \tag{2}$$

where ΔP_E, I_E and O_E stand for the change in the soil pool, the input and the output of element E, respectively. In our case, the equation takes into account the following inputs of element E from soil amendments: either organic or mineral fertilizer (F_E), irrigation water (IRW_E), wet plus dry depositions (WD_E), and biological nitrogen fixation (BNF_E) and the outputs of E through harvested products (HP_E). If also leaching losses (L_E) and gaseous emissions (GE_E) from the soil surface were accounted for, the net change in the soil storage ($\Delta Soil_E$) of element E were calculated as:

$$\Delta Soil_E = (F_E + IRW_E + WD_E + BNF_E) - (HP_E + L_E + GE_E) \tag{3}$$

However, leaching losses and gaseous emissions were only available for some of the studied gardens and fields (Predotova et al. 2009b); they were therefore not included in the nutrient flux equation. The apparent partial, that is horizontal, balance of element E thus resulted from equation (4):

$$\Delta Soil_E = F_E + IRW_E + WD_E + BNF_E - HP_E \qquad (4)$$

For cowpea annual symbiotic N_2-fixation was assumed to amount to 40 kg ha^{-1} as it has been previously reported for the acid sandy soils of the Sahelian zone of Niger and total annual non-symbiotic N_2-fixation was estimated at 5 kg ha^{-1} (Roy et al. 2003). Yearly dry depositions of Harmattan dust were set at 1,200 kg ha^{-1} with nutrient concentrations of 0.0038 kg N kg^{-1} dust, 0.00079 kg P kg^{-1} dust and 0.0187 kg K kg^{-1} dust (FAO 2005).

2.1.6 Vegetable contamination with pathogens and heavy metals

To assess a possible pathogen contamination of produced vegetables, two samples of irrigation water and of different leafy vegetables (cabbage, lettuce - *Lactuca sativa* L., and amaranth - *Amaranthus cruentus* L.) were aseptically (sterile equipments and clean conditions) collected per garden, once in the hot dry season (April 2007) and in the cool dry season (January 2008). Samples were kept in a refrigerator at 4°C after collection and composites per type of material and garden were analysed within 24 hours for total mesophilic aerobic micro-organisms (*Staphylococcus* sp.) and for faecal pathogens of animal origin (*Salmonella* spp., *Escherichia coli*, *Streptococci* and total coliforms following standard procedures (APHA-AWWA-WEF 2001). Additionally, irrigation water (n=2) was sampled in each garden before (May) and after (October) the rains in 2006, and analysed for the total concentrations of the heavy metals copper (Cu), cadmium (Cd), lead (Pb), zinc (Zn) and Nickel (Ni) using Inductive Coupled Plasma Atomic Emission Spectrometry (ICP-AES, Spectro Analytical Instruments, Kleve, Germany; Heinrichs 1989).

2.1.7 Statistical analysis

For each plot, horizontal partial nutrient balances of C, N, P, and K were converted to a hectare basis and F-test performed using the General Linear Models (GLM) procedure within SAS 9.1 (SAS 2003). Independent variables were management intensity, season, and year, while dependent variables comprised soil chemical parameters, inputs and outputs of C, N, P and K as well as plant dry matter (DM) yields. Means were separated by t-tests (LSD) at $P = 0.05$.

2.2 Results

2.2.1 Main characteristics of high and low input systems

In the high input vegetable gardens, annual total nutrient inputs ranged from 1,109 – 3,816 kg N ha^{-1}, 143 - 644 kg P ha^{-1}, and 640 – 2,019 kg K ha^{-1} as opposed to 198 - 782 kg N ha^{-1}, 86 - 253 kg P ha^{-1} and 315 - 898 kg K ha^{-1} for low input gardens. Similarly, for high input millet fields, annual total nutrient inputs varied from 87 - 173 kg N ha^{-1}, 19 - 44 kg P ha^{-1} and 54 - 115 kg K ha^{-1}, while for low input millet fields annual nutrient inputs ranged from 0.1 - 11.4 kg N ha^{-1}, 0.9 - 5.6 kg P ha^{-1} and 13 - 21.9 kg K ha^{-1}.

2.2.2 Nutrient concentrations in irrigation and rain water

The use of wastewater for irrigation was most common in the gardens located along the wadi (Gountou Yena). This water contained, per litre, 150 mg N, 19 mg P and 66 mg K in the dry season (Figure 2). In the rainy season, nutrient concentrations were 5-fold lower for N, 3-fold lower for P, and 50% lower for K. For the other sources of irrigation water, however, seasonal differences in nutrient concentrations were not significant. For the dry season, the nutrient concentrations per litre of well, river (upstream and downstream), and pond water ranged from 0.2 - 19.2 mg N, 0.2 - 0.5 mg P and 4.2 - 8.7 mg K as opposed to rainy season concentrations of 0.1 - 0.9 mg N, 0.4 - 0.5 mg P and 2.9 - 7.4 mg K. Average nutrient concentrations in rainwater were 0.03 mg N l^{-1}, 0.20 mg P l^{-1} and 3.77 mg K l^{-1}.

2.2.3 Horizontal nutrient balances in vegetable gardens

Nutrient inputs varied significantly between the high and the low input gardens. Mineral fertilizers were the major sources of N and P in the high input gardens, accounting for 48% and 80% of total N and P inputs, respectively. Average annual inputs through mineral fertilizers were 711 kg N ha^{-1} and 234 kg P ha^{-1} in the high input gardens (Figure 3) compared to 164 kg N ha^{-1} and 25 kg P ha^{-1} in the low input gardens ($P < 0.05$). Application of livestock manure accounted for 44%, 61% and 75% of the total inflows of N, P and K, respectively, in the high input vegetable gardens, while it supplied 68% N, 73% P and 48% K in the low input gardens. However, no significant differences were found between the two types of gardens as far as the amounts of nutrients applied through manure were concerned. Likewise, C influx through manure plus estimated deposits (root exudates assumed to be equivalent to harvested shoot C) was similar for the two types of gardens (Figure 3). Nutrient inflows through irrigation water were considerable, mainly for high input gardens where wastewater was used for irrigation. Although the amounts of wastewater applied were lower than the amounts of water drawn from other water sources (Table 1). Due to its high nutrient concentrations it supplied annual inputs of up to 2,427 kg N ha^{-1}, 376 kg P ha^{-1} and 1,439 kg K ha^{-1} due to its high nutrient concentrations (Figure 2).

The total amounts of C, N, P and K exported through harvests in high input vegetable gardens significantly ($P < 0.05$) exceeded the exports in low input gardens (Table 3).

Given higher inputs of nutrients as compared to their removal with harvested produce, partial horizontal balances were strongly positive for both types of gardens. Average annual horizontal carbon and nutrient balances in high input vegetable gardens amounted to 9,936 kg C ha^{-1}, 1,133 kg N ha^{-1}, 223 kg P ha^{-1} and 312 kg K ha^{-1} as compared to 9,580 kg C ha^{-1} ($P > 0.05$), 290 kg N ha^{-1} ($P < 0.05$), 125 kg P ha^{-1} ($P > 0.05$) and 351 kg K ha^{-1} ($P > 0.05$) in low input gardens (Figure 4).

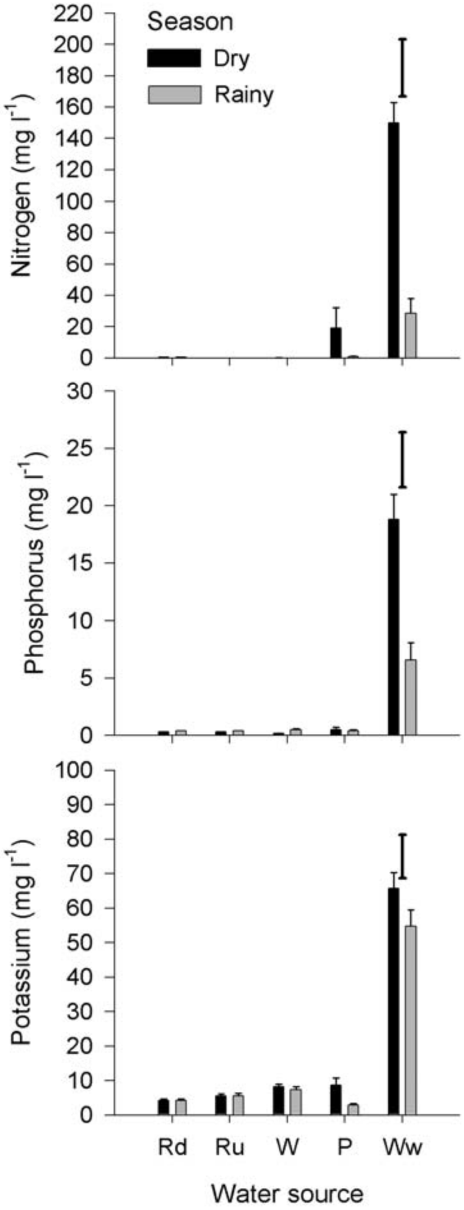

Figure 2. Concentrations of nitrogen, phosphorus and potassium in different sources of irrigation water used in the vegetable gardens of Niamey, Niger. The number of gardens using each type of water are for downstream river (Rd): n=3, upstream river (Ru): n=3, well (W): n=1, pond (P): n=1, and wastewater (Ww): n=2. Two water samples were collected every two months in each garden during January 2006 to January 2008. Data represent annual averages plus one standard error. The isolated vertical lines in charts indicate the least significant difference ($LSD_{0.05}$) of means for the two seasons.

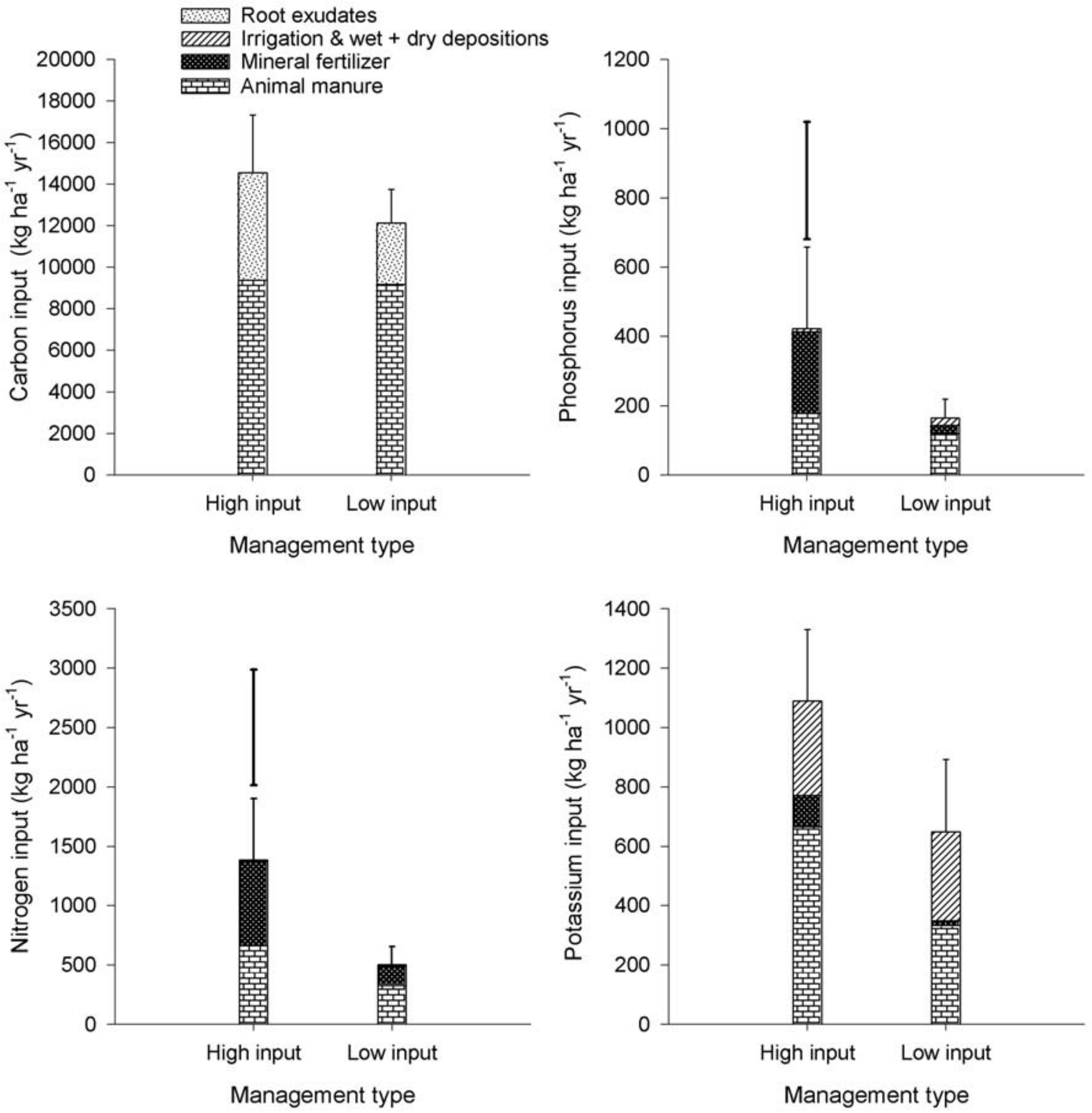

Figure 3. Amounts of carbon, phosphorus, nitrogen and potassium applied in high (n=5) and low (n=5) input vegetable gardens in Niamey, Niger, during January 2006 to January 2008. Data show annual means plus one standard error. The isolated vertical lines in charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management systems. Carbon input resulted from manure and estimated deposits from root exudates.

Table 3. Vegetable crop cycles during the study period (n and (SD)), cumulative yields (t DM[a] ha^{-1} 2 year^{-1}) and average amounts (kg ha^{-1}, one cycle) of nitrogen (N), phosphorus (P) and potassium (K) removed with the edible parts of four vegetables cultivated in low and high input vegetable gardens of Niamey, Niger, from January 2006 to January 2008. Also shown are cumulative nutrient and carbon exports (kg ha^{-1} 2 year^{-1}).

Vegetable gardens	Vegetable	Crop cycles	Yield	N	P	K
High input (n=5)	Lettuce	10.7 (10)	25.6	83	14	173
	Cabbage	5.8 (4)	46.4	260	54	286
	Amaranth	19.0 (11)	45.6	98	15	154
	Tomato	3.0 (1)	1.8	16	3	35
Low input (n=5)	Lettuce	6.4 (4)	16.6	67	14	158
	Cabbage	2.5 (1)	5.3	49	12	93
	Amaranth	1	6.3	202	32	376
	Tomato	1	0.1	3	1	9
			Cumulative nutrient export			
			Total C	Total N	Total P	Total K
High input			59,895	4,306	757	6,541
Low input			14,176	756	157	1,629

[a] DM dry matter

All nutrient outputs are specified in Figure 1.

The outputs (yields for one cycle of cultivation) obtained for the four major vegetables greatly depended on the crop type and the nutrient input rates. In high input gardens, the average amount of carbon and nutrients applied to cabbage (kg ha^{-1}) was 5,613 kg C, 949 kg N, 202 kg P and 435 kg K per cropping cycle (85-days), while 7,515 kg C, 398 kg N, 103 kg P and 416 kg K were applied to tomato for each 3-month cropping cycle. The resulting yields were 8 t DM ha^{-1} of cabbage and 0.6 t DM ha^{-1} of tomato, which exceeded the yields in low input gardens by a factor of 3.8 and 6.0, respectively (Table 4).

Carbon and nutrients applied to lettuce (kg ha^{-1}, per 1.5-month cropping cycle) amounted to 5,260 kg C, 173 kg N, 52 kg P and 195 kg K in low input gardens and were 50% lower for C and P, about 3-fold lower for N and 2-fold lower for K than in high input gardens. For amaranth, nutrient application (kg ha^{-1}, per month of cropping cycle) averaged 81 kg N, 5 kg P and 122 kg K in low input gardens as opposed to 531 kg N, 73 kg P and 300 kg K in high input gardens. Regardless of management intensity, no organic amendments were applied to amaranth (Table 4). For both vegetables, yields in low input gardens amounted to 2.6 t DM ha^{-1} (lettuce) and 6.3 t DM ha^{-1} (amaranth) per cropping cycle, as compared to 2.4 t DM ha^{-1} for lettuce and amaranth, respectively, in high input gardens.

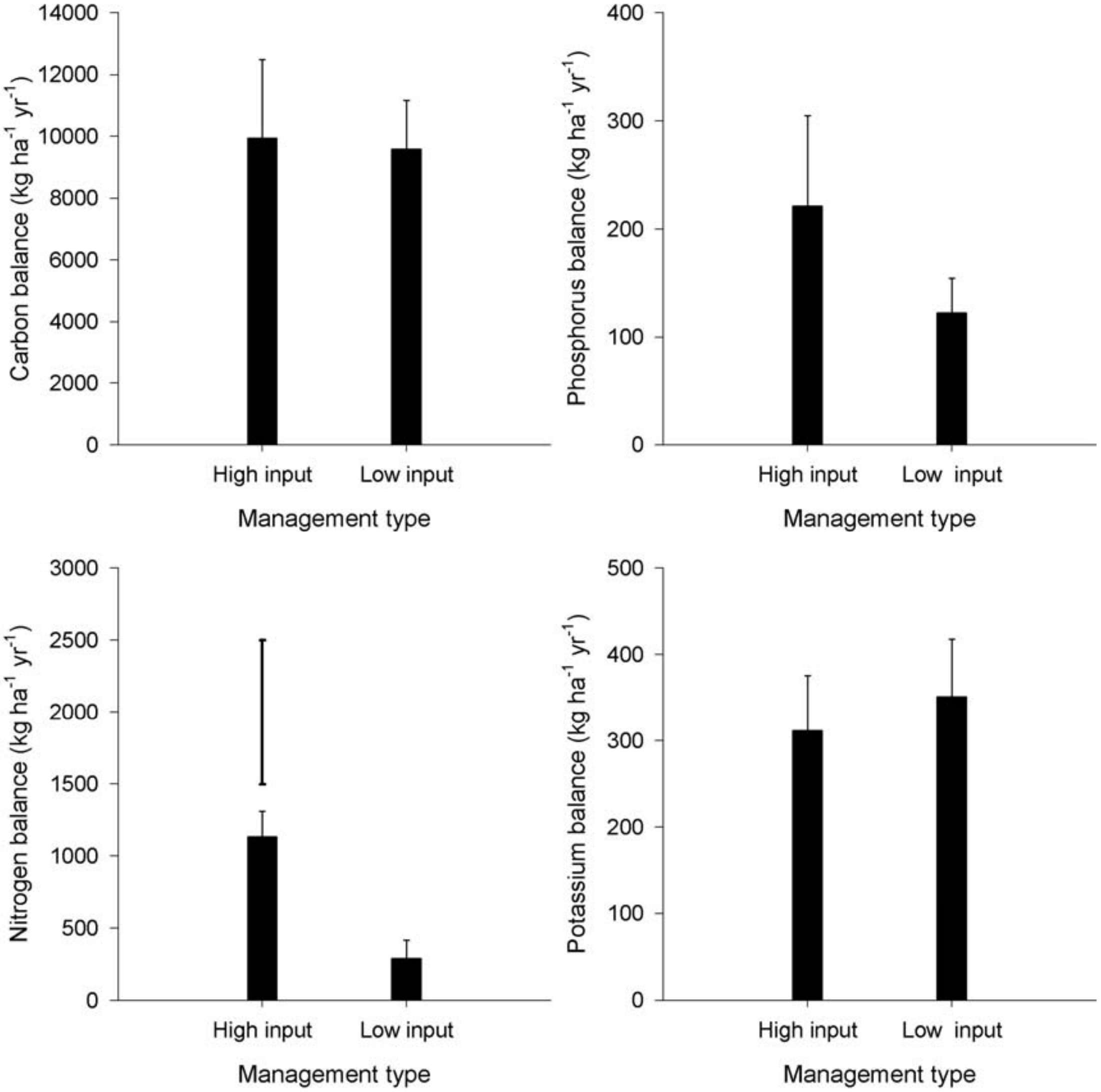

Figure 4. Annual partial horizontal balances of carbon, phosphorus, nitrogen and potassium in high (n=5) and low (n=5) input vegetable gardens in Niamey, Niger, during January 2006 to January 2008. Data show means plus one standard error. The isolated vertical line in the nitrogen chart indicates the least significant difference ($LSD_{0.05}$) of means for the two management systems.

Table 4. Amounts (kg ha^{-1}; mean ± one standard error) of carbon (C) nitrogen (N), phosphorus (P) and potassium (K) applied to four major vegetables during one cropping cycle and the respective yields (t DM[a] ha^{-1}; mean ± one standard error) in high and low input vegetable gardens of Niamey, Niger.

Vegetable garden	Vegetable	Yield	C	N	P	K
High input (n=5)	Lettuce	2.4 ± 0.2	5,561 ± 1,123	474 ± 62	73 ± 9	355 ± 36
	Cabbage	8.0 ± 0.9	5,613 ± 446	949 ± 204	202 ± 59	435 ± 81
	Amaranth[c]	2.4 ± 0.2	-	531 ± 94	73 ± 19	300 ± 30
	Tomato	0.6± 0.2	7,515 ± 1,817	398 ± 138	103 ± 37	416 ± 122
Low input (n=5)	Lettuce	2.6 ± 0.2	5,260 ± 1,051	173 ± 29	52 ± 8	195 ± 24
	Cabbage	2.1 ± 0.6	5,783 ± 1,278	91 ± 10	40 ± 4	164 ± 9
	Amaranth[b,c]	6.3	-	81	5	122
	Tomato[b]	0.1	3,587	34	21	121

[a] DM dry matter

[b] Only one garden was recorded where standard errors do not appear

[c] In both management systems animal manure is not applied to amaranth.

All nutrient sources are specified in Figure 1.

2.2.4 Horizontal nutrient balances in millet fields

Animal manure was the main source of nutrient inputs to millet fields, applied annually at an average rate of 10.3 t DM ha^{-1} (SD = 3.8) in high input fields, thereby supplying 129 kg N ha^{-1}, 25 kg P ha^{-1} and 62 kg K ha^{-1}. Manure application accounted for 76%, 91% and 65% of total N, P and K inputs in high input fields. Additional nutrient inputs originated from mineral fertilizers, which were applied at low rates (Table 1). At an average of 1.5 t DM ha^{-1} (SD = 0.2) the annual amount of manure applied to low input fields was significantly lower ($P < 0.05$), supplying only 7 kg N ha^{-1}, 3 kg P ha^{-1} and 7 kg K ha^{-1} (Figure 5). Annual C inputs through manure plus the estimated deposits (root debris and exudates) amounted to 1,723 kg ha^{-1} in high input as opposed to 1,014 kg ha^{-1} in low input millet fields. In low input fields, calculated wet plus dry depositions supplied up to 93% of the K inputs as compared to calculated 39% in high input fields. Additional N inputs to the fields might have resulted from the unquantified N fixation of cowpea intercropped with millet in both management systems. However, this contribution to horizontal balances is likely to be < 20 kg ha^{-1} given the low stand density of cowpea in all monitored fields (1,000 – 2,000 plants/ha). Annual N removals through harvest of cowpea shoots and hay averaged 6.8 kg ha^{-1} (SD = 5.7) in high input fields and accounted for 16% of the total N exports, while in the low input fields the average removal of 5.8 kg N ha^{-1} (SD = 4.9) accounted for 27% of total N exports.

Nutrient removals from high input millet fields through millet grain and stover harvest exceeded those from low input fields for all nutrients studied (Table 5). During the 2 years cumulative C and nutrient exports were 1.5-fold higher for C and P; 2.4-fold higher for N and 3-fold higher for K in the high input gardens compared to the low input gardens.

In the millet fields about 20 - 25% of the stalks were left on the field after harvest while up to 80% were removed and used as animal feeds at the homestead.

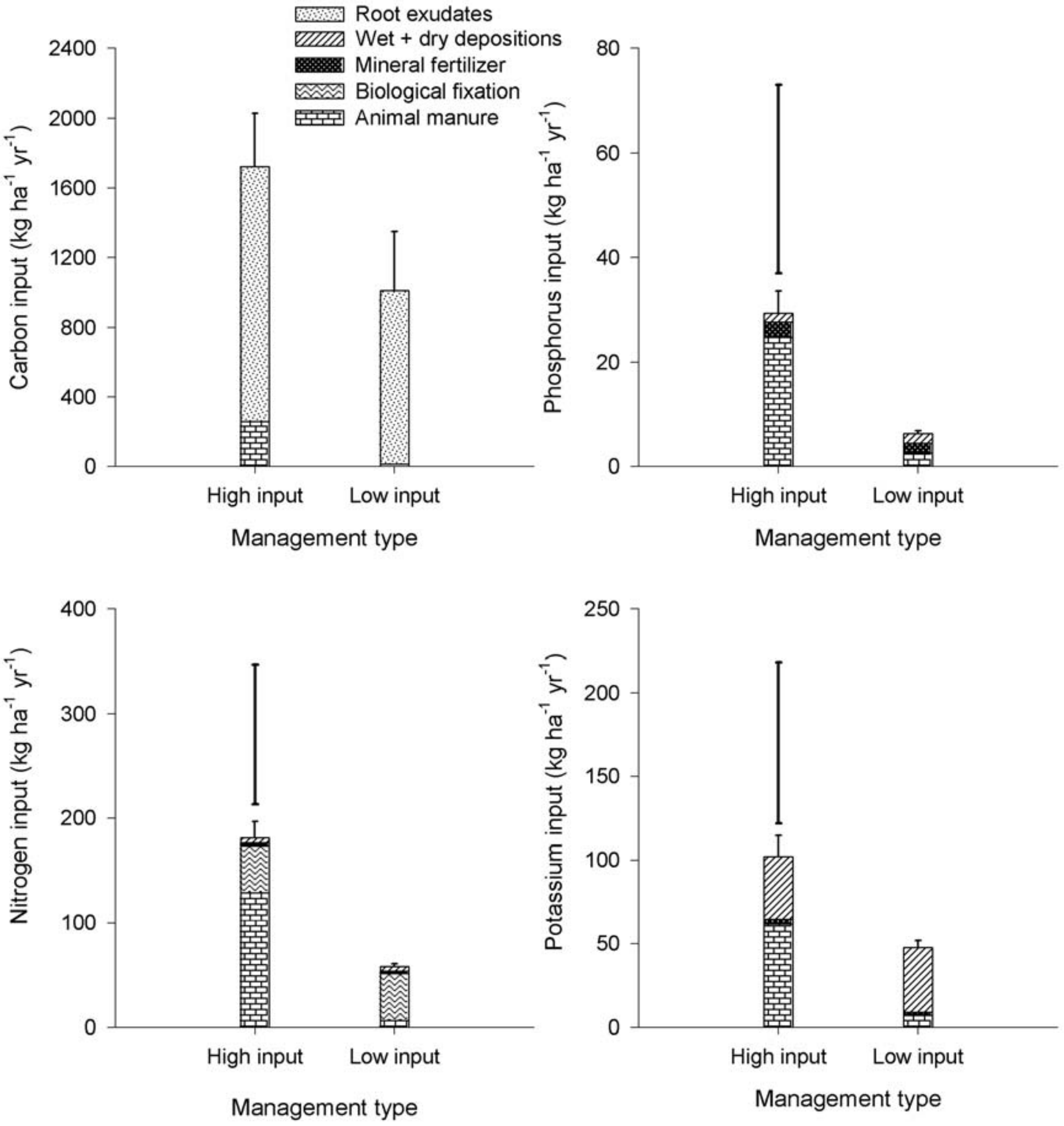

Figure 5. Annual amounts of carbon, phosphorus, nitrogen and potassium applied to high (n=5) and low (n=4) input millet fields in Niamey, Niger, during January 2006 to January 2008. Data show means plus one standard error. The isolated vertical lines in charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management systems. Carbon input resulted from manure and estimated deposits from root exudates.

Partial horizontal balances were positive for C, N, P and K in high input fields with annual carbon and nutrient surpluses of 259 kg C ha^{-1}, 125 kg N ha^{-1}, 20 kg P ha^{-1} and 0.4 kg K ha^{-1}, and differed significantly ($P < 0.05$ for C, N, P only) from those of low input fields (Figure 6). In contrast, in low input fields, partial horizontal balances were negative for P and K and slightly positive for C and N.

Millet stover and grain yields strongly varied with the year and management intensity. In 2006, stover and grain yields averaged 2,932 kg DM ha^{-1} and 644 kg DM ha^{-1} in high input fields *versus* 821 kg DM ha^{-1} for stover and 167 kg DM ha^{-1} for grain in low input fields. However, in 2007, the yields obtained in high input fields were lower (2,603 kg DM ha^{-1} for stover and 614 kg DM ha^{-1} for grain), while stover (1,723 kg DM ha^{-1}) and grain (451 kg DM ha^{-1}) yields were higher in low input fields compared to the previous year.

Table 5. Average millet grain and stover yields (kg DM[a] ha^{-1} year^{-1}) and amounts (kg ha^{-1} year^{-1}) of nitrogen (N), phosphorus (P) and potassium (K) removed from low and high input millet fields near Niamey, Niger, from January 2006 to January 2008. Also shown are cumulative nutrient and carbon exports (kg ha^{-1} 2 year^{-1}; mean ± one standard error).

	Grain		Stover	
Millet system	High input (n=5)	Low input (n=4)	High input (n=5)	Low input (n=4)
Dry matter	630	289	2,767	1,122
N	13.5	6.3	34.2	10.0
P	3.3	1.7	5.0	1.8
K	7.6	5.4	107.4	24.5
	Cumulative nutrient exports			
	Total C	Total N	Total P	Total K
High input	2,928	78	14	187
Low input	2,004	32	9	62

[a] DM dry matter

All nutrient inputs and outputs are specified in Figure 1.

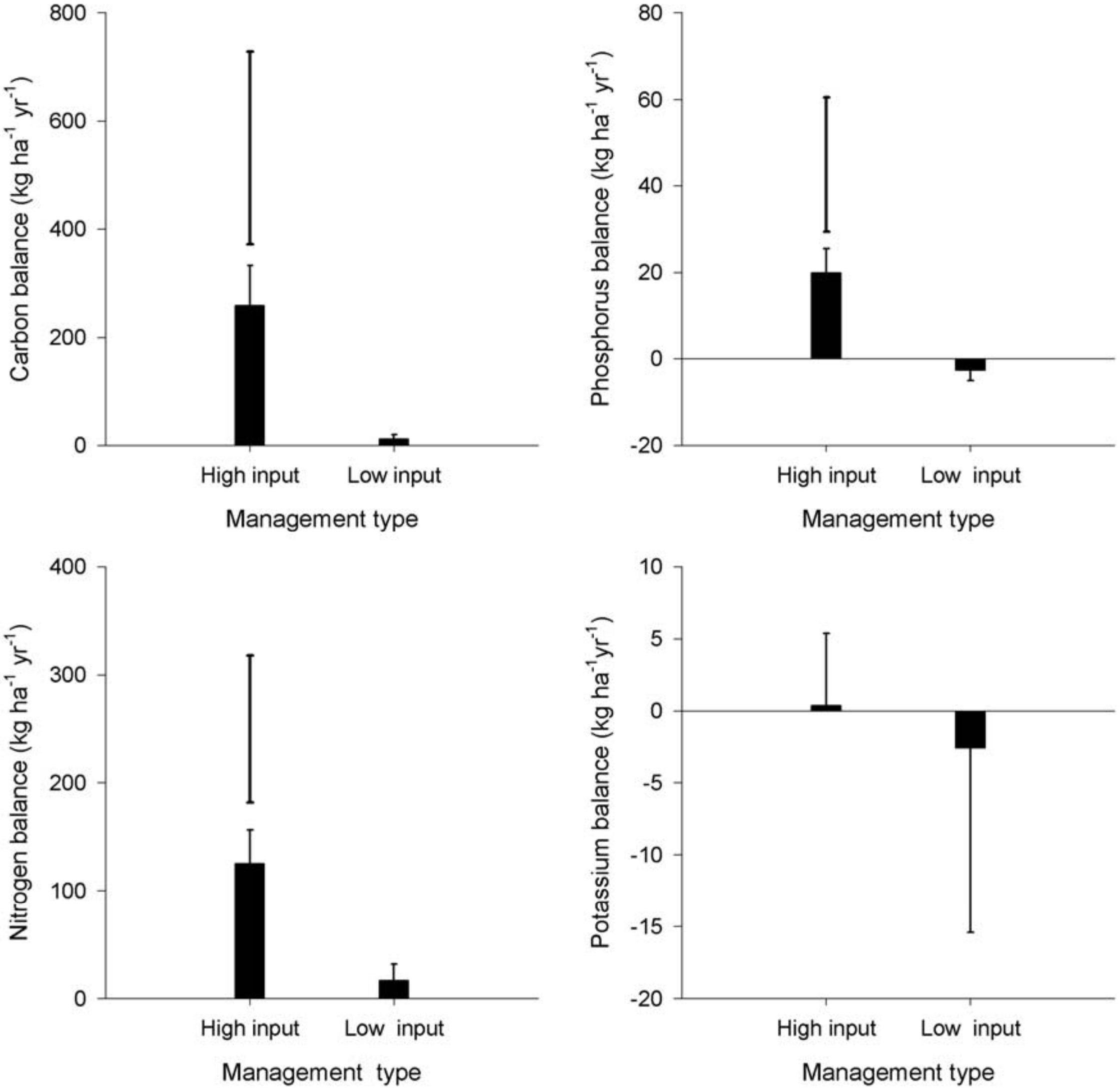

Figure 6. Annual partial horizontal balances of carbon, phosphorus, nitrogen and potassium in high (n=5) and low (n=4) input millet fields in Niamey, Niger, during January 2006 to January 2008. Data show means plus one standard error. The isolated vertical lines in charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management systems.

2.2.5 Changes in the soil nutrient pool and chemical properties of vegetable gardens and millet fields

In high input gardens, average soil pH was 7.1 (SD = 0.5) in 2006, remained unchanged in 2007 and decreased to 6.7 (SD = 0.7) in 2008 ($P > 0.05$). In low input gardens, no changes in soil pH were observed throughout the study period (Table 6). Millet field soils had a much lower pH than those of vegetable gardens, but no significant changes were observed in the topsoil and subsoil pH of millet fields during the study period. In high input gardens soil Corg increased by 36% from 4.9 g kg^{-1} (SD = 1.8) in 2006 to 7.6 g kg^{-1} (SD = 5.3) in 2008, while during the same period it decreased by a factor of 1.2 in low input gardens; a similar trend was determined for soil total N (Table 6). However, these changes were not statistically significant. In the millet fields, in contrast, soil Corg remained unchanged over the 2-year study period.

In soils of vegetable gardens, available nutrients also increased over the study period, notably for exchangeable K ($P > 0.05$) and Nmin ($P < 0.05$, except for NO_3^--N,). The concentrations of NH_4^+-N determined in soils of high input gardens were 53 times higher in 2008 than in 2006, while NO_3^--N decreased by a factor of 7 during the same period. In low input gardens, soil NH_4^+-N increased by a factor of 9 between the start and the end of the study period, while NO_3^--N slightly decreased (Table 6). In high input millet systems, a 55% decrease of NH_4^+-N was determined in the surface soil and a similar trend was observed for NO_3^--N. In the subsoil NH_4^+-N increased by 16%, while NO_3^--N decreased by 57%. In contrast, no major changes in available soil N were observed in low input millet system. Over the 2-year study period, soil concentrations of P-Bray decreased significantly in the high input and slightly in the low input gardens. Effective cation exchange capacity (ECEC) increased significantly in vegetable gardens while no changes were found in millet fields (Table 6).

Table 6. Soil nutrient concentration and selected chemical properties in vegetable plots (top-soil) and millet fields (top and sub-soil) near Niamey, Niger, before (Jan 2006) and after (Jan 2008) two years of cultivation.

Cropping system	Management system	Year	Soil depth (cm)	pH	P-Bray (mg kg^{-1})	Corg. (g kg^{-1})	Total N (mg kg^{-1})	Kexg. (cmol+kg^{-1})	ECEC (cmol+ kg^{-1})	NH_4^+_N (mg kg^{-1})	NO_3^-_N (mg kg^{-1})
Vegetable	High input (n=5)	2006	0-20	7.1	148.9^{b}	4.9	604	0.40	3.2^{a}	3.9^{a}	105.3^{b}
		2008		6.7	101.4^{a}	7.6	701	0.42	5.3^{b}	205^{b}	15.8^{a}
	Low input (n=5)	2006		7.3	69.5^{a}	6.2	830	0.35	1.1^{a}	21.9^{a}	10.3^{a}
		2008		7.4	55.2^{a}	5.3	567	0.39	6.4^{b}	191^{b}	8.9^{a}
Millet	High input (n=5)	2006	0-20	5.8	9.2	1.8	181	0.21	1.3	184^{b}	3.1
		2008		5.8	15.7	1.9	199	0.19	1.6	119^{a}	1.2
		2006	20-50	5.5	7.3	1.3	135	0.16	1.5	101^{a}	1.1
		2008		5.6	7.0	1.4	152	0.21	1.5	120^{a}	0.7
	Low input (n=4)	2006	0-20	5.9	4.5	1.6	168	0.12	2.5	112^{a}	1.1
		2008		5.7	7.0	1.6	159	0.13	2.0	111^{a}	0.7
		2006	20-50	5.5	4.9	1.2	135	0.13	1.9	101^{a}	1.5
		2008		5.5	5.0	1.3	150	0.14	2.1	125^{a}	0.6

For the gardens, and for the millet fields, respectively, values with different letters within columns differ at $P< 0.05$ (t-tests); no letters are given where significant differences do not exist.
Corg. = organic carbon
ECEC = effective cation exchange capacity
Kexg. = exchangeable K

2.2.6 Contamination of water and vegetables with pathogens and heavy metals

Irrigation waters from the river, ponds, and wastewater sources were contaminated with *Staphylococcus aureus* and other pathogens mainly in the cool dry but also the hot dry season, whereby the level of contamination was higher in wasterwater than in the other water sources (Table 7). The outer leaves of vegetables such as amaranth, lettuce and cabbage irrigated with river water or wastewater were contaminated with *Salmonella* spp. as well as with *E. coli*. On cabbage irrigated with wastewater and river water as well as on amaranth irrigated with wastewater, total mesophilic aerobic microorganism counts exceeded 10^6 CFU g^{-1} fresh matter in the hot dry season and were thus above the threshold value recommended by CNERNA (1996). However, in the cool dry season, pathogen levels were low on lettuce and cabbage (Table 8). Although *Salmonella* spp. counts in the wastewater used in garden Gountou Yena1 amounted to 5×10^2 CFU 100 ml^{-1} in the hot dry season, no contamination was determined on cabbage leaves. In the cool dry season *Salmonella* spp. counts in this water source were 12-fold higher (6×10^3 CFU 100 ml^{-1}), and the irrigated lettuce harbored the pathogens at a concentration of 9.8×10^4 CFU 25 g^{-1} fresh matter of the leaves. In the wastewater-irrigated garden Gountou Yena2, amaranth and cabbage leaves were contaminated with *Salmonella* spp. in the hot dry and cool dry season even though no pathogens were detected in the wastewater used for irrigation (Table 8). In the cool dry season, lettuce leaves irrigated with river water were also contaminated with *Salmonella* spp. in the gardens Yantala Bas1, Yantala Bas2 and Nogare2, and with *E. coli* in the gardens Yantala Bas2 and Saga (Table 8).

In the hot dry season of 2006, the concentration (mg l^{-1}) of heavy metals upstream and downstream of the Niger River ranged from 0.00 - 0.02 for Zn, 0.01 - 0.03 for Cu and 0.01 - 0.01 for Ni. In the wastewater running through the wadi, the respective concentrations varied from 0.03 - 0.11 for Zn, 0.03 - 0.04 for Cu and 0.01 for Ni. In pond water Zn, Cu and Ni concentrations averaged 0.16, 0.12 and 0.04, respectively (Table 9). Shortly after the rainy season 2006, no Ni was detected in any of the water sources, and Zn was only present in traces in river and pond water, while for wastewater the Zn concentration ranged from 0.02 - 0.04 mg l^{-1}. Post rainy season Cu concentration in upstream and downstream river water was 0.01 mg l^{-1}, while values of 0.01 - 0.02 mg l^{-1} were determined for wastewater and 0.01 mg l^{-1} for pond water (Table 9).

Table 7. Total counts of microbial cells in irrigation water used in vegetable gardens in Niamey, Niger, during the hot and cool dry season 2007.

Season	Garden	Water source	Total coliforms (CFU 100ml^{-1})	*E. coli* (CFU 100ml^{-1})	*Salmonella* (CFU 100ml^{-1})	Faecal streptococci (CFU 100ml^{-1})	*Staphylococcus aureus* (CFU 100ml^{-1})
Hot dry	Saga	Niger river	none	n.d.	none	none	n.d.
	Gountou Yena 1	Wastewater 'wadi'	15 x 10^2	n.d.	5 x 10^2	27 x 10^2	n.d.
	Gountou Yena 2	Wastewater 'wadi'	88 x 10^4	n.d.	none	none	n.d.
Cool dry	Tondibia Gorou	Pond	n.d.	none	none	n.d.	0.3 x 10^5
	Yantala Bas1	Niger river	n.d.	none	none	n.d.	1.4 x 10^5
	Yantala Bas 2	Niger river	n.d.	none	none	n.d.	4.9 x 10^5
	Nogare1	Niger river	n.d.	none	none	n.d.	0.6 x 10^5
	Nogare2	Niger river	n.d.	none	none	n.d.	3.3 x 10^5
	Saga	Niger river	n.d.	none	none	n.d.	3.2 x 10^5
	Gountou Yena 1	Wastewater 'wadi'	n.d.	none	6 x 10^3	n.d.	26 x 10^5
	Gountou Yena 2	Wastewater 'wadi'	n.d.	2 x 10^5	none	n.d.	21 x 10^5

CFU= colony forming units
n.d.: not determined, specific counts were not performed

Table 8. Total counts of microbial cells on cabbage, amaranth and lettuce irrigated from different water sources in Niamey, Niger, during the hot and cool dry season 2007, and internationally recommended threshold values.

Season	Garden	Water source	Vegetable	Total mesophilic aerobic micro-organisms (CFU g^{-1})	*E. coli* (CFU g^{-1})	*Salmonella* (CFU 25 g^{-1})
Hot dry	Saga	Niger river	Cabbage	$> 10^6$	none	none
	Gountou Yena 1	Wastewater ‘wadi’	Cabbage	$> 10^6$	none	none
	Gountou Yena 2	Wastewater ‘wadi’	Amaranth	$> 10^6$	none	3×10^6
Cool dry	Tondibia Gorou	Pond	Lettuce	0.58×10^5	none	none
	Yantala Bas1	Niger river	Lettuce	2.58×10^5	none	8.7×10^4
	Yantala Bas 2	Niger river	Lettuce	1.46×10^5	2.0×10^4	0.9×10^4
	Nogare1	Niger river	Lettuce	0.13×10^5	none	none
	Nogare2	Niger river	Lettuce	1.27×10^5	none	11.9×10^4
	Saga	Niger river	Lettuce	1.58×10^5	5.8×10^4	none
	Gountou Yena 1	Wastewater ‘wadi’	Lettuce	0.68×10^5	0.6×10^4	9.8×10^4
	Gountou Yena 2	Wastewater ‘wadi’	Cabbage	7.63×10^5	0.2×10^4	3.5×10^4
	CNERNA standard			$< 5\ 10^5$	≤ 10	Absent
	ICSMF standard			$10^6 < X < 5\ 10^7$	≤ 10	Absent

CNERNA, 1996 = Centre Nationale d´Etudes et de Recommandation sur la Nutrition et l´Alimentation (France)
ICSMF, 1974 = International Commission on Microbiological Specifications for Food (Toronto). CFU= colony forming units

Table 9. Concentration (mg l^{-1}; means ± one standard deviation) of heavy metals in different sources of irrigation water before and after the rainy season 2006 in Niamey, Niger, and recommended threshold values.

Site	Sampling point	Zn		Cu		Ni	
		Before rains	After rains	Before rains	After rains	Before rains	After rains
Tondibia Gorou	Pond	0.16 ± 0.01	0.00 ± 0.00	0.12 ± 0.00	0.01 ± 0.00	0.04 ± 0.01	tr[1]
Gountou Yena 1	Wadi affluent (Wastewater)	0.11 ± 0.00	0.02 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	tr
Gountou Yena 2		0.03 ± 0.03	0.04 ± 0.01	0.03 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	tr
Niger River	Upstream (One side)	b.d.l.[2]	b.d.l.	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.02	tr
	Downstream (One side)	0.02 ± 0.01	b.d.l.	0.03 ± 0.02	0.01 ± 0.00	0.01 ± 0.01	tr
Threshold levels[3]		2.0		0.2		0.2	

[1] tr Traces

[2] b.d.l. Below detection limit

[3] Pescod, 1992

For Cadmium (Cd) and lead (Pb), traces were found in all sources of irrigation water

2.3 Discussion

2.3.1 Horizontal nutrient balances in vegetable gardens

The management practices in Niamey's UPA vegetable gardens were characterized by large nutrient inputs from mineral fertilizers and livestock manure to which in some cases high nutrient inputs from wastewater irrigation added. Similar observations were reported for the vegetable systems in and around Kumasi, Ghana, where local application rates of poultry manure amounted to 20 - 50 t ha^{-1} yr^{-1} for cabbage and 50 -100 t ha^{-1} yr^{-1} for lettuce and spring onion, equivalent to annual inputs of 770 - 1650 kg N ha^{-1}, 420 - 900 kg P ha^{-1} and 350 - 750 kg K ha^{-1} (Drechsel et al. 2004). Similarly large application rates of organic (>40 t ha^{-1}) and mineral (360 - 1150 kg ha^{-1}) fertilizers to African eggplant (*Solanum aethiopicum* L.) and amaranth were reported for UPA systems of Cotonou, Benin (Assogba-Komlan et al. 2007).

While in high input gardens of Niamey application rates per cropping cycle to cabbage and lettuce ranged from 10 - 30 t ha^{-1} for animal manure, 43 - 1771 kg ha^{-1} for urea and 120 - 628 kg ha^{-1} for NPK (15:15:15), application rates in low input gardens were 9 - 28 t ha^{-1} for animal manure, 38 - 278 kg ha^{-1} for urea and 55 - 252 kg ha^{-1} for NPK. The high application rates of urea, NPK and livestock dung and the addition of high amounts of N through wastewater in some gardens caused large N surpluses in high input gardens. Although the latter allowed for nutrient extractions in harvested products that were more than 4-fold higher than in low input gardens, nutrient uptake varied greatly among the crops grown and was particularly high for leafy vegetables such as lettuce, cabbage and amaranth. Despite the high extraction, the yields obtained for lettuce and amaranth in high input gardens were below those found in low input gardens. With an average of 45 t ha^{-1} of fresh matter (FM) per cropping cycle, the yield of lettuce in low input gardens corresponded well to the value of 39 t FM ha^{-1} reported for similar production systems elsewhere (Khai et al. 2007), and was substantially higher than the 15 - 20 t FM ha^{-1} reported by PSEAU (2007) in Niamey at a dung application of 15 - 25 t ha^{-1}. Moreover, average cabbage yields of 25 t FM ha^{-1} recorded in low input gardens were within the range of 10 - 40 t FM ha^{-1} reported by PSEAU (2007), while average yields of 97 t FM ha^{-1} obtained in high input gardens were far above this range.

Annual surpluses of 223 kg P ha^{-1} and 312 kg K ha^{-1} were calculated for high input gardens in Niamey. These figures compare well to horizontal balances reported for intensively managed small-scale vegetable systems in Hanoi, Vietnam, for which annual surpluses of 109 - 196 kg P ha^{-1} and 20 - 306 kg K ha^{-1} were reported (Khai et al. 2007). However, at 1133 kg ha^{-1} the average annual N surplus in Niamey by far exceeded the 85 - 882 kg N ha^{-1} balance reported for Hanoi (Khai et al. 2007). Despite the highly positive N balance over the two-year study period, no significant changes in total soil N contents were found. This may be due to gaseous and leaching losses of N, particularly if urea and manure are not incorporated into the topsoil immediately after application. In a companion study of UPA gardens in Niamey, annual losses of 92 kg N ha^{-1} in the form of NH_3 and N_2O were reported, with particularly high emission rates at the end of the dry season and the start of the first rains (Predotova et al.

2009a). For the same gardens, the average annual leaching losses were estimated at 11.4 kg N ha^{-1}, 1.2 kg P ha^{-1} and 24.9 kg K ha^{-1} (Predotova et al. 2009b).

To estimate total annual balances of C, N, P and K for intensively managed gardens in Niamey, the above mentioned gaseous and leaching losses were used and complemented by annual CO_2-C and CH_4-C losses of 27 t C ha^{-1} (Predotova et al. 2009a). The resulting average annual total balances were with 843 kg N ha^{-1}, 70 kg P ha^{-1} and 200 kg K ha^{-1} still strongly positive for these major plant nutrients, which was in contrast to a C deficit of -26 t ha^{-1} reflecting high mineralisation rates of organic matter. While such a negative C balance points to the need of maintaining high rates of manure application, the input of mineral fertilizer could be substantially reduced, which would lower production costs and increase resource use efficiency of UPA vegetable production in Niamey. This is all the more important since in the high input vegetable gardens a decrease in soil pH has been observed during the 24 months of study, which may be due to the high rates of mineral N application and related leaching losses and may in the long run have negative consequences on P availability. A decrease in soil pH by 1.4 units was reported for intensive production of broccoli (*Brassica oleracea* var. *silvestris* L.) in the USA with surface application of ammonium nitrate, leading to increased nitrification and soil acidification (Stamatiadis 1999). Similarly, excessive N application has been reported to increase topsoil acidification in tomato (*Solanum lycopersicum* L.) and maize (*Zea mays* L.) fields (Dougill et al. 2002; Ju et al. 2007) and to cause yield reductions in tomato (Badr and Talaab 2008) and summer cabbage (Smith and Hadley 1992). The substantial accumulation of Nmin, notably NH_4^+ in the topsoil of both high and low inputs vegetable systems may reflect residual N surpluses and increase the acidification of the topsoil. The observed Nmin increases in the topsoil may indicate NO_3^--N accumulation in the cultivated leafy vegetables. However, this would need verification. Pôrto et al. (2008) reported such increases in leaf, stem and roots of lettuce with increased application levels of urea and cattle manure.

2.3.2 Horizontal nutrient balances in peri-urban millet fields

In the peri-urban millet production, partial nutrient balances were strongly positive for high input fields. In low inputs fields, P and K mining occurred as nutrient removal through harvested millet and cowpea grain and stover by far exceeded the very low input levels applied to these subsistence crops, which compares well to earlier reports about typical rural millet cultivation in SW Niger (Bationo and Buerkert 2001). The strongly positive partial horizontal balances in high input millet fields resulted mainly from manure application at an average annual rate of 10.3 t DM ha^{-1} through corralling of sheep, goats and cattle, which reflects the often close agro-pastoral linkages in low-intensity land use systems of Niger. These agro-pastoral linkages were also reported for millet systems in northern Burkina Faso (Quilfen and Milleville 1983; Berger et al. 1987) and underline the role of livestock for the cereal farming systems in the Sahelian zone. To minimize nutrient leaching on sandy Sahelian soils, Brouwer and Powel (1998) recommended not to exceed an annual manure application rate of 2.5 t DM ha^{-1} to minimize nutrient leaching. In the present study the annual quantity of manure applied to the high input fields was 4-fold higher than this amount and by the same magnitude lower than amounts determined in high input vegetable gardens. The stover yields obtained in the low input fields (1122 kg DM ha^{-1} yr^{-1}) compared well to average millet stover yields in the Sahel (1390 kg DM ha^{-1} yr^{-1}, Yamoah et al. 2002), but were lower than the 1625 kg DM ha^{-1} yr^{-1} reported for an on-station experiment in Niger where 2.5 t DM ha^{-1} yr^{-1} of manure were applied (Akponikpe et al. 2008). The grain yields obtained in the studied high input millet fields (630 kg DM ha^{-1} yr^{-1}) were also lower than the 964 kg DM ha^{-1} yr^{-1} reported for farmers' fields in Niger receiving 10 t DM ha^{-1} yr^{-1} of manure (Schlecht et al. 2004), an input similar to the amount applied to millet fields of our study. These findings provide evidence for the poor resource use efficiency in Niamey's UPA millet production. Predotova et al. (2009a) reported average annual losses of 17 kg N ha^{-1} as NH_3 and N_2O and of 5765 kg C ha^{-1} as CH_4 and CO_2 from Niamey's UPA millet fields, accompanied by annual leaching losses of 3.6 kg N ha^{-1} and 2.7 kg P ha^{-1} (Predotova et al. 2009b). Taking into account these gaseous and leaching losses, total annual balances for an intensively managed UPA millet field were estimated at -4.8 t C ha^{-1}, 118 kg N ha^{-1}, 17 kg P ha^{-1} and 95 kg K ha^{-1}. The latter three values are more than twice the total annual balances of 25 kg N ha^{-1}, 7.8 kg P ha^{-1} and 24.1 kg K ha^{-1} calculated for millet fields in Niger that received 2.5 t DM ha^{-1} of manure (Akponikpe et al. 2008). Provided that sufficient family labour is available, farmers might thus be advised to redirect the available manure from high input fields into low input fields, so as to increase the overall productivity and efficiency of UPA millet production.

2.3.3 Contamination of water and vegetables with pathogens and heavy metals

The low amount of mesophilic aerobic microorganisms in the wastewater samples collected during the cool dry season might have been due to dilution effects which occurred during the rainy season. Possible sources of *Staphylococcus aureus* in irrigation water are air-borne particles deposited by sandstorms or harmattan dust, human excreta and skin abrasions, since this pathogen is closely associated with nasal secretions (Bremer et al. 2004). The presence of *Streptococci*, *E. coli* and *Salmonella* in the wastewater is an indication of faecal contamination, which is an issue of general concern when untreated wastewater is used for irrigation. A study in El Azouzzia, Morocco, showed that lettuce and parsley irrigated with untreated wastewater were contaminated with the same serogroups of *Salmonella* B and C that were identified in the wastewater (Melloul et al. 2001). It is evident that the particularities of a crop species and its consumption patterns (e.g. lettuce *versus* carrot) largely determine the level of and risk for bacterial transmission to the consumer. A recent *Salmonella* spp. risk assessment study showed that human infection strongly depends on the type of crop, irrigation method, and most importantly the number of days elapsed between the last irrigation and consumption (Stine et al. 2005). The presence of *E*. *coli* on lettuce at Yantala

Bas1, Nogare2 and Gountou Yena1 may be due to the application of only partially composted ruminant manure in these gardens which is another possible source of contamination. This application practice is quite common in the UPA of Niamey where farmers broadcast manure on the standing crop. A contamination of lettuce with faecal coliforms originating from poultry manure was previously reported from Accra and Kumasi (Ghana), independently of the type of irrigation water used (Drechsel et al. 2000; Amoah 2005). These reports show that health risk assessments should not be limited to the quality of the irrigation water, but also address alternative pathways of vegetable contamination such as by animal manure and soil splash. Recent studies in Kumasi showed that in the dry season the avoidance of lettuce irrigation with wastewater six days before harvest effectively reduced microbial contamination of this important UPA produce (Keraita et al. 2007). Similar results were reported from Yuma, Arizona, where iceberg lettuce subjected to early termination of irrigation showed reduced microbial counts (Jorge 2006). However, in Niger this measure seems to be inefficient in the wet season, and it might adversely affect the productivity and freshness of vegetables in the dry season, thereby decreasing farmers' profits. Therefore, an integrated approach targeting all farm-relevant contamination sources apart from irrigation water and manure is required. Further studies should determine the survival conditions of *Salmonella* spp. and *E. coli* in the soil and manure stacks under the Sahelian conditions, so as to derive more environmentally safe dung management strategies, thereby reducing health risks for vegetable consumers.

The concentrations of Zn, Cu and Ni in all water sources were far below the established threshold values for irrigation water estimated at 2 mg Zn l^{-1}, 0.2 mg Cu l^{-1} and 0.2 mg Ni l^{-1} (Pescod 1992) and for vegetables set at 50 mg Zn kg^{-1} dry weight (DW), 30 mg Cu kg^{-1} DW and 1.5 mg Ni kg^{-1} DW (Awashthi 2000). The difference between the low heavy metal concentrations found in our study and the values of 1.3 mg Zn l^{-1} and 0.7 mg Cu l^{-1} reported for the same water sources by Graefe et al. (2008) can most likely be explained by a difference in sampling location. Our samples were collected at the gardeners' points of water withdrawal for crop irrigation, which were located a few 100 m downstream of the source points used by Graefe et al. (2008), indicating dilution effects. In previous UPA studies, crop irrigation with sewage water and industrial effluents, application of municipal solid wastes and lavish pesticide usage have been identified as the main sources for toxic levels of heavy metals, mainly Zn and Ni, on lettuce (171 and 52 mg kg^{-1} DW), spinach (154 and 69 mg kg^{-1} DW) and radish (139 and 63 mg kg^{-1} DW), respectively (Awashthi 2000; Binns et al. 2003; Gupta et al. 2008). In Lagos, Nigeria, concentrations of 106 mg Cu kg^{-1} and 25 mg Ni kg^{-1} were found in (dried) soil of industrial areas as opposed to 63 mg Cu kg^{-1} and 13 mg Ni kg^{-1} in residential areas (Yusuf et al. 2003). Vegetables such as water leaf (*Talinum triangulare* J.), bush okra (*Corchorus olitorus* L.), bitter leaf (*Vernonia amygdalina* L.) and fluted pumpkin (*Telfairia occidentalis* H.) cultivated in the industrial areas accumulated significantly higher amounts of Cu and Ni than those cultivated in the residential areas (Yusuf et al. 2003). In Titagarh, West Bengal, India, mean concentrations of 1.9 g Zn l^{-1}, 1.6 g Cu l^{-1} and 0.7 g Ni l^{-1} were reported for untreated wastewater used for irrigation. These were leading to soil concentrations of 217 mg Zn kg^{-1}, 90 mg Cu kg^{-1} and 104 mg Ni kg^{-1} and resulted in subsequent accumulation of these metals in vegetables far beyond recommended threshold values (Gupta et al. 2008). Given the low industrial development in Niamey, the accumulation of metal elements in wastewater irrigated vegetables seems at present of only minor concern.

2.4 Conclusions

The findings of this study indicate that UPA vegetable and millet production in Niamey are characterized by poor nutrient use and management:

(i) large surpluses of N, P and K were observed in vegetable gardens of low and high input intensity but C balances remain critical and require recycling of manure to maintain soil C levels;

(ii) in peri-urban millet cultivation, surpluses of N (for high and low input fields), P and K (high input fields only) prevailed, however, mining of P and K was shown for low input fields;

(iii) the observed surpluses were derived from a wide range of sources whose contribution varied among sites. In the vegetable gardens, mineral fertilizers accounted for 34-48% of N, 15-80% of P and 2-12% of K inputs. Animal manure contributed 69-79% to the C input, 44-68% to N, 61-73% to P and 48-75% to K. In the millet fields manure contributed significantly to the positive partial nutrient balances and accounted for 13-76% of N, 79-91% of P and 17-65% of K inputs, while root exudates were estimated to contribute 85-99% of the C inputs. Atmospheric deposition contributed mainly to the K input and biological N_2-fixation to the N input.

The results of this study suggest that there is a scope for improved nutrient use efficiency and management in Niamey´s UPA systems. To achieve this, strategies that better match nutrient supply to crop demand need to be applied. Pre-treatment of wastewater prior to use for irrigation and application of composted animal dung will contribute to minimize produce contamination, NO_3^- leaching and ammonia volatilisation and to enhance food safety, thereby reducing the negative externalities of UPA on the environment and human health.

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Resource use efficiency in urban and peri-urban livestock enterprises of Niamey, Niger

Abstract

Urban livestock husbandry receives growing attention given the increasing urban demand for livestock products. At the same time, little is known about the resource use efficiency in urban livestock enterprises and eventual negative externalities. These questions were investigated in Niamey, capital of the Republic of Niger, a typical West African city, where urban livestock production is constrained by feed scarcity, especially during the dry season. Resource use efficiency was studied in 13 representative and differently managed sheep/goat and cattle enterprises characterized by high and low feed input, respectively, during a period of 28 months. Nitrogen (N), phosphorus (P) and potassium (K) inflows into each farm through livestock feeds and outflows through manure were determined using a semi-structured questionnaire; interviews were accompanied by regular weighing of feed supplied and dung produced. Live weight gain (LWG), feed dry matter (DM) utilization and efficiency of feed conversion (kg FDM kg^{-1} LWG) were computed along with nutrient balances per tropical livestock unit (TLU = 250 kg LW). Nutrient balances (TLU^{-1} day^{-1}) in high input (HI) sheep/goat enterprises were with +110.8 g N, +8.0 g P and +85.7 g K significantly higher ($P < 0.05$) than those in low input (LI) units where +4.4 g N, -6.2 g P and +1.0 g K were determined. In HI cattle enterprises, daily balances averaged +28.6 g N, +2.5 g P and +21.5 g K compared to +2.2 g N, -0.6 g P and +4.3 g K ($P >$ 0.05) in LI cattle husbandry enterprises. All systems were characterized by poor feed conversion efficiencies with ranges from 13 - 42.1 kg DM kg^{-1} LWG in cattle and 15.7 - 43.4 kg DM kg^{-1} LWG in sheep/goats. LWG in HI sheep/goats was 53 g day^{-1} in the rainy season, 86 g day^{-1} in the hot dry season and 104 g day^{-1} in the cool dry season, while HI cattle lost 232 g day^{-1} and 651 g day^{-1} in the rainy and the hot dry season and gained only 33 g day^{-1} in the cool dry season. These data indicate that there is waste of nutrients and scope for improvement of feeding strategies in Niamey's livestock enterprises which might also decrease nutrient losses to the urban environment.

Keywords: cattle, dung, live weight changes, nutrient balances, roughage, small ruminants, urban agriculture, West Africa

3 Introduction

In the past 40 years the urban population of sub-Saharan West Africa (SSWA) has dramatically risen (Tiffen, 2004), reaching an average urbanization rate of 36% in 2005 (UN-Habitat, 2007). This has spurred urban demand for food, mainly for cereals, pulses, and livestock products (Tiffen, 2004; Pistocchini et al., 2009). In the region, urban livestock husbandry becomes increasingly widespread as a social security strategy, source of food, income and employment, savings and as an insurance system (Thys et al., 2005; Fernández-Rivera et al., 2005, Ayantunde et al., 2007). In Bamako, Mali, reportedly over 20,000 households keep livestock under urban conditions (Schiere, 2001), while in Kumasi, Ghana, 47% of 60 surveyed households kept mainly chicken (Poynter and Fielding, 2000). Similarly, in the Niayes zone in Senegal, livestock keeping is well integrated into urban production systems, with poultry and sheep being the most important species (Fall and Cisse, 2000). In Ougadougou, Burkina Faso, 26% of the 1979 households interviewed by Thys et al. (2005) were livestock keepers; poultry (chicken, duck, guinea fowl) were the most prevalent (59%), followed by sheep and goats (20%), pigs (8%) and cattle (7%). In Niamey, Niger, 82% of 130 interviewed households kept animals while 42% were involved in gardening and 58% cultivated millet fields (Graefe et al., 2008). In the 106 households involved in animal husbandry, 51% kept cattle, 46% sheep, 31% goats, and 15% donkeys (Graefe et al., 2008). Sheep and goats were mainly kept in the city center, while cattle husbandry dominated in the outskirts. A recent livestock census estimated that Niamey’s livestock population comprises 36,577 head of cattle, 138,762 sheep and 75,300 goats (RGAC, 2005). These high livestock numbers reflect a high demand for livestock feeds which can not be satisfied by supply from the urban area alone but often relies on the rural surroundings to sustain the production within urban settlements (Guendel, 2000; Graefe et al., 2008). In Kumasi, Ghana, however, no evidence of urban-rural linkages was found (Poynter and Fielding, 2000). Nevertheless, livestock keepers in larger towns recurrently face problems in obtaining sufficient feed and water for their animals (Araya et al., 2007). In traditional livestock production, a wide array of feed resources is being used. In the Greater Banjul town in The Gambia, *Moringa oleifera* Lam. (drumstick tree) serves as a supplement feed for ruminants (Akinbamijo, 2000), while in Kumasi, Ghana, kitchen wastes (cassava and plantain peelings), brewers´ grains, maize chaff, maize grain, fishmeal, rice grain and fodder tree leaves are reportedly fed to livestock (Poynter and Fielding, 2000). In Khartoum, Soudan, the use of organic garbage was reported to be a feed supplement for goats and sheep as well as for cattle (Richardson, 1995), while in Mekelle, Ethiopia, innovative livestock keepers collect residues from local beer-making industries and waste from vegetable markets to feed their animals (Araya et al., 2007). With an increased consumption of livestock products (Pistocchini et al., 2009) and the hope to benefit of this demand of Niamey’s rapidly growing population, intensive supplementation systems have evolved among the urban and peri-urban livestock farmers (Tiffen, 2004). Animals are kept in small sheltered enclosures at the homestead and are fed crop residues and other available waste products (Fernández-Rivera et al., 2005). Because of the limited availability of feed especially in the dry season and its high cost (Urassa and Raphael, 2004; Thys et al., 2005) an efficient utilization of this resource is mandatory (Sumberg, 2002; Nkya et al., 2007). Optimization of animal feeding strategies and management have been described as key factors governing the economic performance of animal husbandry (Oenema and Pietrzak, 2002). Certainly, intensive animal husbandry systems in the midst of an urban setting might lead to negative environmental externalities (Petersen et al., 2007), and manure management is thus a major challenge (Thys et al., 2005; Powell, 2008). Against this background, the present study aimed at (i) investigating inflows and outflows of nitrogen (N), phosphorus (P) and potassium (K) through feeds offered and dung produced in differently managed livestock enterprises, (ii) assessing the effects of seasonal variations in nutrient intake on sheep/goat and cattle performances and (iii) quantifying nutrient use efficiencies in differently managed urban and peri-urban livestock (UPL) enterprises in Niamey, capital of Niger.

3.1 Materials and methods

3.1.1 Study site and household selection

The study was carried out in Niamey, Niger, where the semi-arid Sahelian climate is characterised by three distinct seasons. The rainy season lasts from June to October, and the annual rainfall averages 577 mm (L´Hôte et al., 2002). In the cool dry season (November-February) average daily temperatures range from 16 - 32°C, while in the hot dry season (March-May) they vary from 27 - 41°C. Urban and peri-urban agricultural activities are expanding within and around Niamey due to increasing urban demand for plant and livestock products (Belli et al., 2008; Graefe et al., 2008).

A comprehensive nutrient management monitoring was conducted in 13 representative and differently managed livestock keeping households selected from 130 households characterised in a preceding study (Graefe et al., 2008). These households were surveyed during a period of 28 months (November 2005 - January 2008) to collect data on the different inputs and outputs in their livestock units. To determine the impact of management on nutrient use efficiency, households were classified as high and low input farms (HI, LI) based on the amount of total feed dry matter (TDM) offered daily to the animals at the homestead. The average stock number per household varied from 1 - 10 in cattle and from 4 - 37 in sheep/goats, whereby more cattle and sheep/goats, respectively, were kept in LI than in HI enterprises (Table 1). Four out of the 13 households combined indoors HI sheep/goat rearing (plus very sporadic grazing) with grazing plus stall feeding of LI cattle; 4 households managed LI cattle as well as LI sheep/goats; one and two households, respectively, only kept cattle and sheep/goats, combining HI stall feeding with grazing, and another two households combined HI cattle rearing (stall feeding plus grazing) with LI sheep/goat management.

Table 1. Characteristics of the investigated thirteen[†] urban livestock enterprises in Niamey, Niger.

Species	Feeding intensity	Households (n)	Herd size (TLU[#])	Forage TDM* (kg TLU^{-1} day^{-1})	Feeding strategy**
Cattle	High input	6	1.4 ± 0.3	23.0 ± 3.7	++
	Low input	5	2.4 ± 1.4	9.4 ± 2.0	++
Sheep/goats	High input	4	1.1 ± 0.3	29.6 ± 5.5	-+
	Low input	8	1.6 ± 0.5	9.3 ± 1.9	++

[†] Several households combined sheep/goat and cattle units. Please refer to the text for detailed explanation of the repartition of units across the 13 households.

[#] TLU: Tropical livestock unit; 1 sheep/goat = 0.1 TLU, 1 cattle = 0.8 TLU.

* TDM: Total dry matter; 28-months average

** Strategy: ++ = grazing plus stall feeding; -+ = little or no grazing, mainly or solely stall feeding

3.1.2 Forage supply and quality assessment

Every 4 - 6 weeks, the origin, type and quantity of feeds supplied at the homestead and the frequency of feeding (sometimes feeds were only offered every second day) were assessed in each of the 13 households by semi-structured interviews, accompanied by quantitative weighing of the daily feed offered using an electronic weighing scale (0 - 50 kg, accuracy 0.02 kg). The feed supplied comprised roughages (crop residues and bush feeds) and some supplementary brans or grains of millet, sorghum, maize, rice and wheat, as well as cotton seed cake. Feed samples (two per type of feed) were collected in each household every six weeks and were pooled per season and type of feed. Samples were analyzed for their concentrations of dry matter (DM), organic matter (OM), nitrogen (N), phosphorus (P) and potassium (K), digestible organic matter (DOM) and metabolizable energy (ME) using standard procedures (see below). Based on the analyses, feeds were classified as bush (BF), energy (EF) and protein (PF) feeds. Feed intake from pasturing was not accounted for in the calculations of seasonal nutrient flows and nutrient balances.

3.1.3 Weight development and body condition scoring

All cattle, sheep and goats of each household were identified by a permanent number. Their live weight (LW) was determined every six weeks using a suspended weighing scale (0 - 100 kg, accuracy 0.5 kg) for small ruminants and calves up to 100 kg. For adult cattle, the body condition was scored according to Nicholson and Butterworth (1986) based on a 9-score scale. To convert the body condition scores (BSC) to live weight, the regression equation [1] by Otto et al. (1991), which is based on a 5-score scale for Holstein dairy cows, was adapted to a 10-score scale using the equation [2] developed by Roche et al. (2004) which has similarities with the 9-score BCS scale used. We used a correction factor of 2.14 to convert the live weight of Holstein cows to that of

Zebu cattle, assuming an average adult LW of 750 kg for Holstein and 350 kg for the local Gudali and Azawak breeds of Zebu cattle.

$$LW = 56.02\ BCS - 570.82 \qquad [1]$$

$$BSC\_5 \text{ - point system} = 0.81 + 0.4 \times BSC\_10 \text{ - point system} \qquad [2]$$

3.1.4 Quantification of milk and dung produced

Milk offtake from cows by the herders/owners was quantified during two consecutive days at 6-week intervals. However, this data was available only for 2 households who milked their cows.

As far as dung (faeces plus urine plus organic material such as feed residues, straw bedding, etc.) is concerned, the amount produced in the 13 livestock rearing households was quantified by weighing the dung heap monthly. Two representative dung samples were collected per assessment date in each household and were pooled per season and type (dung from small ruminants and from cattle, respectively) to determine their concentration of dry matter, organic matter, N, P and K using standard procedures (see below).

3.1.5 Calculation of horizontal nutrient balances and nutrient use efficiencies

To assess the resource use efficiency in the livestock sector, horizontal nutrient balances (NB) were calculated on a daily basis for one tropical livestock unit (TLU = 250 kg LW) using equation [3]. Since milk data was only available from two households, it was not included in the nutrient balance equation.

$$NB\ [g\ (DM, N, P, K)\ TLU^{-1}\ day^{-1}] = \text{Feed offered}\ [g\ (DM, N, P, K)\ TLU^{-1}\ day^{-1}] - \text{Dung produced}\ [g\ (DM, N, P, K)\ TLU^{-1}\ day^{-1}] \qquad [3]$$

The balance was considered equilibrated if it was close to zero, while any major deviation of NB from zero indicated inefficient resource management. To assess the efficiency of conversion of forage DM into live weight gain (LWG) by small ruminants and cattle, the feed conversion ratio (FCR, kg FDM kg^{-1} LWG) was calculated.

3.1.6 Qualitative analyses of feed and manure samples

For chemical analyses all feed and dung samples were dried to constant weight at 65°C and ground to pass a 1-mm screen. Dry matter concentration was determined by drying 5 g of air dry sample material at 105°C for five hours, and organic matter concentration was derived by subsequent ashing of the sample at 550°C for four hours (Naumann et al., 2004). Total phosphorus was determined colorimetrically (Hitachi U-2000 spectrophotometer) according to the vanado-molybdate method (Gericke and Kurmies, 1952) and total potassium was determined by flame emission photometry (Auto Cal 743, Diamond Diagnostics, Holliston, MA, USA). Total N was determined with an N-analyzer (Leco FP-328, Leco Corp. St. Joseph, MI, USA) based on the thermal conductivity cell measurement. The concentration of crude protein (CP) was calculated by multiplying the concentration of N by 6.25 (Naumann et al., 2004). *In vitro* digestibility was derived from the gas production of the sample material incubated with rumen liquor for 24 hours (Menke et al., 1979). The concentration of digestible organic matter (DOM) and of metabolizable energy (ME) was calculated according to Close and Menke (1986) and Menke and Steingass (1987), respectively.

3.1.7 Statistical analysis

Residuals of all data were tested for normal distribution and homogeneity of variances before F-tests were performed using the General Linear Models (GLM) procedure of SAS 9.1 (2003). Independent variables were feeding intensity, season, and year, while dependent variables comprised inputs and outputs of DM, N, P and K as well as live weight changes of animals. Correlation between herd size and amount of feed offered was tested using Spearman's rank correlation coefficient. Means were separated by t-tests (LSD) at $P = 0.05$.

3.2 Results

3.2.1 Quality of feeds in urban livestock production

The four types of husbandry enterprises differed in their practice of grazing: while stall feeding was mostly combined with grazing in LI sheep/goats and LI and HI cattle, stall feeding was prevailing in HI sheep/goats (Table 1).

Since there were no significant differences in the proximate composition of feeds between the two feeding intensities and the two species groups, respectively, further statistical analyses evaluated average values across the four distinguished livestock husbandry enterprises. Feed quality varied significantly between seasons and types of feed. During the rainy season, the offered rations were dominated by protein (PF) and energy (EF) feeds and had higher concentrations of N, P and K ($P < 0.05$ for PF and $P > 0.05$ for EF except for P, Table 2) than the rations offered in the hot dry season when millet stover and grasses such as *Schizachyrium exile* Hochst. and *Ctenium elegans* Kunth. dominated the ration. During the rainy season, hay from cowpea (*Vigna unguiculata* Walp.), seed cake from cotton (*Gossypium hirsutum* L.) and *Zornia glochidiata* Reichb. consisted the major PF, whereas brans of wheat, sorghum and millet represented the major EF. During the cool dry season the offered rations were dominated by highly digestible EF with maize, millet and wheat brans and pods from *Faidherbia albida* Chev. being the main components; in these rations, the concentration of N was higher than in the rations offered in the hot dry season ($P < 0.05$, Table 2). Concentrations of metabolizable energy varied between 7.6 - 9.8 MJ ME kg^{-1} DM in the rainy, 7.2 - 9.9 MJ ME kg^{-1} DM in the cool dry and 7.2 - 9.5 MJ ME kg^{-1} DM in the hot dry season (Table 2).

Table 2. Proximate composition of feeds offered to sheep/goats and cattle raised in high and low input systems in Niamey, Niger, during the rainy, cool dry and hot dry season (2005 - 2008).

Season	Feed type*	DM	OM	N	P	K	DOM	ME
		(g kg^{-1} ADM)			(g kg^{-1} DM)			(MJ kg^{-1} DM)
Rainy	PF	934^{a}	830	$24.4^{b;\beta}$	$4.7^{b;\beta}$	14.6^{β}	659^{b}	$9.0^{b;\beta}$
	EF	$931^{a;\alpha\beta}$	838	$23.2^{b;\alpha\beta}$	$8.5^{c;\beta}$	13.1	$704^{b;\beta}$	9.8^{c}
	BF	941^{b}	828	$14.3^{a;\beta}$	1.9^{a}	12.5	618^{a}	7.6^{a}
Cool dry	PF	930^{a}	830	$18.1^{b;\alpha}$	$2.2^{a;\alpha}$	$14.2^{b;\beta}$	653^{a}	$8.3^{b;\alpha}$
	EF	$926^{a;\alpha}$	813	$23.0^{c;\beta}$	$6.8^{b;\alpha}$	10.6^{a}	$718^{c;\beta}$	9.9^{c}
	BF	937^{b}	825	$11.8^{a;\alpha\beta}$	1.9^{a}	14.5^{b}	589^{b}	7.2^{a}
Hot dry	PF	932	835	$16.2^{b;\alpha}$	$1.2^{a;\alpha}$	$8.4^{a;\alpha}$	633	$8.0^{a;\alpha}$
	EF	937^{β}	842	$17.3^{b;\alpha}$	$6.7^{b;\alpha}$	10.2^{b}	626^{α}	9.5^{b}
	BF	937	826	$8.7^{a;\alpha}$	1.6^{a}	14.5^{b}	586	7.2^{a}

ADM = air dry matter; DM = dry matter; DOM = digestible organic matter; ME = metabolizable energy;
* PF = protein feeds, EF = energy feeds, BF = bush feeds
Within seasons, different Roman letters indicate significant differences ($P < 0.05$) between different types of feeds; within one type of feed, different Greek letters indicate significant differences between seasons. Where no Roman or Greek letters are given, the respective differences are insignificant.

3.2.2 Feed offer and growth rates in small ruminants

In all seasons, the amount of feed offered to sheep/goats differed significantly between HI and LI enterprises. During the rainy season, daily TDM (all feed types included) in HI sheep/goats averaged 507 g kg$^{-0.75}$ compared to 189 g kg$^{-0.75}$ ($P < 0.05$, Figure 1) in the LI units. In the HI sheep/goat units, PF and BF were offered in daily amounts providing 2,347 kJ ME kg$^{-0.75}$ and 1,761 ME kJ kg$^{-0.75}$, respectively, which was over 3-fold and 2-fold higher than the respective values in the LI sheep/goat units ($P < 0.05$; Figure 2). The total daily offer of metabolizable energy to HI sheep/goats amounted to 5,661 kJ kg$^{-0.75}$ compared to 2,067 kJ kg$^{-0.75}$ in the LI sheep/goat enterprises.

During the cool dry season, daily TDM offered to HI animals averaged 546 g kg$^{-0.75}$ and was 50% higher than the values recorded in the rainy and in the hot dry season. This trend was also observed in the LI units, where PF accounted for 33% of the daily TDM compared to 51% ($P < 0.05$) in the HI units (Figure 1). Metabolizable energy offer from PF amounted to 2,524 kJ ME kg$^{-0.75}$ in HI compared to 691 kJ ME kg$^{-0.75}$ ($P < 0.05$) in LI animals (Figure 2), and total daily metabolizable energy offered averaged 4,315 kJ kg$^{-0.75}$ in the HI compared to 2,465 kJ kg$^{-0.75}$ in the LI units. In the hot dry season, daily TDM offered to HI animals was similar to the rainy season values and the contribution of protein feeds significantly affected the daily offer of metabolizable energy (Figure 2), which at 4,947 kJ ME $kg^{-0.75}$ was more than 2-fold higher for HI than for LI sheep/goats.

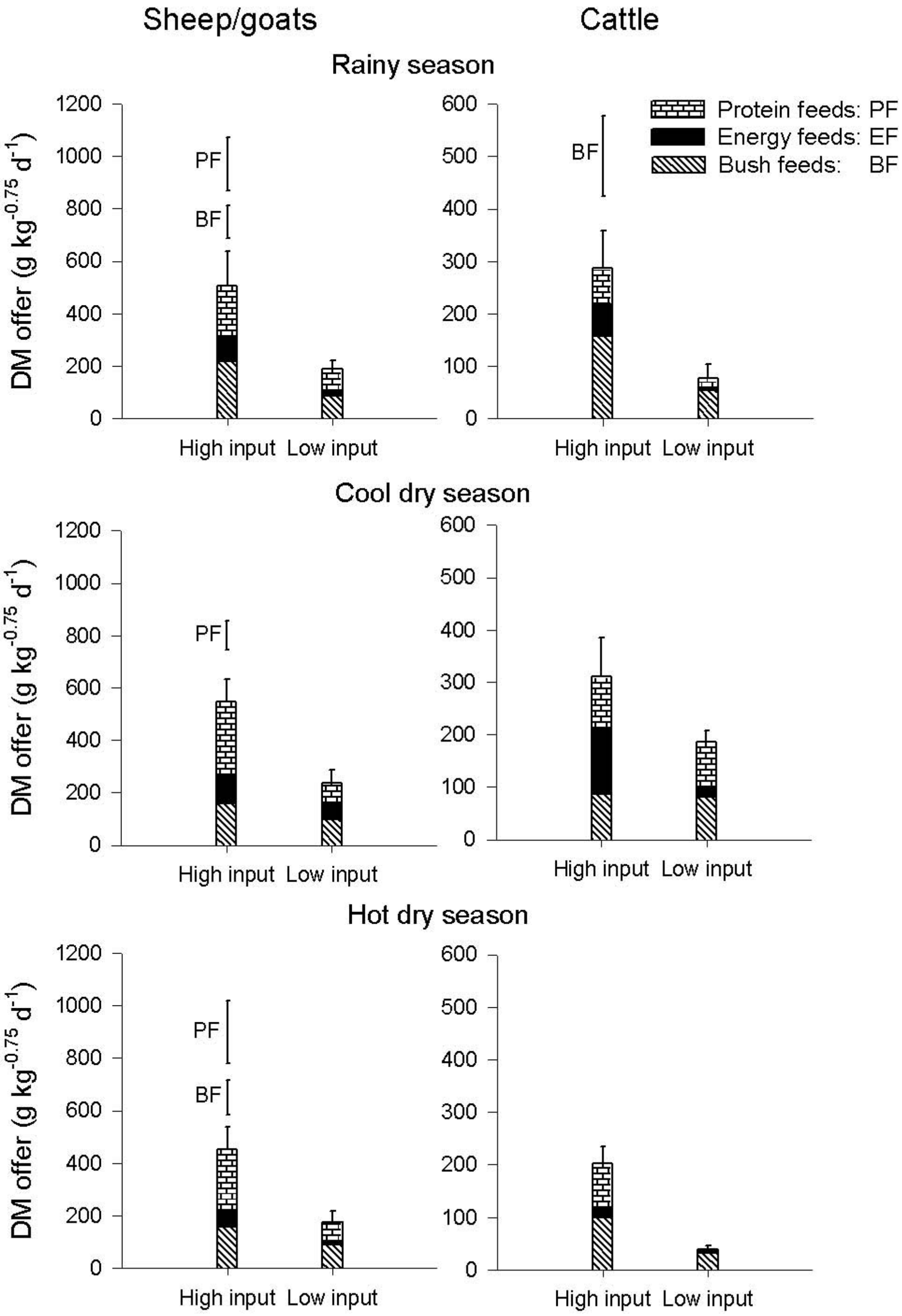

Figure 1. Mean (plus one SE) daily feed dry matter (DM) offer to small ruminants and cattle during the rainy, cool dry and hot dry season in high and low input livestock management units in Niamey, Niger, during November 2005 to January 2008. The isolated vertical lines in the charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management intensities. Please note the different scaling of Y-axes for sheep/goats *versus* cattle.

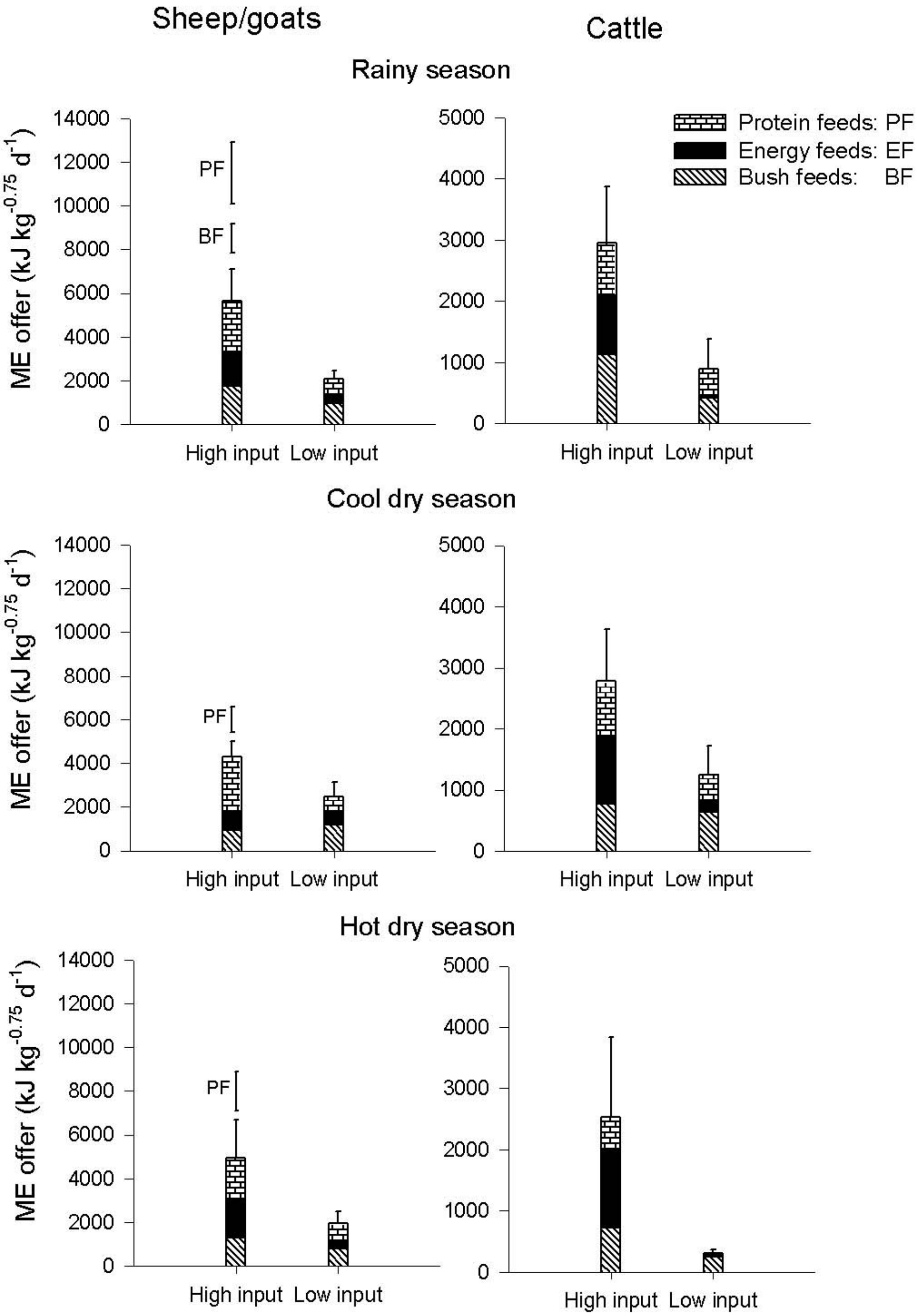

Figure 2. Mean (plus one SE) daily metabolizable energy (ME) offer to small ruminants and cattle during the rainy, cool dry and hot dry season in high and low input livestock management units in Niamey, Niger, during November 2005 to January 2008. The isolated vertical lines in the charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management intensities. Please note the different scaling of Y-axes for sheep/goats *versus* cattle.

As far as individual nutrients are concerned, the daily offer of N in the cool dry season amounted to 3.3 g $kg^{-0.75}$ in HI sheep/goats and was similar to the amounts offered in the rainy and the hot dry season ($P > 0.05$); these values were all significantly higher than the amounts of N offered to LI sheep/goats in the respective seasons ($P < 0.05$, Figure 3), and also exceeded the requirements for maintenance plus 120 g of daily LW gain of a 50 kg LW sheep (Table 3). Similar observations were made with respect to offers of P and K in the rainy and the cool dry season. In the hot dry season however, differences in the amounts of P and K offered were not significant between HI and LI sheep/goats (Figures 4, 5).

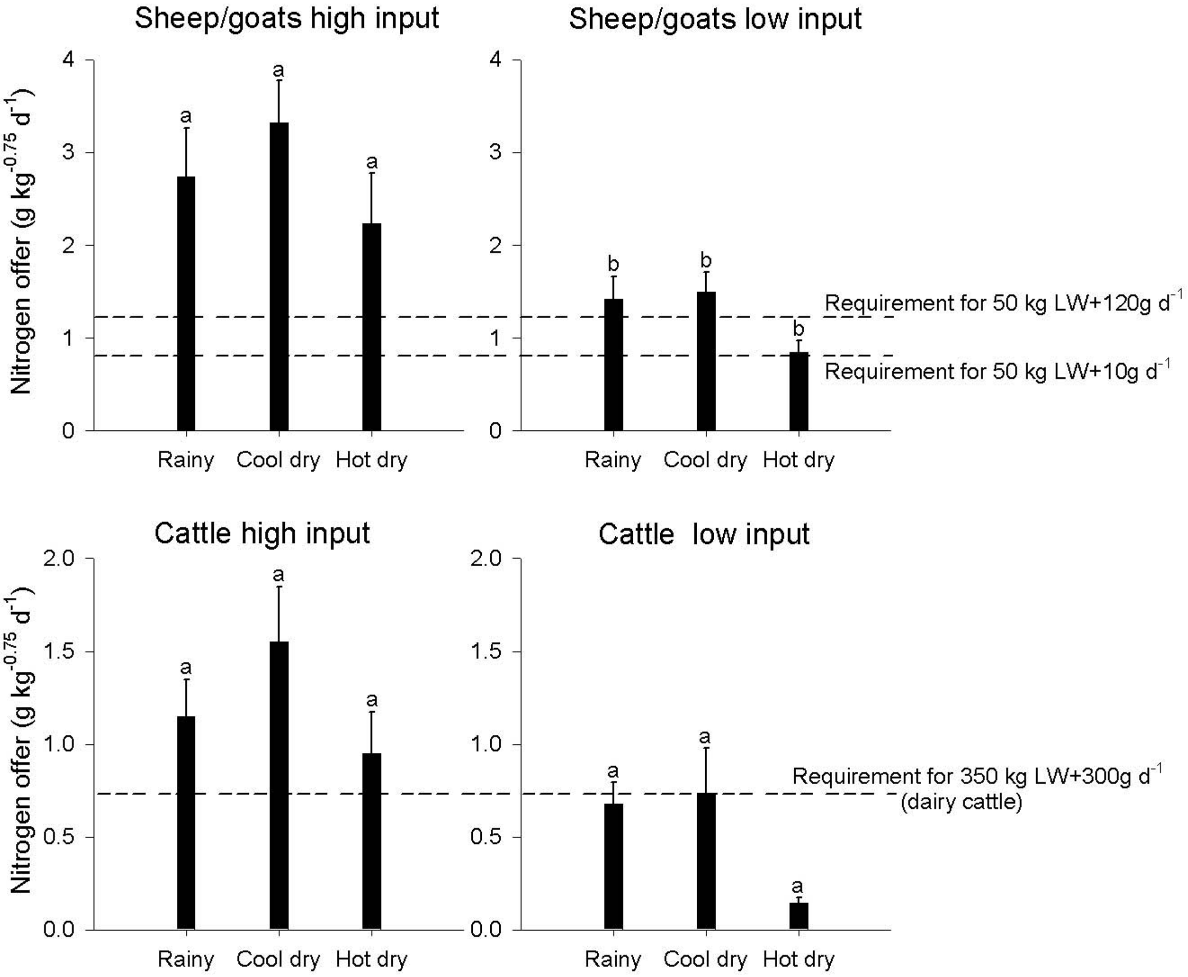

Figure 3. Mean (plus one SE) daily nitrogen offer to small ruminants and cattle during the rainy, cool dry and hot dry season in high and low input livestock management units in Niamey, Niger, during November 2005 to January 2008. Within the same season, different letters in charts indicate significant differences ($P < 0.05$) between the two management intensities. Please note the different scaling of the Y-axes for sheep/goats *versus* cattle.

Table 3. Daily dry matter (DM), metabolizable energy (ME) and nutrient requirements of fattening sheep/goats and dairy cattle.

Species	Growth rate ($g\ day^{-1}$)	DM	N	P	K	ME ($kJ\ kg^{-0.75}\ day^{-1}$)	Source
		($g\ kg^{-0.75}\ day^{-1}$)					
Fattening sheep/goat (50 kg LW)	+10	53.17	0.81	0.10	0.27	443	NRC 1985, 2006
	+120	79.63	1.16	0.13	0.34	710	
Dairy cattle (350 kg LW)	+300	61.75	0.79	0.10	0.32	398	NRC 1989, 2001
	+600	89.97	1.73	0.22	0.71	879	
	+700	95.63	1.84	0.23	0.75	933	

$kg^{-0.75}$ = metabilic body mass

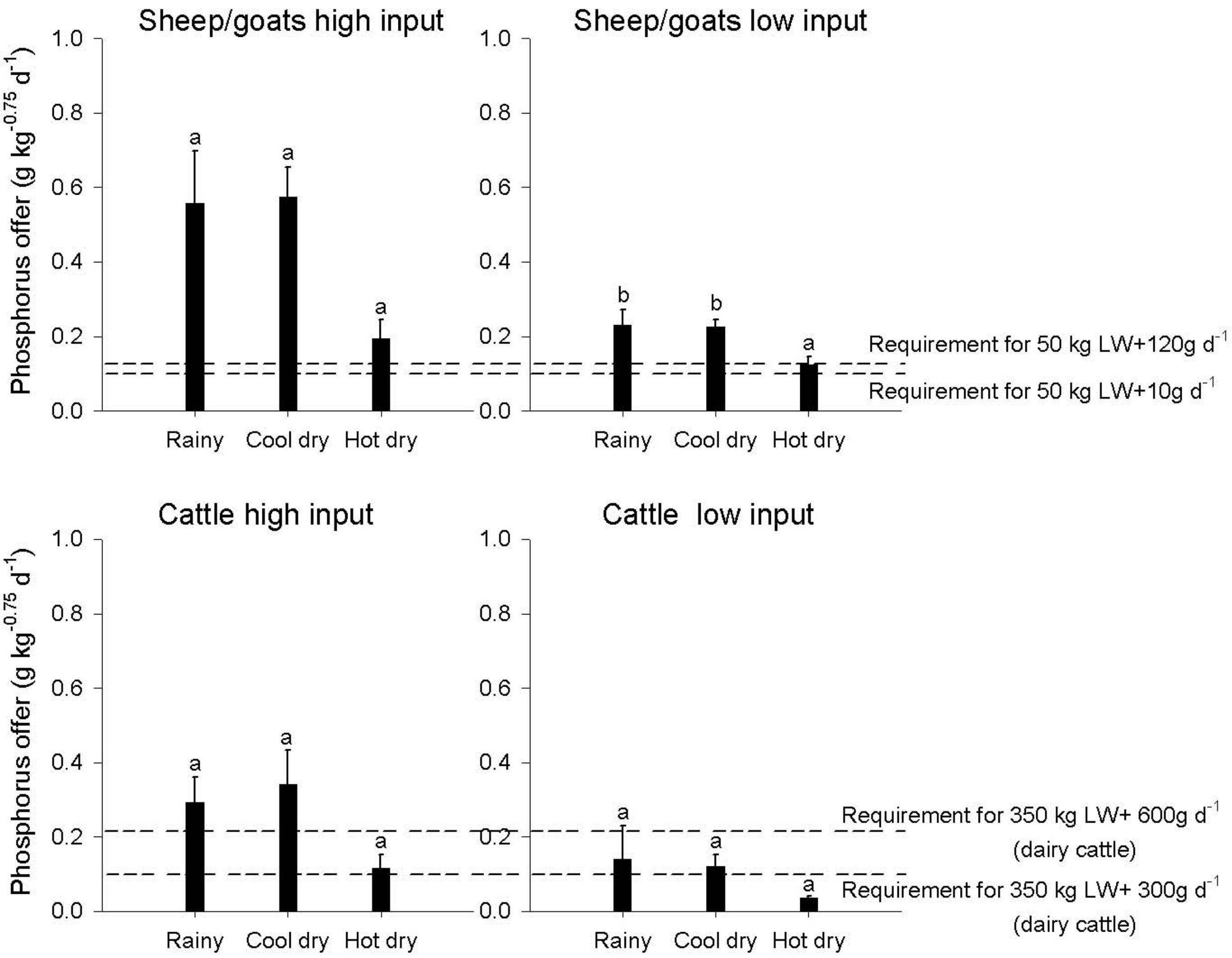

Figure 4. Mean (plus one SE) daily phosphorus offer to small ruminants and cattle during the rainy, cool dry and hot dry season in high and low input livestock management units in Niamey, Niger, during November 2005 to January 2008. Within the same season, different letters in charts indicate significant differences (*P* < 0.05) between the two management intensities.

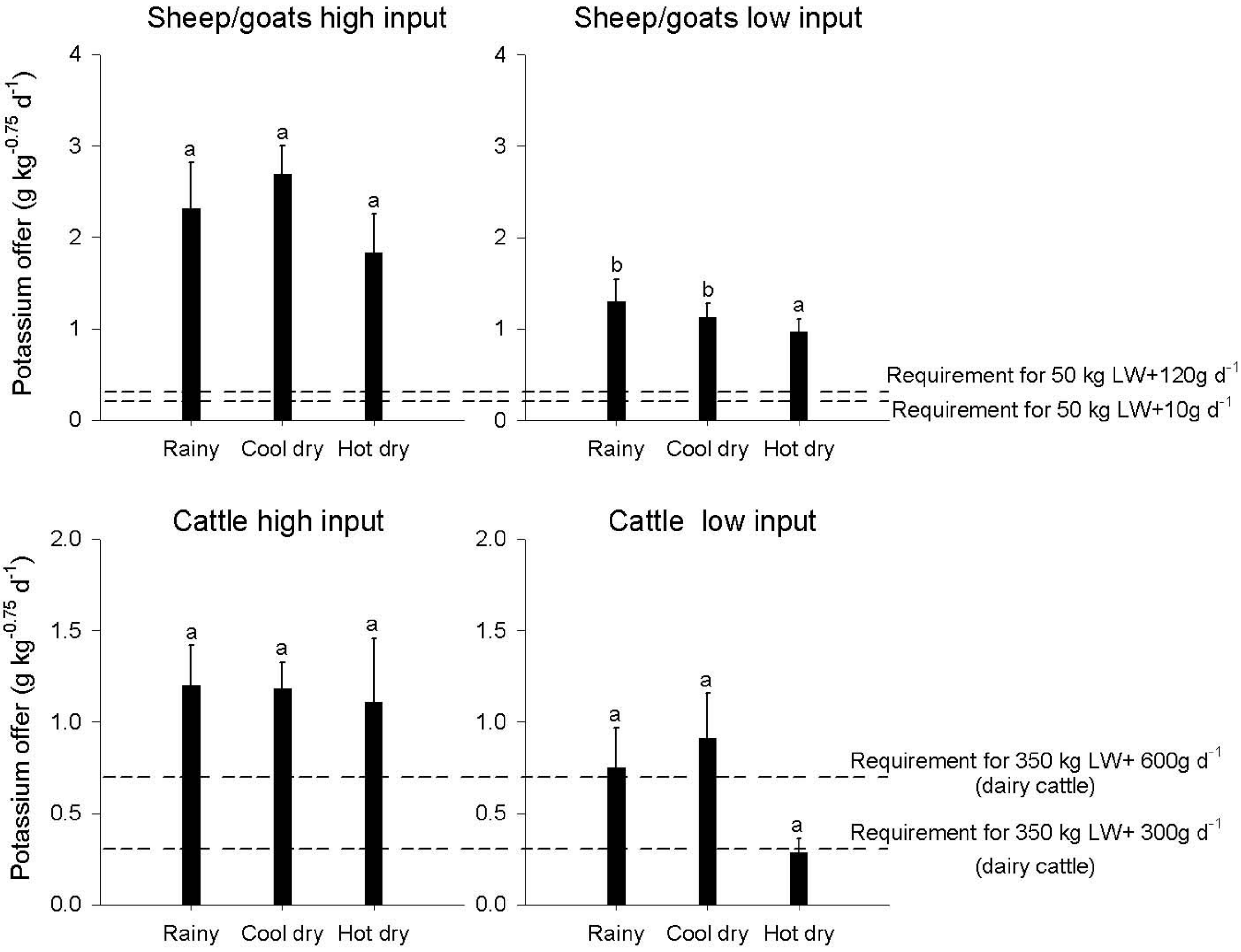

Figure 5. Mean (plus one SE) daily potassium offer to small ruminants and cattle during the rainy, cool dry and hot dry season in high and low input livestock management units in Niamey, Niger, during November 2005 to January 2008. Within the same season, different letters in charts indicate significant differences ($P < 0.05$) between the two management intensities. Please note the different scaling of Y-axes for sheep/goats *versus* cattle.

At 104 g day^{-1}, the growth rate of HI sheep/goats in the cool dry season was higher than the 48 g d^{-1} ($P < 0.05$) of LI animals in the same season. During the hot dry and the rainy season, weight gains in HI animals were 86 and 53 g day^{-1} and exceeded those of LI animals by a factor of 1.2 and 2.4 ($P > 0.05$, Table 4), respectively.

For HI sheep, the effects of the seasonal variation in intake of DM, N, P and K on daily weight changes were further investigated for the following four LW classes: I ≤ 10, II: > 10 ≤ 20, III: >20 ≤ 40, IV: >40 ≤ 60 kg. Daily feed and nutrient intake did not differ significantly between sheep of different LW classes; across the classes, daily intake of BF per animal averaged 1,102 g DM (±286.6) in the cool dry season and differed ($P < 0.05$) from that of the hot dry season (269 g DM, ±77.9) and the rainy season (238 g DM, ±132.8). The daily intake of nutrients during the rainy season averaged 37 g N (±10.4), 9 g P (±3.6) and 34 g K (±8.8) per animal and was similar to the N, P and K intake in the cool dry season. In the hot dry season, N, P and K intake were 3-fold, 2.6-fold and 4.4-fold lower than in the rainy season ($P < 0.05$ for all nutrients). During the cool dry season, daily LWG in class I, II, III and IV was 92 g (±8.8), 54 g (±6.1), 43 g (±6.2) and -15 g (±15.5), respectively, as opposed to 72 g (±14.4), 54 g (±8.0), 5 g (±6.7), and -39 g (±16.4) in the hot dry season ($P > 0.05$ for I, II, IV, $P < 0.05$ for III) and 74 g (±37.2), 42 g (±7.3), 33 g (±8.1) and 3 g (±29.0) in the rainy season ($P > 0.05$ in all cases).

3.2.3 Feed offer and growth rates in cattle

During the rainy season, daily TDM offered to cattle averaged 287 g $kg^{-0.75}$ in the HI compared to 77 g $kg^{-0.75}$ in the LI units ($P < 0.05$; Figure 1). The HI rations comprised 55% bush feeds *versus* 71% ($P < 0.05$) in the LI rations. During the cool dry season, daily TDM offer averaged 310 g $kg^{-0.75}$ in HI cattle and exceeded the offers recorded in the hot dry season (202 g $kg^{-0.75}$); a similar trend was found in LI cattle. Concerning the offer of metabolizable energy, differences between the two feeding systems were not significant, although higher amounts of energy feeds were offered to HI than to LI cattle (Figure 2). Daily quantities of N offered to HI cattle averaged 1.5 g $kg^{-0.75}$ in the cool dry, 1.1 g $kg^{-0.75}$ in the rainy and 0.9 g $kg^{-0.75}$ in the hot dry season ($P > 0.05$); these amounts were higher ($P > 0.05$) than the amounts of N offered to LI cattle in the respective seasons (Figure 3). Similar trends were found with respect to the daily offer of P and K (Figures 4, 5). Overall, TDM, ME and N, P and K offered at the two feeding intensities exceeded the animals' respective requirements (Table 3) in the cool dry and the rainy season.

In HI cattle only a slightly positive LWG was obtained during the cool dry season (33 g day^{-1}), while animals lost 232 g day^{-1} and 651 g day^{-1} in the rainy and the hot dry season. Cattle raised under LI conditions, in contrast, showed substantial weight gains in the cool dry (714 g day^{-1}; $P > 0.05$) and the rainy season (300 g day^{-1}; $P > 0.05$), but during the hot dry season average weight losses of 914 g day^{-1} were determined ($P > 0.05$; Table 4).

3.2.4 Feed conversion efficiencies and nutrient balances

The efficiency with which offered forage DM was converted into live weight differed between feeding intensities and seasons and between cattle and small ruminants. For farms where complete data records for 28-months were obtained (HI cattle: 5, LI cattle: 5, HI sheep/goats: 4, LI sheep/goats: 7), average FCR ranged from 2.7 - 13.0 kg FDM kg^{-1} LWG in cattle and from 3.5 - 16.4 kg FDM kg^{-1} LWG in small ruminants (Table 5). Extreme individual values exceeded 42 kg FDM kg^{-1} LWG in cattle and in sheep/goats and were independent of feeding intensity. For cattle, horizontal DM balances were positive irrespective of feeding intensity; for small ruminants DM balances were positive in the HI and negative in the LI units (Figure 6). For sheep/goats, daily surpluses of N, P and K were significantly higher in the HI than in the LI units (Figure 7b, d, f).

Table 4. Growth rate (g day^{-1}; means ± one SE) of sheep/goats and cattle kept under two different management intensities in Niamey, Niger, during November 2005 to January 2008.

System	High input			Low input		
Season	CDS	HDS	RS	CDS	HDS	RS
Sheep/goats	104^b ± 36.9	86^a ± 15.6	53^a ± 14.7	48^a ± 6.3	70^a ± 20.0	22^a ± 6.5
Cattle	33^a ± 14.5	-651^a ± 729.2	-232^a ± 619.2	714^a ± 1026.8	-914^a ± 405.7	300^a ± 358.6

CDS: cool dry season; HDS: hot dry season; RS: rainy season
Within season and animal species, values with different letters differ at $P < 0.05$ between sheep/goats and cattle.

Table 5. Feed dry matter conversion into live weight gain (kg FDM kg^{-1} LWG; means ± one SE) by sheep/goats and cattle raised under two different management intensities in Niamey, Niger, during November 2005 to January 2008.

System	High input			Low input		
Season	CDS	HDS	RS	CDS	HDS	RS
Sheep/goats	15.7 ± 11	32.2 ± 17	-9.5 ± 11	-3.5 ± 8	43.4 ± 16	16.4 ± 15
Cattle	42.1 ± 24	-8.7 ± 13	-2.7 ± 35	2.8 ± 18	10.2 ± 11	13.0 ± 12

CDS: cool dry season, HDS: hot dry season; RS: rainy season

No significant differences were found between seasons and management intensities for both species. Only farms with a complete 28-months data set were included. Sample sizes were for sheep/goats: n=4 in HI and n=7 in LI; for cattle: n=5 in HI and n=5 in LI.

In cattle no significant differences in horizontal nutrient balances were observed between the two feeding intensities, although the surpluses in the HI units exceeded those of the LI units for all nutrients (Figure 7a, c, e). Overall, nutrient surpluses were higher in small ruminant holdings than in the cattle units.

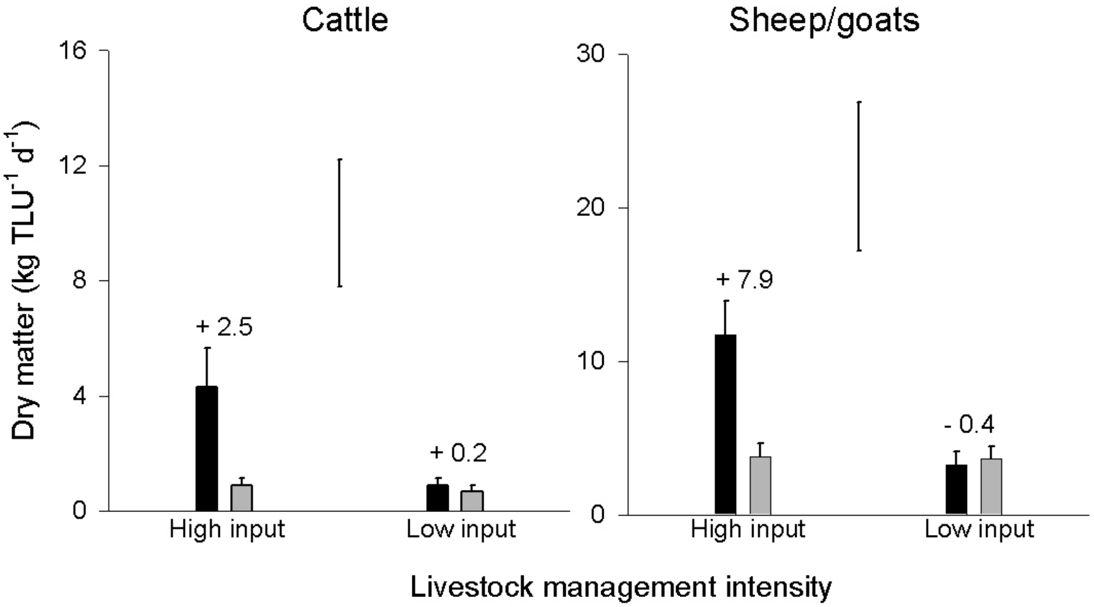

Figure 6. Average daily DM balances (numbers) in high and low input cattle and sheep/goat enterprises in Niamey, Niger, during November 2005 to January 2008. Data show average daily offer of feed (black) and manure output (excreta plus litter, grey) plus one SE. The isolated vertical lines in the charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management intensities. Please note the different scaling of Y-axes for sheep/goats *versus* cattle.

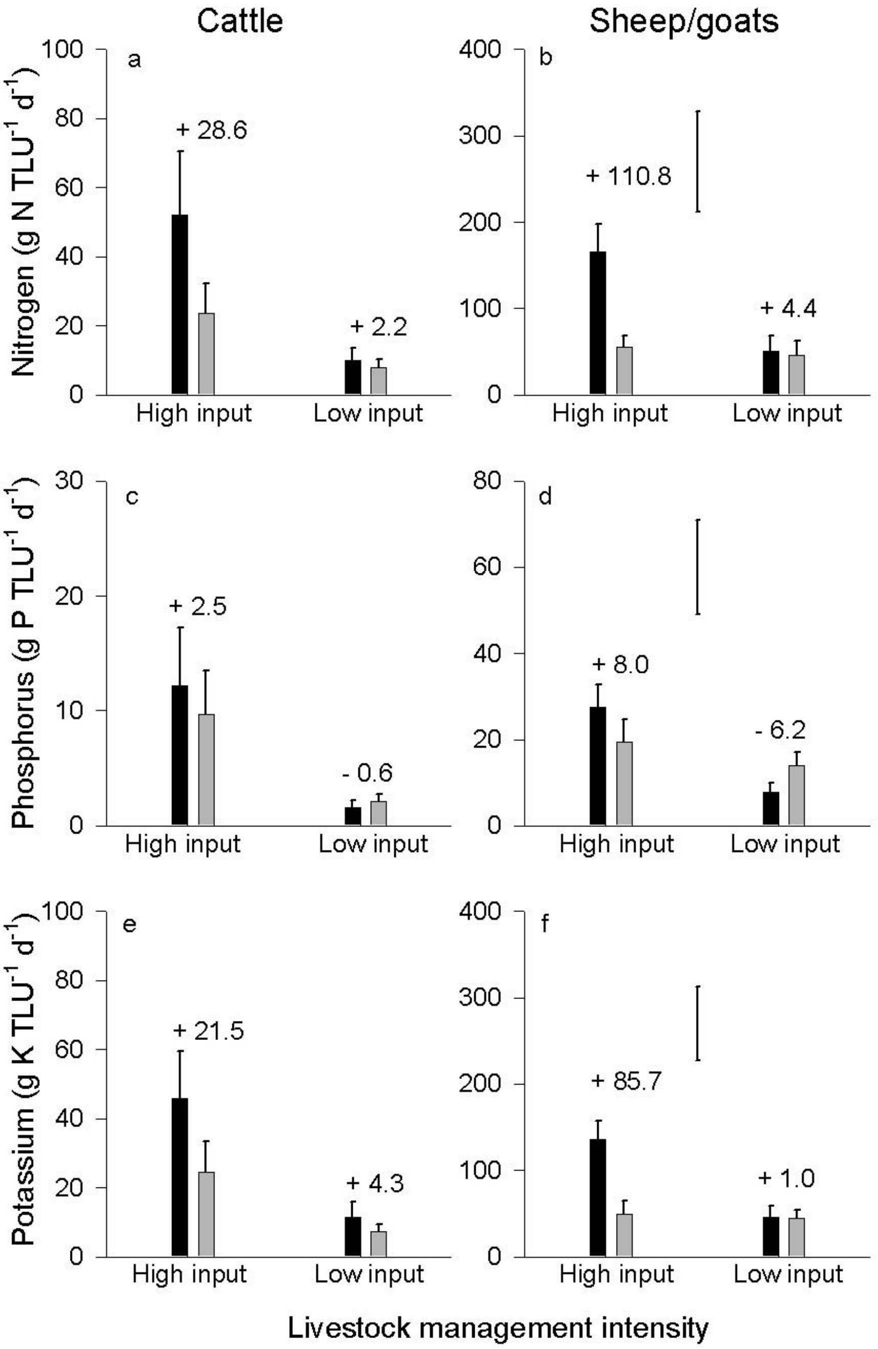

Figure 7. Average daily input (black) and output (grey) of nitrogen (a, b), phosphorus (c, d) and potassium (e, f) through feed and manure in high and low input cattle and sheep/goat enterprises in Niamey, Niger, during November 2005 to January 2008. Bars show means plus one SE, numbers signify the balances. The isolated vertical lines in the charts indicate the least significant difference ($LSD_{0.05}$) of means for the two management intensities. Please note the different scaling of Y-axes.

3.3 Discussion

3.3.1 Feed and nutrient inputs

The analysis of current feeding practices in Niamey's UPL indicates that considerable wastage of DM, N, P and K occurs in all livestock holdings and in all seasons, the only exception being LI cattle during the hot dry season. Resource wasting might be partly due to the small herd sizes, an assumption that is supported by – weak – negative linear correlations obtained between the number of TLU per unit (X-variable) and the amounts of DM, N, P and K offered (individual Y-variables), with R^2 ranging from 0.111 - 0.147 ($P < 0.0001$ for all correlations). Further variables explaining feed wasting might be the cheaper price of feed mainly during the cool dry season (on per kg basis, bush hay: 0.03 – 0.22 Euro; cowpea hay: 0.11 – 0.42 Euro; maize bran: 0.09 – 0.15 Euro; millet bran: 0.10 – 0.32 Euro; *Zornia* hay*:* 0.04 – 0.33 Euro). Although livestock feeds were expensive, especially during the hot dry and the rainy season (on per kg basis, bush hay: 0.03 – 0.42 Euro; cowpea hay: 0.25 – 1.91 Euro; maize bran: 0.09 – 0.22 Euro; millet bran: 0.09 – 0.47 Euro; *Zornia* hay: 0.12 – 0.76 Euro) farmers seemed to have sufficient financial resources to buy even excessive amounts of feeds, since they were also engaged in urban vegetable gardening and trading generating additional income (Graefe et al., 2008). Feed supply in excess of requirements might also be due to suboptimal management conditions since large amounts of roughage feeds were mostly offered to groups of animals in narrow troughs, leading to high spillage through tearing feed out of the trough and trampling it onto the ground, from where it was shifted to the dung heap.

The amounts of DM offered (Figure 1) exceeded values of DM intake reported in other studies: from an on-station experiment in Niger, Ayantunde et al. (2007) reported a daily DM intake of 62 g kg$^{-0.75}$ for sheep fed groundnut haulms while a daily intake of 93 - 98 g DM kg$^{-0.75}$ was obtained for West African Dwarf goats fed different forage leaves plus concentrates (Ajayi et al., 2005). From Mali, Sangaré and Pandey (2000) reported a voluntary intake of 64 - 93 g DM kg$^{-0.75}$ for Sahelian 'Peul' goats on dry season rangeland, and for lactating Alpine does the highest daily DM intake obtained was 181 g kg$^{-0.75}$ (Sauvant et al., 1991). For cattle, an *ad libitum* DM intake of 120 - 150 g kg$^{-0.75}$ day^{-1} was reported for unsupplemented animals grazing rainy season pasture in semi-arid Mali (Dicko et al., 1983; Sangaré, 1985); in the same region Zebu cattle ingested 85 - 143 g kg$^{-0.75}$ day^{-1} of organic matter in the dry season (Mahler, 1991; Schlecht et al., 1999a; Rath, 1999). Even during the hot dry season when grazing resources are scarce and expensive for urban farmers (Val-Arreola, 2004; Heredia-Navan, 2007), the daily offer of metabolizable energy (Figure 2) was high and exceeded the requirement of fattening sheep/goats (Table 3) at both feeding intensities; this was also observed in the other two seasons. Similarly in HI cattle, the daily offer of energy exceeded the requirement (Table 3) for maintenance of a 350 kg LW dairy cow gaining 300 g LW day^{-1} in all seasons (Figure 2). The same observation was made for LI cattle during the cool dry and the rainy season; here oversupply might have been due to then availabile high quality energy and protein feeds. Graefe et al. (2008) estimated the average energy intake of sheep and goats in Niamey's UPL systems at 900 kJ ME kg$^{-0.75}$ day^{-1}, which is much lower than the values obtained in the present study. However, also Graefe et al. (2008) only assessed the amount of feed offered and not the animals' actual intake; since their values are based on a 3-months survey only, they might not be extrapolated to a yearly time-scale.

3.3.2 Growth performances

Despite the oversupply of DM, energy and nutrients in all seasons, the maximum growth rate (LWG) in sheep/goats was achieved during the cool dry season and averaged 104 g day^{-1} in HI animals. This performance was lower than the 120 g day^{-1} which, according to NRC (2006) data, should have been obtained under the observed feeding regimes, pointing again to inefficiencies in terms of nutrient management by the farmers and utilization by the animals. Feed conversion efficiency could be increased by adjusting the total amount of feed offered to the animals' true needs of protein and energy. On the other hand, year-round growth rates of HI sheep/goats were higher than the 40 g day^{-1} reported for sheep fed groundnut haulms elsewhere in Niger (Ayantunde et al., 2007), the 56 g day^{-1} obtained for Sahelian goats fed pods of *Acacia senegal* Willd. in northern Burkina Faso (Sanon et al., 2008) and the 63 g day^{-1} obtained in goats grazing dry season rangeland in semi-arid Mali (Sangaré and Pandey, 2000).

Concerning cattle, although amounts of DM, energy and nutrients offered in the HI units exceeded the requirements of dairy cattle in all seasons, daily weight losses were substantial in the rainy and the hot dry season. However, in the cool dry season a slight weight gain was determined. These results may indicate a poor health status - diarrhoea and coughing were observed in several cattle units – and, as already mentioned above, feed wasting. In LI cattle, DM and ME offers in the cool dry and the rainy season exceeded the requirements of a 350 kg dairy cow gaining 300 g of LW daily (Table 3), while N, P and K offers were below the respective requirements in the hot dry season only. In contrast to this, the cool dry season growth rate of 714 g day^{-1} of LI cattle was above the 300 g day^{-1} that could have been obtained with the feed offered at the farm. This substantial gain, which was higher than the 400 - 500 g day^{-1} reported for three Sahelian village cattle herds during the same season (Fernández-Rivera et al., 2005, Ayantunde et al., 2001) must thus be attributed to a significant, although not quantified contribution of feed intake from grazing. The average rainy season growth rate of LI cattle of 300 g day^{-1} was only slightly lower than the 350 g day^{-1} obtained for grazing Mpwapwa Zebu cattle in Central Tanzania (Jung et al., 2002). However, daily weight losses of -232 to -914 g day^{-1} observed in HI (rainy season) and LI (hot dry season) cattle largely exceeded the -300 to -400 g d^{-1} reported by Fernández-Rivera et al. (2005) from Niger. Weight losses in grazing animals are common in rural Sahelian cattle husbandry systems, mainly during the dry season and the transition period from the dry to the rainy season (Fernández-Rivera et al., 2005), and Schlecht et al. (1999b) reported body weight losses of up to 22% in non-supplemented cattle during the dry season. While the situation of urban LI cattle might have been quite similar to the situation of village cattle herds given their large reliance on feed intake during pasturing, the weight loss of HI cattle especially during the hot dry season is very atypical and might be due to a faulty conversion of body condition scores to LW through the two-step conversion approach; this problem might be linked to variations in the magnitude of LW change associated with each unit of BCS change as discussed by Jaurena et al. (2005) and Berry et al. (2006).

3.3.3 Nutrient use efficiency

Efficient utilization of resources is an important economic component in livestock production systems whereby the efficiency of feed conversion is greatly influenced by DM intake, digestibility of feeds as well as production performance (Linn et al., 2007). The rainy season FCR of 9.5 kg FDM kg^{-1} LWG obtained in HI sheep/goats compares well to the 7 - 8 kg FDM kg^{-1} LWG reported by Bourzat et al. (1987) for intensively fed Mossi sheep in Burkina Faso. Likewise, in HI and LI cattle, the obtained hot dry season and rainy season values of 8.7 to 13 kg FDM kg^{-1} LWG agree with the 9.8 - 14.9 kg FDM kg^{-1} LWG reported for suckler cows in an intensive stall feeding system in Germany (Jürgen et al., 2006). Furthermore, they compare well to the 8.9 - 12.7 kg FDM kg^{-1} LWG obtained in stall-fed Malawi Zebu (Munthali, 1986). Apart from these specific cases, the predominantly poor FCR obtained across feeding intensities and species in our study point to large inefficiencies within the enterprises, corroborated by the predominantly low growth rates. At feeding, lactating animals are not separated from non lactating ones and different age groups are kept together in one enclosure. This may lead to strong competition among animals and could affect the DM intake of younger or lighter individuals. Our findings indicate that the currently practised fattening of sheep is inefficient beyond a LW of 40 kg and emphasize that ULP farmers need to reconsider fattening rations if sheep of higher LW should be produced for specific marketing occasions.

Today, appropriate nutrient management is of major concern in the highly professional production systems of Europe and America, due to high N surpluses originating from an oversupply of high quality feeds (Kyllingsbæk and Hansen, 2007; Arriaga et al., 2009). In the case of Niamey's ULP systems, the slightly to strongly positive nutrient balances also point to considerable surpluses of inputs at both feeding intensities, whereby more nutrients were wasted in small ruminant than in cattle units. This is explained by the high amounts of protein and energy feeds offered to fattening small ruminants. The N balance obtained in HI cattle (28.6 g N TLU^{-1} day^{-1}) is much lower than that obtained for sheep/goats (110.8 g N TLU^{-1} day^{-1}) but is slightly higher than the 27 g N cow^{-1} day^{-1} reported for a Wisconsin dairy system with confined Holstein cows (Powell et al., 2008). It is also higher than the 17 g N TLU^{-1} day^{-1} calculated for Friesian-Ayrshire steers in smallholder farming systems in the central highlands of Kenya (Delve et al., 2001). These nutrient surpluses could be reduced through a better feeding strategy: by partitioning the total amount of feed offered into two to three portions per day to reduce spillage (Jonker et al., 2002; Rotz, 2004), by grouping animals according to age/weight and physiological status (St Pierre and Thraen, 2001) and by adjusting the daily supply of protein and energy to the animals' requirements. Adjusting the offer of crude protein to animals' requirements was reported to substantially improve nitrogen utilization efficiency of lactating dairy cattle in the Basque Country, Spain (Arriaga et al., 2009). Else, feeding diets with high amounts of protein-binding tannins to minimize N excretion via urine and thus ammonia volatilization can effectively reduce N losses (Satter et al., 2002*).* In Niamey's ULP, the poor feeding management is further aggravated by the poor management of nutrients that are diverted to the dung heap. The latter is usually piling up in the courtyard without any cover and exposed to high temperatures during the hot dry season and to rainfall during the wet season. This management practise leads to substantial N losses through denitrification and ammonia volatilization (Predotova et al., 2009). Consequently, improved manure handling and storage by covering the dung heap with branches or plastic sheets could also reduce nutrient losses (Rufino et al., 2007) in urban livestock production systems and thus reduce the negative environmental externalities of such enterprises.

3.4 Conclusions

The present results indicate that urban livestock enterprises in Niamey are characterized by an oversupply of nutrients to cattle and sheep/goats, which is due to poor feeding management and results in inefficient nutrient use. This might be financially disadvantageous for the farmers, especially in periods of feed scarcity (rainy and hot dry season). The low growth performance of small ruminants and cattle and the quasi-absent milk extraction underline the need for improved feeding management in West Africa's urban livestock husbandry systems, which must be based on the nutritional requirements of specific age/weight and production groups. For animals that are grazing at the city fringes during daytime, a reduction of the amount of feed offered at the homestead, especially during periods of high feed availability on pastures (cool dry season) is recommended. By doing so, more feed nutrients should be converted into LWG and milk, and fewer nutrients be diverted to the dung heap, be it by excretion or by feed spillage and conversion into litter. Since most of the presently observed oversupply of feed N, P and K ends up in the dung heap, there is substantial risk for environmental pollution, and livestock farmers should therefore also improve manure handling and storage.

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Economic benefit of gardeners and retailers from cultivating and marketing of vegetables in Niamey, Niger

Abstract

Little is known about the effects of season and marketplace on return that urban gardeners and retailers in West African cities obtain from cultivation and sale of vegetables such as amaranth, cabbage, lettuce and tomato. To fill this gap of knowledge, measurements of yields and weekly price interviews were conducted in Niamey, Niger, during the rainy season (RS: August - October) and the cool dry season (CDS: November - January) of 2007/2008. Using gross margin (GM) analysis, net profits (NP) and returns (R) on investments were calculated. During the RS farm-gate prices of tomato averaged 660 FCFA kg^{-1} fresh matter (FM) compared to 450 FCFA kg^{-1} FM ($P < 0.05$) in the CDS, while prices of amaranth, lettuce and cabbage were similar across seasons. Estimated GM per hectare and R per FCFA invested were 5.825 Mio FCFA (R = 12.78 FCFA) for amaranth; 10.091 Mio FCFA (R = 18.98 FCFA) for cabbage, 5.903 Mio FCFA (R = 12.21 FCFA) for lettuce and 6.396 Mio FCFA (R = 16.58 FCFA) for tomato during the CDS compared to 4.712 Mio FCFA (R = 8.44 FCFA, amaranth), 9.477 Mio FCFA (R= 13.48 FCFA, cabbage), 6.516 Mio FCFA (R= 7.08 FCFA, lettuce) and 15.173 Mio FCFA (R= 23.46 FCFA, tomato) in the RS. Cabbage and tomato prices averaged 804 FCFA kg^{-1} FM and 832 FCFA kg^{-1} FM in the RS compared to 410 FCFA kg^{-1} FM ($P < 0.05$) and 574 CFAF kg^{-1} FM ($P < 0.05$) in the CDS. For amaranth and lettuce, the NP of market retailers depended only on the marketplace, whereas NP of cabbage and tomato strongly depended on season and marketplace. Labour, fertilizer inputs and seeds strongly affected R. Improving labour productivity and reducing input costs through a reduction of mineral fertilizers would help maximizing the profits and reducing negative environmental externalities of urban vegetable production in Niamey.

Keywords: gross margin analysis, net profit, return on investment, urban agriculture, West Africa

4 Introduction

In recent years the importance of urban and peri-urban agriculture (UPA) for the livelihoods of urban households and the food supply to the growing cities has well been documented (Asomani-Boateng 2002; van Veenhuizen and Danso 2007; Akegbejo-Samsons 2008). In sub-Saharan Africa, the number of people involved in such activity is on the rise and varies between 25 - 80% of the urban population (World Bank 2007). In Africa and South-East Asia, crops produced include mainly high value perishable leafy vegetables (either exotic or traditional) such as amaranth (*Amaranthus spp*.), sorrel (*Hibiscus sabdariffa* L.), water convolvulus (*Ipomea aquatica* F.), morel (*Solanum aethiopicum* L. and *Solanum nigrum* L.), cabbage (*Brassica spp*.), lettuce (*Lactuca sativa* L.), and chive (*Allium fistulosum* L., De Bon et al. 2009). In Niamey, Niger, the main cultivated vegetables are lettuce, cabbage, sorrel, amaranth, tomato, and paprika (*Capsicum annuum* L.). Also cultivated are fruits such as mango (*Mangifera indica* L.), lemon (*Citrus aurantifolia* C. & P.) and guava (*Psidium guayava* L., Graefe et al. 2008). The main reason for producers and market retailers to get involved in UPA-based fruit and vegetable production and sale is the financial benefit obtained, which is largely used to satisfy subsistence needs (Gockowski et al. 2003; Nguni and Mwila 2007). Against this background there is surprisingly little solid data available on market prices and benefits obtained in UPA production systems (Danso et al. 2003). Most often, available income is reported on a per household basis, which in different West African cities reportedly ranges from 120,000 – 5,000,000 FCFA (Franc Communauté Financière Africaine, 100 FCFA = 0.15 Euro) per annum and strongly depends on management capacity and farm size (Kessler 2002). For Niamey, Niger, a net monthly income of 23,155 FCFA per UPA farm was reported recently (Drechsel et al. 2006). However, data on the variation of such income throughout the year and on the contribution of specific crops are lacking. In Nigeria, returns to commercial vegetable production in Lagos yielded 0.65 FCFA per invested FCFA as compared to 0.61 FCFA per FCFA gained in commercial floriculture in Port Harcourt (Ezedinma and Chukuezi 1999). Estimates of returns per FCFA invested in dry season amaranth production in Edo South, Nigeria, depended strongly on farm size, ranging from 1.01 - 1.43 FCFA (Emokaro et al. 2007a). Given, the seasonality of crops, the small size of the often scattered plots and the strong effects of input costs, household level income from UPA activities is rather difficult to estimate (Adeniyi and Omotunde 1992; Moustier 2001; Hawkes and Libbin 2007; De Bon et al. 2009).

Using a gross margin analysis approach, this study aimed at analyzing the scope for improved factor productivity (Diogo et al. 2009) within UPA garden systems of Niamey. Based on a characterization of the resource and crop management of UPA gardeners in Niamey and a quantification of yields of high value vegetables, accompanied by an assessment of seasonal market prices of crops, the seasonal fluctuations of economic returns to gardeners and market retailers cultivating and selling amaranth, lettuce, cabbage and tomato were determined.

4.1 Materials and methods

4.1.1 Study sites

The study was conducted during a period of six months in Niamey, the capital city of the Republic of Niger in the Sahelian zone of West Africa. Inhabited by 1.033 Mio people (INS 2008), Niamey has a high demand of fresh foodstuff. Eight gardening areas were selected to characterize UPA gardening activities related to the four highly appreciated vegetables, and to determine the returns to gardeners. Of these eight garden areas six were located in the urban zone (Gamkale, Bangou Bana, Gountou Yena, Nogare, Yantala Bas, and Gnalga) and two in the city's peri-urban zone (Saga1, Saga2). At each production location (Figure 1), five gardeners were interviewed, whereby the selected gardens were representative for market-oriented production of lettuce, amaranth, cabbage, and tomato. Based on the sale's volume of the target vegetables at the specific locations, five vegetable markets (Petit Marché, Grand Marché, Rive Droite market, Katako market, Wadata market) were selected for surveys of retail prices, which where collected from three randomly selected retailers per marketplace.

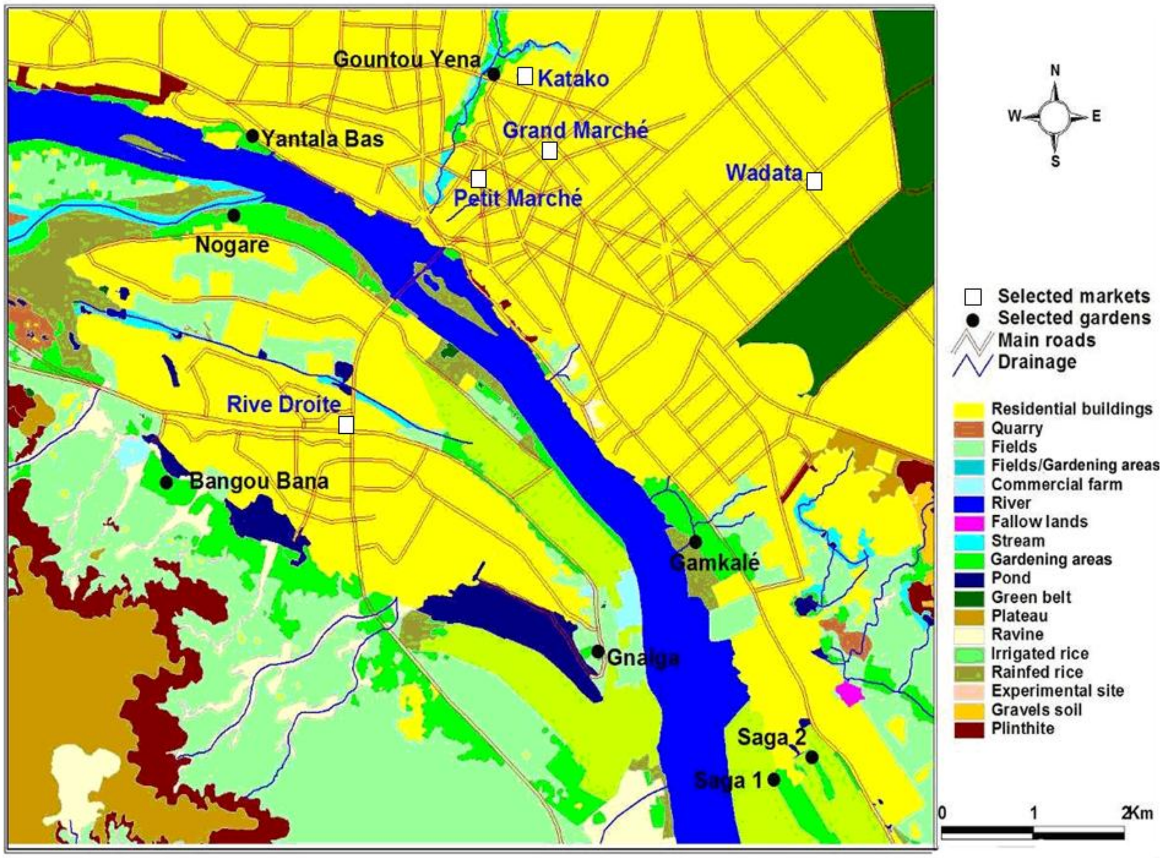

Figure 1. Map of Niamey, Niger, with locations of the studied markets and UPA gardening areas.

4.1.2 Interview-based data collection

Three types of questionnaires were used of which the first one addressed the cultivation practices of Niamey's gardeners for lettuce, amaranth, cabbage, and tomato. Questions covered cultivation practices, type of irrigation water and equipment used, seasonality of cropping, and motivation for cultivating specific vegetables. The second questionnaire addressed production costs and sale's prices of the target vegetables at the garden level, and the third interview inquired the proportion of harvested produce sold on urban markets, and the purchase and selling prices of the target vegetables when traded by retailers.

In August 2007 the first interview was conducted with each of the 40 selected gardeners. The second interview was once conducted during the rainy season (August - October 2007) and once during the cool dry season (November - January 2008). In addition, the market prices of the selected vegetables were collected weekly during 6 months at the five markets by randomly choosing three retailers (each time new retailers were selected) per market. Each time the fresh weight of two sales-units of each of the four target vegetables (a bundle of lettuce and amaranth, a head of cabbage, a small bowl of 4 - 8 tomatoes) was taken using an electronic balance (0 - 50 kg, accuracy 0.02 kg) and the actual selling price was noted. Questions were asked about (i) the origin of the vegetables sold, (ii) the price of the vegetables upon purchase at the garden, and (iii) the costs incurred after purchasing (taxes, transport and handling). To determine the economics of vegetable production, two gardens were selected among the five per location, based on their continuous production throughout the seasons of study as determined in August 2007. In these gardens, all costs of the different inputs for the target vegetables were assessed every week on two representative plots for each type of vegetable and cropping cycle during the rainy and the cool dry season. Costs of seeds/seedlings, fertilizers, pesticides, labour and land rent were also recorded. Furthermore, the farmgate prices of the target vegetables were recorded in each of the 2 x 8 gardens, whereby n=2 replicates of the harvested vegetables were weighed and the sale's price asked. In addition, problems farmers encountered in cultivating the target vegetables were noted down.

4.1.3 Determination of economic variables

Gross margin (GM) analysis was used to determine producers' benefits from the four target vegetables, whereby the gross output (total revenue from sale) was subtracted from the direct costs of production (total variable costs) for each type of vegetable during the cool dry and the rainy season separately. Variable costs included seeds, mineral fertilizers, manure, pesticides and labour, and as far as the latter is concerned, the gardeners distinguished well between paid labour and family labour. The costs of mineral fertilizers, manure and pesticides were calculated by multiplying the respective amounts applied by the unit prices of individual inputs. The gross margin for each type of vegetable was calculated on per hectare basis and per cropping cycle.

To determine the economic returns to the applied nutrients nitrogen (N), phosphorus (P) and potassium (K), the respective concentrations in manure (0.99% N; 0.31% P and 1.03% K) and the four studied vegetables (Table 1) were taken from Diogo et al. (2009) and were valued with the respective prices of inputs and products. Nutrient concentrations in urea (46% N), NPK fertilizer (15:15:15) and di-ammonium phosphate (DAP; 18% N, 46% P_2O_5) were taken from the manufacturers' indications on the fertilizer bags.

Economic efficiency (E) of nutrient use was calculated for each single nutrient as the difference between the total revenue and all variable costs except nutrient costs of manure and fertilizers, divided by the costs of the individual nutrients as follows:

If X= Total revenue – variable cost without nutrient costs, then:

$$E = X / \text{costs of applied nutrient}$$

Nitrogen (ditto for P and K): $E_N = X /$ costs of applied N;

Hereby, N, P and K are efficiently utilized if E_N, E_P and E_K equate to unity (Emokaro et al. 2007a); a ratio less than unity indicates over-supply of inputs in the production process ('inefficient'), while a ratio greater than unity shows that the specific resources are yielding a high revenue ('efficient').

The net profit of market retailers was calculated by subtracting the costs that incurred after purchasing the vegetables (handling, transport and taxes) from the revenue of produce sold. Gardeners' returns (R) to investment were calculated as the ratio of the profit over total costs.

Table 1. Nutrient concentrations (%, in dry matter) in four high value vegetables produced in Niamey, Niger.

Crop	Nitrogen	Phosphorus	Potassium
Amaranth	3.85	0.60	6.26
Cabbage	3.17	0.62	3.99
Lettuce	3.10	0.57	6.82
Tomato	2.86	0.63	6.32

Source: Diogo et al. (2009)

4.1.4 Data analysis

Seasonal effects on quantities of produce harvested and sold, on produce farm-gate prices, revenues, variable costs and on gross margins were analyzed using the General Linear Models (GLM) procedure of SAS 9.1 software package (SAS 2003), whereby residuals of data were tested for normal distribution and homogeneity of variances prior to analysis. Market prices of vegetables were compared by t-tests ($LSD_{0.05}$). Net revenues of market retailers and the economic efficiencies of nutrient use were converted to a ranked response using PROC RANK and a two-way nonparametric ANOVA was performed on these ranks using the GLM procedure in SAS.

4.2 Results

4.2.1 Characteristics of the gardening systems

Urban and peri-urban gardening in Niamey is characterized by high input / high output systems especially during the cool dry season. A wide array of vegetables is cultivated during the cool dry and the rainy season, whereby the predominant ones are leafy vegetables such as lettuce, cabbage, and amaranth along with tomato. During the two monitored seasons, six out of 40 gardeners cultivated lettuce plus cabbage; three gardeners produced lettuce plus amaranth while five intercropped lettuce and tomato. In another five gardens amaranth plus cabbage were produced and four gardeners combined tomato and cabbage; three gardeners grew lettuce plus cabbage plus tomato while in only two out of the 40 gardens lettuce was intercropped with cabbage and amaranth. The remaining eleven gardens intercropped lettuce with mint and sorrel; occasionally maize was also grown during the rainy season (2 out of 11 gardens). All 40 interviewed gardeners claimed to be engaged in UPA activities to generate income in order to cover their families' subsistence needs. In 30 of the 40 gardens the irrigation water used in vegetable production was predominantly drawn from the river Niger, whereas five gardens used waste water from a major riverbed (wadi) crossing the town, through which water flows year-round into the Niger River but which is littered with household waste. Another five gardeners took their irrigation water from shallow hand-dug wells. The tools employed in the cultivation of vegetables were mostly hoes, shovels and rakes (n=22), water pumps with diesel engine (n=14), and watering cans (n=4). Seeds included exotic and local varieties purchased on local markets and, for lettuce and amaranth, were sometimes self-produced (n=5).

4.2.2 Fertilizer and pesticide use

In 25 of the studied gardens, urea was applied to the four target vegetables. Compound NPK fertilizer was applied to tomato, lettuce and cabbage (n=14), whereas DAP fertilizer was applied to lettuce only (n=1). Application of manure from sheep/goats and cattle was also common (n=15) except to amaranth. The manure was usually collected at the gardeners' household or (typically without payment) in neighbouring barns; however, some gardeners (n=10) also purchased manure, whereby the price of one cartload of 413 kg (± 194) of dry matter (DM) was 700 FCFA (± 307). The frequency of application of both mineral and organic fertilizers depended on the vegetable species. For one cycle of amaranth (29 - 36 days) and cabbage (3 months) respectively, mineral fertilizers were applied at a mean frequency of 2.0 (± 0, n=2) and 1.4 (± 0.53, n=5) times, whereas for tomato (3 months cropping cycle) and lettuce (1.5 months cropping cycle) the mean application frequencies of mineral fertilizers were 1.8 (± 0.72, n=5) and 1.9 (± 0.68, n=14) times. The latter applications were commonly paralleled by 1.2 (± 0.45, n=4) applications of manure to tomato and 1.6 (± 0.62, n=11) to lettuce. In addition to the mineral fertilizer, cabbage received 1.3 (± 0.58, n=3) manure applications. In the 16 closely monitored gardens, application rates of urea per cropping cycle were 277 kg ha^{-1} (± 48.6, n=2) to amaranth, 214 kg ha^{-}

^{1} (± 104.5, n=5) to cabbage, 211 kg ha^{-1} (± 100.3, n=14) to lettuce and 185 kg ha^{-1} (± 24.6, n=5) to tomato. Per cropping cycle compound NPK was applied at rates of 207 kg ha^{-1} (± 118.1, n=4) to cabbage, 207 kg ha^{-1} (± 148.7, n=6) to lettuce and 205 kg ha^{-1} (± 125.9, n=5) to tomato, whereas DAP was applied at a rate of 621 kg ha^{-1} (n=1) to lettuce. An average manure DM application rate per cropping cycle of 13.6 t ha^{-1} (± 8.62, n=11) was determined for lettuce, while cabbage received 11.9 t ha^{-1} (± 7.15, n=3) and tomato 10.7 t ha^{-1} (± 7.47, n=4).

The most frequently applied pesticides determined in the 16 gardens included ‘Rocky C 386 EC’ (cypermethrin), ‘Cypercal C 186 EC’ (cypermethrin, pyrethrinoid plus profenofos), ‘Decis’ (deltamethrin) and ‘Conquest’ (cypermethrin plus acetamiprid). Amaranth received on average 1.7 (± 0.49, n=3) applications of 12.4 l ha^{-1} (± 3.42) of Cypercal. In five of the 16 gardens an average dose of 10.9 l ha^{-1} (± 2.92) of Decis was sprayed onto cabbage in 2 (± 0.55) applications. Lettuce (n=14) was on average 1.9 (± 0.52) times sprayed with Rocky plus Conquest, the total dose amounting to 9.5 l ha^{-1} (± 5.13). Five of the 16 gardens applied Rocky to tomato at an average total dose of 11.1 l ha^{-1} (± 6.75) and a frequency of 1.9 (± 0.96) times per cropping cycle. The average price of concentrated pesticide (250 ml) purchased by the gardeners amounted to 1250 FCFA (± 0) for Cypercal, 1375 FCFA (± 258.2) for Rocky, 1364 FCFA (±269.9) for Decis and 1373 FCFA (± 270.6) for Conquest.

4.2.3 Labour needs and general problems

In all vegetable gardens labour was needed for land preparation, seeding/planting, weeding, manure and fertilizer application, irrigation and harvesting. Irrespective of the type of work, a wage of 25 FCFA per working day per plot of 10 m^{2} (± 2.79) was paid. In tomato and lettuce cultivation, one paid labourer was employed per garden for the different activities mentioned above. Family labour employed per garden averaged 1.1 persons (± 0.31, n=4) for lettuce, 1 person (± 0, n=3) for amaranth, 1.2 persons (± 0.42, n=4) for cabbage and 1.7 persons (± 0.52, n=2) for tomato. However, while paid labourers worked 6.3 h d^{-1} (±1.25) in the gardens, family members worked less regularly, spending only 25% of a paid worker’s time in the gardens; therefore their workforce per plot was valued at 25% of a paid labourer’s wage.

The main production problems reported by the gardeners were the high costs of mineral fertilizers (n=21), labour scarcity during the rainy season (n=26), pests and diseases that hampered the growth of leafy vegetables (n=14), water scarcity during the cool dry season (n=15), and high costs of seeds (n=11) and of pesticides (n=10).

4.2.4 Gross margins and efficiencies of nutrient use

For all products, the marketable yield obtained did not differ significantly between the two seasons (P >0.05, Table 2). For amaranth, lettuce and cabbage, farm-gate price per unit of produce sold (FCFA kg^{-1}) was similar in the two seasons ($P > 0.05$), whereas the price of tomato was 1.5 times higher in the rainy season than in the cool dry season ($P < 0.05$). Consequently, the average revenue of gardeners from the farm-gate sale of tomato was significantly higher during the rainy season than in the cool dry season (Table 2): in the rainy season, the return to one FCFA invested in tomato was estimated at 23.46 FCFA compared to 16.58 FCFA obtained in the cool dry season ($P > 0.05$). For cabbage, lettuce and amaranth, the returns were 13.48, 7.08 and 8.44 FCFA, respectively, per FCFA invested during the rainy season compared to 18.98, 12.21 and 12.78 FCFA during the cool dry season ($P < 0.05$, Table 2). For amaranth, cabbage and lettuce, the average GM per cropping cycle (FCFA ha^{-1}) did not differ significantly between the rainy and the cool dry season ($P > 0.05$). For the GM of tomato, significant differences were obtained between the two seasons whereby in the rainy season the GM was 2.4 times higher ($P < 0.05$) than in the cool dry season. Season had no effect on the economic efficiencies of N, P and K use, but differences between crops persisted. Therefore, statistical analyses only compared the average values across the two seasons (Table 3). Economic efficiencies for N use (E_N) were lower for lettuce and amaranth than for cabbage and tomato ($P < 0.05$). Efficiencies for P (E_P) and K (E_K) use were both lower for cabbage and lettuce than for tomato ($P < 0.05$), and especially for the latter crop the calculated E_K value was extremely high.

4.2.5 Supply and market prices of vegetables and economic returns to retailers

During the cool dry season all investigated vegetables except amaranth were abundant on Niamey's markets. The share of produce originating from the city's UPA gardens as compared to other origins averaged 0.41 (± 0.155) for tomato, 0.78 (± 0.301) for lettuce and 0.62 (± 0.061) for cabbage in the cool dry season. During the rainy season, these values changed only slightly ($P > 0.05$), to 0.36 (± 0.160) for tomato, 0.67 (± 0.180) for lettuce and 0.48 (± 0.194) for cabbage. The proportion of locally produced UPA amaranth on the city markets increased significantly ($P < 0.05$) from 0.53 (± 0.139) during the cool dry season to 0.70 (± 0.049) during the rainy season. Both season and marketplace significantly influenced the price of cabbage and tomato (Figure 2).

Table 2. Average gross margins per unit of land and three-months cropping cycle* and average returns on investment of four high value vegetables produced in Niamey, Niger.

Crop	Amaranth		Cabbage		Lettuce		Tomato	
Season	CDS	RS	CDS	RS	CDS	RS	CDS	RS
Output								
Marketable yield (t FM ha^{-1})	40.34^{a}	40.71^{a}	89.38^{a}	100.90^{a}	83.38^{a}	90.04^{a}	14.3^{a}	23.6^{a}
Price (FCFA kg^{-1} FM)	155.25^{a}	142.13^{a}	122.11^{a}	93.45^{a}	83.81^{a}	84.78^{a}	452.83^{b}	659.90^{a}
Average total output (FCFA ha^{-1})	6,261,969^{a}	5,263,277^{a}	10,797,481^{a}	10,165,429^{a}	6,666,811^{a}	7,578,621^{a}	6,903,218^{b}	15,906,077^{a}
Variable costs (FCFA ha^{-1})								
Seeds	123,537	168,291	165,731	210,701	289,527	291,238	198,568	146,689
Mineral fertilizers	167,674	141,336	103,035	137,047	202,370	259,929	90,967	118,448
Animal manure			62,039	43,678	59,631	88,776	10,009	26,976
Pesticides	184,624	193,288	110,865	107,844	136,179	224,078	60,673	118,844
Labour	106,210	127,930	448,983	494,958	412,051	603,077	373,174	496,911
Average total variable costs	436,440^{a}	551,406^{a}	705,954^{a}	688,775^{a}	763,395^{b}	1,062,643^{a}	507,485^{a}	733,239^{a}
Average gross margin† (FCFA ha^{-1})	5,825,529$^{a\alpha\beta}$	4,711,870^{ab}	10,091,526$^{a\alpha}$	9,476,653^{ab}	5,903,416$^{a\beta}$	6,515,978^{ab}	6,395,733$^{b\alpha\beta}$	15,172,839^{aa}
Average return (FCFA) **per FCFA invested**†	12.78$^{a\alpha}$	8.44^{ab}	18.98$^{a\alpha}$	13.48^{aab}	12.21$^{a\alpha}$	7.08^{bb}	16.58$^{a\alpha}$	23.46^{aa}
Fixed costs								
Land rent (FCFA 90-days^{-1})$^{\#}$	3,108	3,208	3,108	3,208	3,108	3,208	3,108	3,208
Total costs (FCFA ha^{-1})	439,548	554,614	709,062	691,983	766,503	1,065,851	510,593	736,447
Average "profit" (FCFA ha^{-1})‡	5,822,421	4,708,662	10,088,418	9,473,445	5,900,307	6,512,770	6,392,624	15,169,630

* Note: per three-months cropping cycle, 1 harvest of tomato and cabbage and 2 harvests of amaranth and lettuce are achieved by the farmers.
CDS cool dry season (3 months); RS rainy season (3 months)
100 FCFA = 0.15 Euro
For a specific vegetable, different Roman letters indicate significant differences ($LSD_{0.05}$) of means within crop between seasons

[†] For average gross margin and working capital different Greek letters indicate significant differences ($LSD_{0.05}$) of means between crops within the cool dry season; different italic Roman letters indicate significant differences ($LSD_{0.05}$) of means between crops within the rainy season.

[#] Land rent was included as fixed cost for lettuce and as opportunity cost for amaranth, cabbage and tomato.

[‡] Fixed costs of machinery were not included because reliable information could not be obtained from the farmers.

Table 3. Economic efficiency (means ± one SE) of nitrogen (E_N) phosphorus (E_P) and potassium (E_K) use for four high value vegetables produced in Niamey, Niger, averaged across the cool dry and rainy season.

Vegetable	E_N	E_P	E_K
Amaranth[#]	$2.2^b \pm 0.34$		
Cabbage	$8.2^a \pm 1.37$	$6.4^b \pm 1.11$	$76.7^b \pm 18.35$
Lettuce	$2.5^b \pm 0.22$	$3.5^b \pm 0.38$	$133.8^b \pm 27.51$
Tomato	$6.7^a \pm 1.97$	$10.5^a \pm 2.19$	$417.9^a \pm 100.70$

[#] Only urea was applied to amaranth during the study period.

For E_N, E_P and E_K respectively, different letters within each column indicate significant differences (P <0.05) of means between the vegetables.

Across the five markets, the average price of tomato was 832 FCFA (± 167) per kg fresh matter (FM) during the rainy season compared to 574 FCFA kg^{-1} FM (± 135) in the cool dry season ($P < 0.05$). In contrast, market prices of lettuce and amaranth were not significantly affected by season and market. For cabbage, the prices at Petit Marché, Rive Droite and Wadata market ranged from 814 - 915 FCFA kg^{-1} FM during the rainy season and were higher than in the cool dry season when average prices of 346 - 422 FCFA kg^{-1} FM were obtained (Figure 2). The average price of cabbage at all markets (n=5) was 804 FCFA kg^{-1} FM (± 160) during the rainy season compared to 410 FCFA kg^{-1} FM (± 242) during the cool dry season (P <0.05).

Net profits (NP) of market retailers depended on the type of vegetable marketed: for amaranth and lettuce, no seasonal variations in retailers' NPs were observed, but a significant market influence was evident (Figure 3). For amaranth, the average NP was higher for retailers at Rive Droite and Wadata markets than at the other markets (P <0.05). In contrast, for lettuce, a significantly lower NP was obtained at Petit Marché compared to Katako and Wadata markets. As for cabbage and tomato, retailers' NP was higher in the rainy season compared to the cool dry season, whereby marketing these crops at Grand Marché was more profitable (P <0.05) compared to the other markets (Figure 4). For tomato, lowest profits were obtained at the Rive Droite market whereas NPs at Petit Marché, Katako and Wadata markets were similar and varied on average between 47 and 56 FCFA kg^{-1} FM.

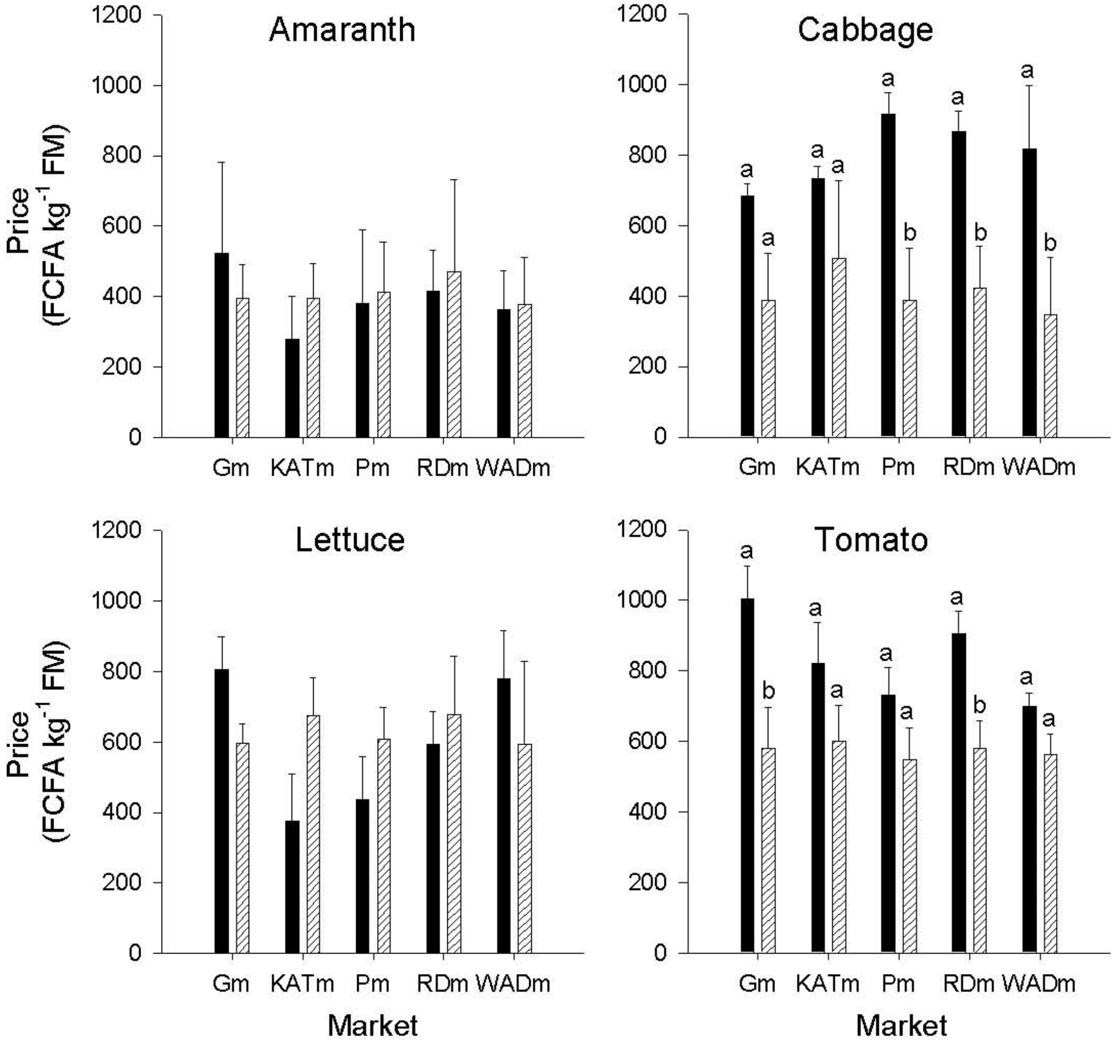

Figure 2. Market price (mean plus one SE) of amaranth, lettuce, cabbage and tomato in Niamey, Niger, during the rainy season (August - October 2007; black bars) and the cool dry season (November - January 2008; dashed bars). Within a specific market, different letters indicate significant differences ($LSD_{0.05}$) of means between the two seasons.

Gm = Grand Marché; KATm = Katako market; Pm = Petit Marché; RDm = Rive Droite market; WADm = Wadata market.

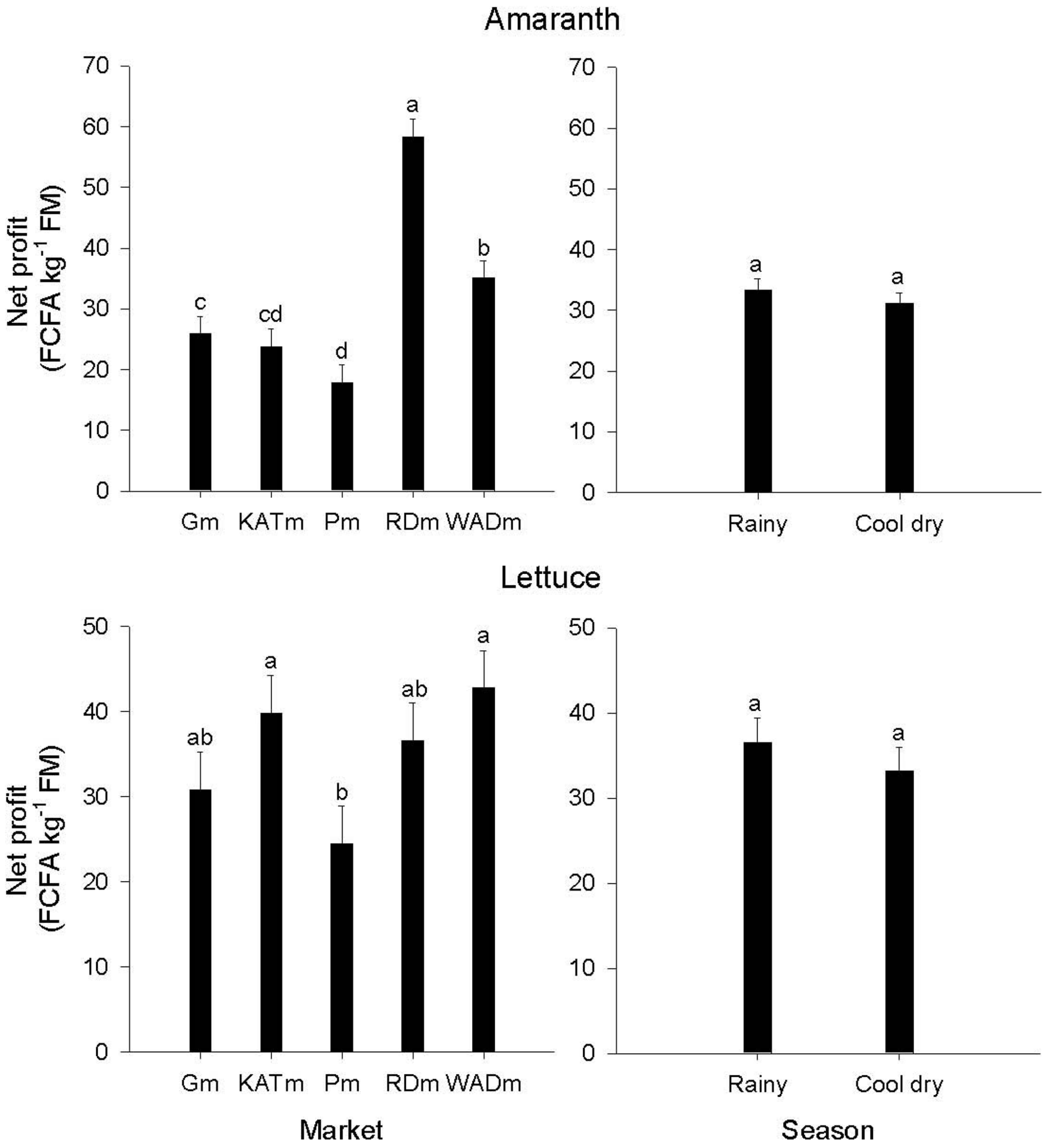

Figure 3. Net profit (mean plus one SE) of market retailers for selling amaranth and lettuce as influenced by market and season in Niamey, Niger, during August 2007 - January 2008. Different letters indicate significant differences ($P < 0.05$, LSMEANS/PDIFF) of means between markets and seasons. Note the different scales of Y-axes.

Gm = Grand Marché; KATm = Katako Market; Pm = Petit Marché; RDm = Rive Droite market; WADm = Wadata market.

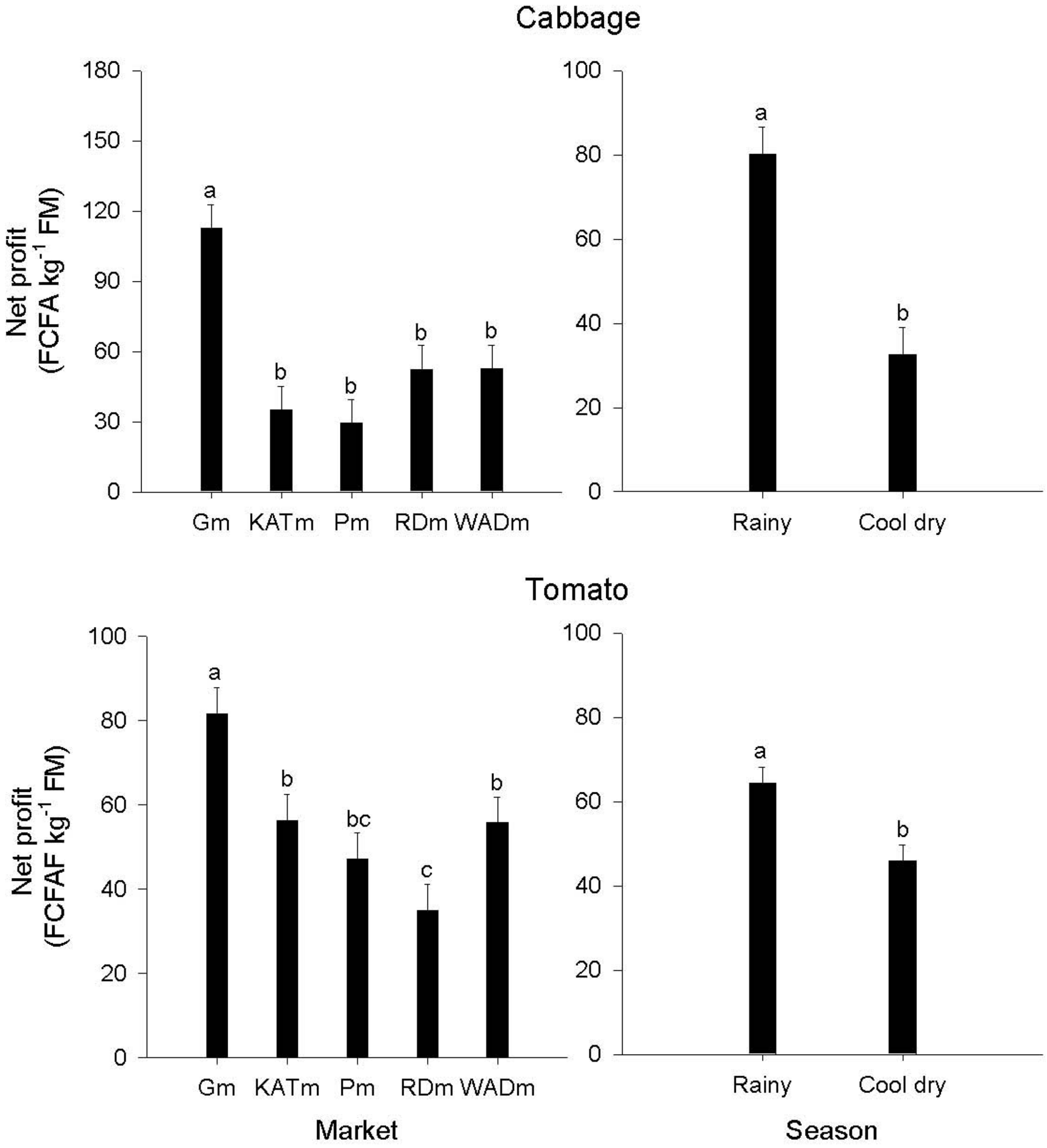

Figure 4. Net profit (mean plus one SE) of market retailers for selling cabbage and tomato as influenced by market and season in Niamey, Niger, during August 2007 - January 2008. Different letters indicate significant differences ($P < 0.05$, LSMEANS/PDIFF) of means between markets and seasons. Note the different scales of Y-axes for cabbage.
Gm = Grand Marché; KATm = Katako market; Pm = Petit Marché; RDm = Rive Droite market; WADm = Wadata market.

4.3 Discussion

4.3.1 Economic benefits of vegetable production to gardeners

During the rainy season, an important part of Niamey's supply of tomato and cabbage came from Burkina Faso, but imports from Madaoua (Niger), Ghana, Nigeria and Malanville (Benin) were also reported, for which season-specific quantities could not be determined within the scope of this study. The highest GM was calculated for tomato during the rainy season, which was largely caused by a strong seasonal price increase for this commodity, leading also to a 64.4% import from outside the city. This price increase for tomato was apparently demand-dependent as marketable yields and total area harvested were similar in the two seasons studied. Gross margins obtained for cabbage with its three-months cropping cycle were higher than the 5.753 Mio FCFA ha^{-1} $120d^{-1}$ obtained for the same crop in the Chipata wetlands of eastern Zambia (Kuntashula et al. 2004) and outstripped the GM obtained for tomato in the cool dry season by 1.5-fold. Moreover, GMs of cabbage were substantially higher than those of lettuce and amaranth irrespective of the season. For lettuce, the GMs obtained in our study were higher than the 4.642 Mio FCFA ha^{-1} $30d^{-1}$ reported for lettuce production in Bamako, Mali, and the 1.437 Mio FCFA ha^{-1} $30d^{-1}$ obtained in Ougadougou, Burkina-Faso (Eaton 2002). Compared to the other vegetables, lowest GMs were obtained for amaranth. However, these GMs were more than 5-fold higher than the 906,828 FCFA ha^{-1} obtained for the same crop in Edo South, Nigeria, during 4 months of dry season (Emokaro et al. 2007b). Moreover, the values were higher than the 404,721 FCFA ha^{-1} obtained in Lagos, Nigeria, for 30 - 50 days of amaranth cropping (Olujide and Oladele 2007). In this study, a rate of compound NPK application of 200 kg ha^{-1} was reported, but although costs of mineral fertilizer and pesticide use amounted to 22 - 29% and 30 - 32% of the total production costs, they where not accounted for (Olujide and Oladele 2007). The fact that despite this omission in the Lagos study, amaranth in Niamey yielded a higher GM is explained by the high rates of urea applied to amaranth in Niamey (554 kg ha^{-1}), which resulted in yields of 20 t FM ha^{-1} (during one cycle of 30 days) compared to 16 t FM ha^{-1} obtained in Lagos. Moreover, farm-gate prices of amaranth (142 - 155 FCFA kg^{-1} FM) were higher in Niamey than in Lagos (48 FCFA kg^{-1} FM; Olujide and Oladele 2007). The differences in returns to investments between the four studied crops (Table 2) are to a certain extent due to differences in their production costs. For tomato, lettuce and cabbage, the main factor cost was labour which represented 55%, 41% and 50%, respectively, of the total production costs in the rainy season, and 51%, 38% and 50% in the cool dry season. Labour is especially scarce during the rainy season, since many paid workers move to the peri-urban and rural areas for the cultivation of the staple crops millet (*Pennisetum glaucum* L.), sorghum (*Sorghum bicolor* Moench) and cowpea (*Vigna unguiculata* Walp.). Unfortunately it was not possible in the present study to calculate net returns to labour, since the opportunity costs for labour could not be determined. However, labour scarcity and high labour costs are of general concern in urban vegetable production, and similar observations were made in the commercial vegetable production systems in Lagos and Edo South, Nigeria, where labour costs accounted for 30% and 90% of the total production costs (Ezedinma and Chukuezi 1999; Emokaro et al. 2007b). Other important factors are seed or seedling costs, accounting for 16.2% and 27.1% of total production costs in all four crops studied. This is due to the gardeners' predominant utilization of expensive hybrid seed varieties, for which prices varied from 1,250 to 5,000 FCFA per 250 g cabbage seeds, 800 to 2,000 FCFA for 250 g lettuce seeds and 1,000 to 3,000 FCFA for 25 g tomato seeds.

The costs of mineral fertilizers were also important and varied between crops, due to the variation in the prices of fertilizers purchased (250 - 375 FCFA kg^{-1}) and the different amounts applied to each crop. Especially the high rates of fertilizer application lead to high costs for this production factor; it seemed however, that the costs of mineral fertilizer did not matter that much to the vegetable producers. This observation in Niamey contrasts with the reported shift of smallholder vegetable farmers in eastern Zambia to the use of cattle manure or leguminous green manuring strategies due to price increases for mineral fertilizers (Kuntashula et al. 2004). In contrast to mineral fertilizers, manure use in Niamey's UPA caused relatively small costs (1.4 - 2.9% of total production costs for tomato; 5.4 - 6.1% for lettuce; 4.4 - 7.0% for cabbage, indicating the low value of this production factor. This probably explains the high application rates observed, leading to excessively high nutrient inputs in Niamey's vegetable production systems (Diogo et al. 2009). Analysis of the economic efficiency of nutrient use indicated that N and P were relatively 'efficiently' utilized with lower E_N and E_P values than E_K values in cabbage, lettuce and tomato (Table 3). This is probably explained by the fact that N and P are also supplied through manure which has no costs. The very high under-utilization of K (high E_K values) is not meaningful in the present context, since the main K sources were NPK fertilizer and manure, which were both applied to provide N and P. Moreover, K is abundantly supplied through dry deposition in the Sahel during March to May (Herrmann, 1996). Our results contrast with the findings of Emokaro et al. (2007a) who reported an under-utilization of fertilizer resources in dry season amaranth production in Edo South, Nigeria, but agree with the findings of Graefe et al. (2008) who claimed that Niamey's gardens are oversupplied with nutrients due to heavy fertilization and pointed to the inefficient nature of these production systems that may lead to considerable negative externalities while being economically profitable. Since in developing countries output quantity and short-term individual profit is the ultimate goal of most intensive agricultural production processes (Olujide and Oladele 2007), UPA farmers tend to apply high rates of fertilizers. The oversupply of nutrients in Niamey compares to that of urban vegetable production systems in Bamako, Mali, and Ougadougou, Burkina-Faso, where N application to lettuce and cauliflower, respectively ranged from 130 - 241 kg N ha^{-1} and 141 - 469 kg N ha^{-1} (Eaton 2002). According to this author, Ougadougou's producers applied almost 10 times as much mineral and organic fertilizer per cropping cycle than gardeners in Bamako. However, GMs determined for lettuce and cauliflower were 3-fold lower in Ougadougou than in Bamako (Eaton 2002). This indicates the potential for higher sales profits for UPA gardeners if fertilizer application rates are adjusted to the actual requirements of the individual crops.

4.3.2 Price variations and benefits to market retailers

The high market prices for tomato and cabbage during the rainy season were primarily due to the scarcity of these vegetables and the seasonally irregular supply pattern from Niamey's gardens. In 2006 for example, the prices of tomato and cabbage at Petit Marché were 507 FCFA kg^{-1} and 743 FCFA kg^{-1} during the rainy season, and 402 FCFA kg^{-1} for tomato and 509 FCFA kg^{-1} for cabbage in the cool dry season (SIMA 2006) and were thus lower than those determined in the current study for the same crops and market. In the rainy season, market retailers' NP from tomato was also higher than the 57 FCFA kg^{-1} reported for a middleman in the Tabelot Aïr region, Niger (Weill and Ahiaba 2002). Variations in NP are also explained by differences in the purchase price of vegetables at the farm-gate or from a market wholesaler. Market prices of vegetables are also influenced by the seasonality of the demand, product perishability and market structure; however variations in any year and from year to year are hardly predictable (Kohls and Uhl 1990). During the rainy season, domestic supply was low and vegetable imports from Ghana, Nigeria and Burkina Faso prevailed at Niamey's markets, resulting in higher prices and substantial NPs for the market retailers. The high NPs obtained for cabbage and tomato at Grand Marché (the largest market in Niamey) are to a great extent explained by the fact that this market is not specialized in vegetable marketing; consequently the demand there is higher than the supply. On the other hand, retailers' NP for amaranth and lettuce were rather low at Petit Marché, which is Niamey's central market for vegetables. The supply of these commodities, including tomato and cabbage, is usually high at this market, affecting price negotiations and leading to low NPs for retailers

4.4 Conclusions

Our results indicate that urban vegetable production in Niamey generates benefits for both, producers and markets retailers. The production of high value vegetables is characterized by high use of mineral fertilizers, which increases the production costs. Since manure has a very low economic value, vegetable producers in Niamey could reduce the quantities of mineral fertilizer inputs and, where necessary, substitute by manure application, thereby meeting economic and environmental goals. The use of labour saving production methods such as increased use of water pumps and irrigation devices, along with more productive crop varieties could allow to enhance profits for urban gardeners. A comprehensive analysis of the structure of (vegetable) markets based on retailers' net profits for specific vegetables would allow to categorize these markets, and would deliver valuable information to retailers, helping them to decide which vegetable to sell at which market so as to increase their profit.

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General discussion

5 Analysis of resource use efficiencies of UPA activities

5.1 Review of methodological aspects of this study

The formulation of strategies to mitigate environmental concerns caused by the management-related oversupply of N, P, and K in urban crop and livestock husbandry requires accurate determination of inflows and outflows that originate from different sources. To assess nutrient use efficiency, in this study a nutrient budgeting approach were used (Chapters 2, 3), following the example of other studies (Bassanino et al. 2007; Khai et al. 2007). Results obtained are a contribution to filling the data gaps on nutrient flows that still prevail for the UPA systems of sub-Saharan Africa. As such, they compare well to findings from similar small-scale vegetable farming systems of other regions (Khai et al. 2007; Wang et al. 2008), and to intensive livestock husbandry systems of developed countries (Powell et al. 2008).

As far as the vegetable gardens are concerned (Chapter 2), our data were collected through a frequent quantitative monitoring of farmers' management strategies. Despite the high nutrient surpluses determined, significant changes in soil total N stock could not be observed during the two years of study - an observation also made by Wang et al. (2008) in their 2 year studies. This indicates that nutrient balance data needs to be critically viewed with respect to factors such as denitrification (De Boer and Kowalchuk 2001), soil type (Karlen and Cambardella 1996), leaching (Ersahin and Karaman 2001) and runoff (Fierer and Gabet 2002) that are affecting nutrient outflows, but also with respect to the methodological approaches used to determine these outflows. Overall a time frame of two years seems too short to determine changes in the soil pool. In a 30 year study of intensive vegetable farming of the Yangtze River Delta Region, China, however, an accumulation of soil total N, P, and K and of available P and K was noted (Huang et al. 2006). Since our approach was based on input and output flows and did not account for nutrient turnover processes within the system, uncertainties are introduced (Lesschen et al. 2007). Furthermore, biological N_2 fixation by cowpea interplanted in millet fields was not measured but only accounted for through transfer functions based on regional data (Chapter 2), which might have been another source of error.

Our study of the livestock sub-system where nutrient concentrations of inputs such as feeds and outputs such as manure were regularly measured (Chapter 3) also merits a critical assessment. The nutrient flows in these systems were highly variable due to seasonal fluctuations in weather conditions and are also subject to erroneous information by farmers (Mulier et al. 2003). If manure was removed from the barn in-between our visits (on a few occasions by farmers themselves, but particularly by neighbors), the removed amount was only estimated by the farmer and could not be cross-checked by own measurements; therefore we suspect that overall manure output was underestimated. This underlines the view of Redding et al. (2007) who found interview-based approaches of inflow and outflow relations inadequate for the determination of manure management patterns and potential risk of underground water contamination from dung heaps.

For cattle, the two-step conversion approach from body condition scores to live weight (Chapter 3) may have introduced another source of error since the hot dry season weight losses calculated for high intensity cattle were higher than those reported by Fernández-Rivera et al. (2003) for supplemented village cattle in grazing systems of the same region. This problem did not occur in small ruminants since their life weight was measured using accurate weight scales. To avoid such a problem in the future, direct weighing of cattle is suggested; if for technical, logistic or social reasons this is not possible, further studies should at least take some accurate weight measurements to fit the chest girth, rump length and body length measurements (Buvanendran et al. 2009) to existing regression equations for male and female Zebu cattle (Dodo et al. 2001). Moreover, the lack of quantification of feed intake on pasture constitutes another limitation of the livestock study, since it results in an underestimation of nutrient inflows to livestock units where stall-feeding is combined with grazing. Faecal marker methods could be used to indirectly estimate total feed intake of grazing ruminants (Mahler et al. 2007; Titgemeyer et al. 2001) but this was beyond the scope and feasibility of the present study.

The returns to investment calculated for urban gardeners (Chapter 4) may have been overestimated since fixed costs such as depreciation of tools were not accounted for. However, farmers have been using these tools for a long period; they could not remember the purchase prices, therefore this calculations factor cost was not considered. In addition, the economic ‘efficiency’ of N and P use should be regarded with caution; it would be interesting to check how different prices of N and P from manure are from those of the same nutrients from mineral fertilizer. Only, if the gardeners would have to pay for the quality of manure used, the real efficiency of N and P contain therein could be calculated.

5.2 Management-related horizontal nutrient flows in urban agriculture and implications for improving resource use efficiencies

While optimising the use of scarce nutrient resources to achieve a more sustainable production is the major challenge for agricultural production systems in sub-Saharan Africa (Schlecht and Hiernaux 2004), UPA systems tend to be large sinks of nutrients (Buerkert and Hiernaux 1998). The results on nutrient use efficiencies in urban vegetable and millet cultivation (Chapter 2) as well as in cattle and sheep/goat enterprises (Chapter 3) indicate that the current management practices of Niamey’s small-scale UPA farmers are unlikely to be sustainable. In all investigated production systems (Figure 1) nutrient resources were inefficiently used. Nutrient budget analysis revealed substantial nutrient accumulations in vegetable gardens and millet fields as well as in the livestock units (Chapters 2, 3), the main causes of which are highlighted within the framework analysis graphically depicted in Figure 1. Through mineral fertilizers and organic manures, nutrients were applied in excess of plant requirements, to which nutrient-rich wastewater added (Chapter 2). This is similar to the situation reported for other African UPA production systems (Fall et al. 2002; De Bon 2003; Tallaki 2005; Assogba-Komlan et al. 2007) and those of emerging countries such as China and Mexico (Buechler 2006; Khai et al. 2007) and is explained by the nature of UPA, which utilizes heavy fertilization as a result of growing plants in limited space (Mougeot 2006). In the livestock systems investigated (Chapter 3), all nutrients were supplied in excess of the animals' requirements for maintenance and substantial growth, but were not matched by a correspondingly high meat production. This nutrient waste was further aggravated by poor management of dung heaps (Predotova et al. 2009b) to which substantial amounts of nutrients were diverted, owing to feed spillage and conversion of feedstuffs to litter. Much of the nutrients accumulated in manure can certainly be conserved through simple management techniques: efficient manure collection and appropriate coverage of heaps with branches or plastic sheets (Ruffino et al. 2007; Predotova et al. 2009b). Measures to improve nutrient use efficiency in the studied types of small-scale urban livestock husbandry systems need to increase nutrient utilization by the animals. A reduction of the amount of protein fed to better match the amount and quality of protein fed and that required by the animal can reduce the amount of nitrogen diverted to manure (Rotz et al. 2004). Also, strategic feeding of different age and production groups of animals needs to be established.

In the same way, vegetable farmers should improve their management system by better adjusting nutrient supply to crop requirements. Some alternatives for system improvement are suggested (Figure 1). With the nutrient surpluses determined (Chapter 2), C and nutrient losses through denitrification and ammonia volatilization were calculated for the UPA gardens studied here (Predotova et al. 2009a). Reducing the use of mineral fertilizer and incorporating manure in the topsoil at the moment of application can diminish gaseous losses: rapid incorporation and shallow injection of manure were shown to be effective in decreasing N losses by 50%, while deep injection into the soil essentially eliminated these losses (Rotz 2004).

Urban farmers should therefore take advantage of those management approaches that could substantially improve nutrient availability and use efficiency to the subsequent crop, provided that labour demands for other activities are not critical. A better integration of different crop production units can help improve nutrient use efficiency (Hedlund et al. 2003). In addition, the (better) integration of livestock husbandry and horticulture with horticultural residues being used as livestock feed has been proposed (Akinbamijo et al. 2002). Lower levels of inputs and improved nutrient use efficiencies would moreover improve economic returns to farmers (Eaton et al. 2002; Hedlund et al. 2003). The monetary evaluation of nutrient use efficiency in selected vegetable production systems (Chapter 4) pointed to the over-supply of N and P being the cause for low economic returns to the studied vegetables, owing to the high application rates of mineral fertilizers and their high cost.

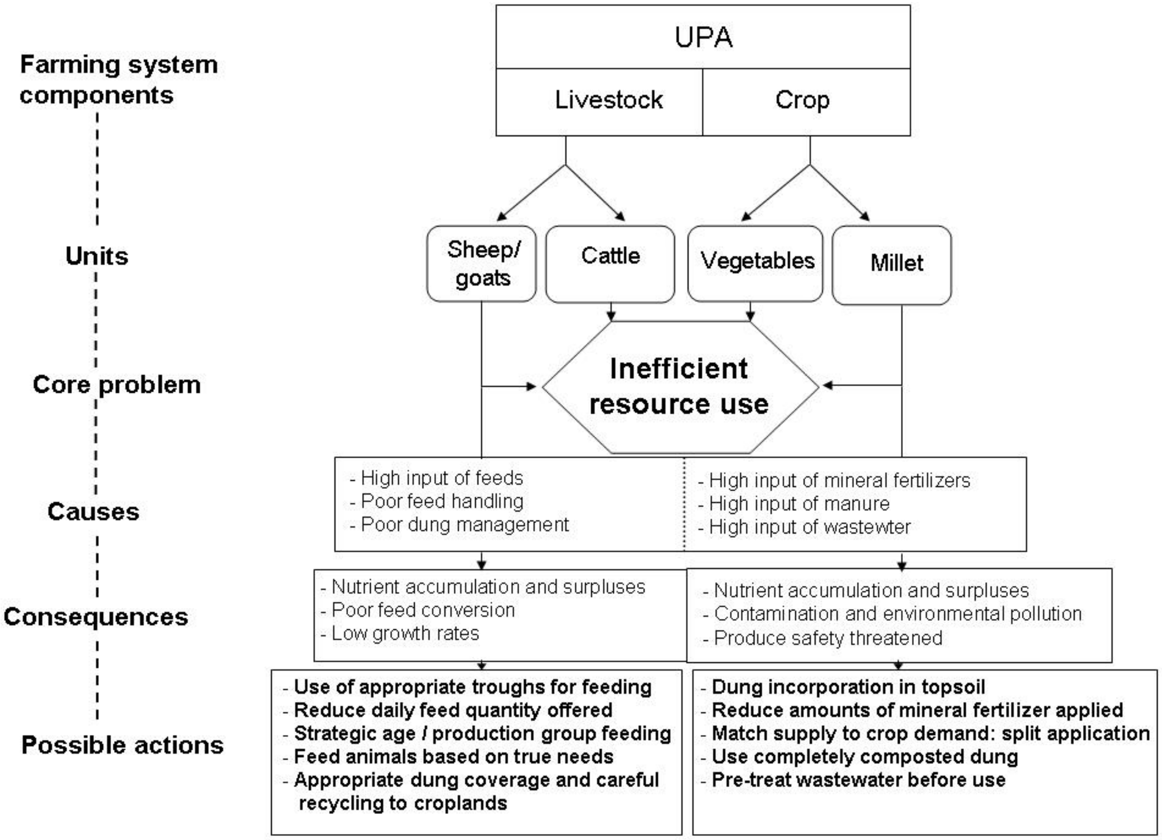

Figure 1. Schematic framework of the analysis of resource use efficiency in urban and peri-urban (UPA) activities in Niamey, Niger, and alternative management options for improvement

Beyond the economic contribution of UPA to farmers' incomes, key factors affecting nutrient management and resulting nutrient conversion into produce, flows and losses must be critically assessed if a more sustainable production and a substantial economic return to producers is to be achieved. As outlined in Chapter 3, larger livestock herds tended to use the offered feed resources more efficiently than smaller ones. This points to the sometimes neglected fact that nutrient use efficiency depends on the scale of the system considered (Oenema et al. 2003); therefore, measures aiming at mitigating nutrient losses from UPA production systems and reduce negative side-effects need to be tailored to match the specific (sub)system.

5.3 Safety of UPA production systems

Today there is increasing concern about food safety and sustainability of UPA. As shown by the current case study, UPA operates under economically viable (Chapter 4) but ecologically critical (Chapter 2, 3) conditions. However, for UPA to continue fulfilling its basic functions (Chapter 1) and to be sustainable, nutrient use efficiency needs to be substantially increased in all production units (Figure 1). If there is a net loss of nutrients from vegetable gardens or millet fields, the soil will eventually be depleted, and if there is an excess of nutrient inputs, the likelihood of environmental pollution is high (Van Horn et al. 1996). Wastewater was identified as an important source of N, P and K and could be used much more safely if contained contaminants or toxic elements were removed through an adequate pre-treatment (Khai et al. 2007). The use of wastewater for crop production in developing and emerging countries (De Bon et al. 2009) for urban food production is common and its use is economically beneficial for vegetable growers (Cornish and Kielen 2004). In Kumasi, Ghana, and Nairobi, Kenya, respectively, the average annual revenues per hectare of irrigated garden level were 397 € (in Kumasi, dry season only) and 1,267 €, but the wastewater represented a source of environmental pollution and produce contamination (Binns et al. 2003; Amoah et al. 2005; Ndiaye et al. 2006; Khai et al. 2007). The main faecal pathogens identified in the wastewater used by the current case study's UPA producers comprised *Escherichia coli*, *Salmonella* spp. and *Streptococci* along with *Staphylococcus aureus;* these pathogens were shown to contaminate amaranth, lettuce and cabbage (Chapter 2), implying potential health risks for the consumers. Partially composted livestock dung and river water were also identified as potential sources of health risk (Chapter 2). Lagoon sewage treatment with *Psitia stratiotes* was shown to effectively improve the quality of the water by reducing the presence of parasites, but not of faecal pathogens (Gaye and Niang 2002). Apart from vegetable contamination, livestock products such as meat, milk and eggs could also be infested directly with pathogens when originating from infested animals, or indirectly through excreta (FAO/WHO 2008). Milk contamination with faecal coliforms was reported for the UPA livestock systems of Kampala (Uganda), Niamey (Niger) and Bamako (Mali) (Grimaud et al. 2007; Pistocchini et al. 2008; Bonfoh et al. 2003); this issue deserves particular attention although it was not investigated within the scope of this study. The accumulation of heavy metals in the soil and subsequent translocation to vegetables (Binns et al. 2003; Huang et al. 2006; Gupta et al. 2008) constitutes another potential health risk for consumers. In the present study, no risks of Cu, Cd, Pb, Zn and Ni contaminations were determined (Chapter 2) most likely due to the low industrial development observed in Niamey. However, the results of this PhD study still support the initial hypotheses (Table 1) and show that high input UPA production systems are potentially threatening consumers' health. Despite high nutrient inputs, vegetable farmers in Niamey were not able to supply the hypothesized >50% share of the studied high value vegetables to the city markets for the two seasons investigated.

5.4 Conclusions

As the urban demand for food rises, UPA will develop at the same pace as in the past years or even expand more rapidly, while the pressure on urban land will increase. To partly counteract this problem, nutrient use efficiency in UPA crop and livestock systems should be improved through informed management decisions at the level of the production unit or the urban farm, addressing specifically the management of nutrient flows.

Table 1. Comparison of initial study hypotheses (Chapter 1) and degree of verification by the study results (Chapters 2-4)

Hypotheses	Degree of verification
(i) The livestock production in Niamey is characterized by inefficient forage management resulting in low growth rates of animals and sub-optimal nutrient use efficiency.	(i) Confirmed at 100%
(ii) The vegetable production in Niamey is characterized by high nutrient inputs through organic or inorganic fertilizers and irrigation with wastewater and sewage	(ii) Confirmed at 100%
(iii) The high value vegetables produced in Niamey cover more than 50% of the demand in town.	(iii) Partly confirmed: tomato were supplied below 50% in the rainy and the cool dry season, while the supply of cabbage was below the 50% only in the rainy season; the degree of supply of amaranth and lettuce was always > 50%
(iv) The use of untreated irrigation water, livestock dung and household wastes in urban agriculture leads to a contamination of leafy vegetables with faecal pathogens and heavy metals.	(iv) Confirmed at 100% as for the contamination of leafy vegetables. But the heavy metal concentrations were all below the threshold limits: this part of the hypothesis was not confirmed.

Proper integration of crop and livestock units at the farm level and across urban farms is seen as an essential means to increasing the efficiency of nutrient use in UPA, thereby reducing negative side-effects of nutrient wasting on the environment and human health. The following specific recommendations are emerging from the present study:

- Nutrient inputs need to be better matched to the requirements of crops and animals through informing farmers' about nutrient concentrations in the wastewater and the amounts of irrigation water that needs to be applied to specific crops in specific seasons.
- Following the line of the above recommendation, urban agricultural extension services are needed to supply vegetable farmers with proper fertilizer recommendations and provide technical assistance in the field.

- Likewise, in the livestock systems, extension officers are strongly required to advise stockowners on key feeding strategies that could be applied to reduce feed spoilage. Moreover, knowledge about feed quality and good livestock management techniques are lacking and need to be provided to the farmers.
- More space in the barn is required for urban livestock keepers, since high-density animal production and waste accumulation in the stable may increase disease incidence and hinder feed intake.
- Frequent dung removal from the stable is mandatory.
- More research on applicable ways of minimizing losses from both inorganic and organic nutrient sources in crop and livestock production is needed to design optimal management practices and determine their costs and benefits.
- In order to properly advice farmers and design strategies that fit within their agriculture-comprising livelihood systems, understanding of farmers' rationale is a key factor.
- Strengthen the legal status of UPA farmers
- Encourage product certification

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Affidavit

I assure that this dissertation was written independently and without non-permissible help and that I used no sources other than those specified in the dissertation. All quotations that have been extracted from published or unpublished sources have been marked as such. No part of this work has been used in other PhD processes.

(Hiermit versichere ich, dass ich die vorliegende Dissertation selbständig und ohne unerlaubte Hilfe angefertigt und keine anderen als die in der Dissertation angegebenen Hilfsmittel benutzt habe. Alle Stellen, die aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Kein Teil dieser Arbeit ist in einem anderen Promotionsverfahren verwendet worden.)

Witzenhausen, 27 July 2009 Rodrigue V.C. Diogo

Appendix

Table A1
Horizontal (input and output) and total balances of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in differently managed vegetable gardens of Niamey, Niger.

				Input-Output (kg ha^{-1} year^{-1})			
Management intensity	Type of irrigation	Gardens	Source	C[#]	N	P	K
Low input	River	Nogare 1	Manure	5,693	112	42	138
			Urea		90	n.a.	n.a.
			NPK		9	9	9
			Compost		65	30	83
			Irrigation		4	6	85
			Dry & wet deposits		5	2	38
			Harvest	-1,239	-101	-23	-204
			Partial balance	**4,454**	**184**	**66**	**149**
Low input	River	Goudel	Manure	30,518	443	192	433
			Urea		28	n.a.	n.a.
			Irrigation		2	12	81
			Dry & wet deposits		5	2	34
			Harvest	-2,198	-104	-27	-242
			Partial balance	**28,320**	**374**	**179**	**306**
			Gaseous losses	-25,000	-53		
			Leaching losses		-6	-1	
			Total balance	**3,320**	**315**	**178**	**306**
Low input	River	Nogare 2	Manure	8,160	329	178	470
			Urea		287	n.a.	n.a.
			NPK		18	18	18
			DAP		20	28	n.a.
			Ashes		1	23	204
			Irrigation		12	7	71
			Dry & wet deposits		5	2	38
			Harvest	-1,946	-233	-51	-318
			Partial balance	**6,214**	**439**	**205**	**483**

[#] C influx resulted from manure plus estimated deposits from root exudates.

Table A1, continued

				Input-Output (kg ha^{-1} $year^{-1}$)			
Management intensity	Type of irrigation	Gardens	Source	C[#]	N	P	K
Low input	River	Yantala Bas 1	Manure	12,274	572	141	552
			Urea		186	n.a.	n.a.
			NPK		20	20	20
			Irrigation		4	8	257
			Dry & wet deposits		5	2	37
			Harvest	-2,187	-189	-34	-354
			Partial balance	**10,087**	**598**	**137**	**512**
			Gaseous losses	-20,000	-48		
			Leaching losses		-2.2	-0.1	
			Total balance	**-9,913**	**548**	**136**	**512**
Low input	River	Saguia	Manure	14,561	183	43	70
			Irrigation		14	64	828
			Dry & wet deposits		5	2	36
			Harvest	-6,059	-344	-70	-631
			Partial balance	**8,502**	**-142**	**39**	**303**
High input	River	Yantala Bas 2	Manure	24,597	800	235	972
			Urea		457	n.a.	n.a.
			Irrigation		3	4	77
			Dry & wet deposits		5	2	37
			Harvest	-5,009	-374	-64	-736
			Partial balance	**19,588**	**891**	**177**	**350**
High input	River	Saga	Manure	13,715	375	139	492
			Urea		1,522	n.a.	n.a.
			NPK		183	183	183
			DAP		100	257	n.a.
			Irrigation		6	11	113
			Dry & wet deposits		5	1	32
			Harvest	-5,989	-534	-130	-624
			Partial balance	**7,726**	**1,657**	**461**	**196**

[#] C influx resulted from manure plus estimated deposits from root exudates.

Table A1, continued

				Input-Output (kg ha^{-1} year^{-1})			
Management intensity	Type of irrigation	Gardens	Source	C$^{\#}$	N	P	K
High input	Pond	Tondibia Gorou	Manure	15,859	813	162	534
			Urea		250	n.a.	n.a.
			NPK		29	29	29
			Irrigation		17	7	77
			Dry & wet deposits		5	2	41
			Harvest	-1,347	-77	-17	-206
			Partial balance	**14,512**	**1,037**	**183**	**475**
High input	River	Gountou Yena (School)	Manure	6,432	72	36	71
			Urea		303	n.a.	n.a.
			Irrigation		1,037	108	858
			Dry & wet deposits		5	2	37
			Harvest	-4,739	-470	-74	-741
			Partial balance	**1,693**	**947**	**72**	**225**
			Leaching losses		7.3	0.7	
			Total balance	**1,693**	**940**	**71**	**225**
High input	River	Gountou Yena (Katako)	Irrigation	7,816	3,816	644	2,019
			Dry & wet deposits		5	2	37
			Harvest	-7,031	-829	-131	-1,043
			Partial balance	**785**	**2,992**	**515**	**1,013**
			Gaseous losses	-27,000	92		
			Total balance	**-26,215**	**2,900**	**515**	**1,013**

[#] C influx resulted from manure plus estimated deposits from root exudates.

Table A2

Horizontal (input and output) balances of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in differently managed millet fields of Niamey, Niger.

			Input-Output (kg ha^{-1} $year^{-1}$)			
Management intensity	Gardens	Source	C[#]	N	P	K
Low input	Gabgoura 2	Manure	185			
		NPK		2	2	2
		Dry & wet deposits		5	2	34
		Biological N fixation		45		
		Harvest	-153	-6	-1	-10
		Partial balance	**32**	**46**	**3**	**26**
Low input	Nogare	Dry & wet deposits		5	2	38
		Harvest		-27	-10	-53
		Partial balance		**-22**	**-8**	**-15**
Low input	Tondibia Gorou 2	Manure	993			
		Dry & wet deposits		5	2	41
		Biological N fixation		45		
		Harvest	-978	-39	-6	-72
		Partial balance	**15**	**11**	**-4**	**-31**
Low input	Tondibia Gorou 3	Dry & wet deposits		5	2	41
		Biological N fixation		45		
		Harvest		-15	-3	-31
		Partial balance		**35**	**-1**	**10**
High input	Gabgoura 1	Manure	697	170	41	75
		NPK		3	3	3
		Dry & wet deposits		5	2	34
		Biological N fixation		45		
		Harvest	-339	-14	-6	-28
		Partial balance	**358**	**209**	**40**	**84**
High input	Saguia 1	Manure	2700	87	19	43
		Dry & wet deposits		5	2	36
		Harvest	-2434	-69	-13	-262
		Partial balance	**266**	**23**	**8**	**-183**

[#] C influx resulted from manure plus estimated deposits from root exudates.

Table A2, continued

Horizontal (input and output) balances of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in differently managed millet fields of Niamey, Niger.

			Input-Output (kg ha^{-1} year^{-1})			
Management intensity	Gardens	Source	C[#]	N	P	K
High input	Saguia 2	Manure	1838	159	25	35
		Dry & wet deposits		5	2	36
		Biological N fixation		45		
		Harvest	-1610	-50	-5	-59
		Partial balance	**228**	**159**	**22**	**12**
High input	Tondibia Gorou 1	Manure	2388	116	18	59
		Dry & wet deposits		4	2	41
		Biological N fixation		45		
		Harvest	-2157	-66	-10	-106
		Partial balance	**231**	**99**	**10**	**-6**
High input	Tondibia Gorou 4	Manure	990	111	22	97
		Dry & wet deposits		5	2	41
		Biological N fixation		45		
		Harvest	-779	-22	-4	-42
		Partial balance	**211**	**139**	**20**	**96**

[#] C influx resulted from manure plus estimated deposits from root exudates.