# Nutrient flows in urban and peri-urban agroecosystems in three West African cities

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# Abstract

Urban and peri-urban agriculture (UPA) is defined as the cultivation of crops and keeping livestock within and around cities. In addition to providing the cities' demand of fresh vegetables, crops and livestock products, it plays an important role in the livelihoods of the urban farmers. With the rapid urbanization in sub-Saharan Africa, UPA provides food and jobs for many urban dwellers. UPA makes use of a diverse range of urban resources such as labour, waste and wastewater to produce food and raise livestock, and it is characterized by large nutrient imports into farms or gardens, often accompanied by environmental and human health risks. In view of the complexity and diversity of the UPA systems, there is a need to understand the socio-economic characteristics of UPA as drivers to farm management practices. This research was conducted in three secondary West African cities with important UPA activities: Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). From principal component analysis of categorical variables (CATPCA) and two-step cluster analysis, six major farm types were identified based on production systems and market orientation, of which three are common in the three cities and one farm type is unique to each city. The six farm types are commercial gardening plus field crop-livestock (cGCL); commercial gardening plus semi-commercial cropping (cGscC); commercial livestock plus subsistence field cropping (cLsC); commercial gardening plus semi-commercial livestock (cGscL); commercial cropping (cC); and commercial gardening (cG). The former three are common for the three cities, the latter three farm types are unique for one city, each. The diverse activities in these farm types contributed differently to household income. Nutrient balance studies are useful indicators to assess the sustainability of farming systems. From the identified farm types, in-depth assessment of nutrient flows and balances as well as the economic performance of the different production systems was conducted in Kano (Nigeria) using the nutrient monitoring toolbox (NUTMON/MONQI). Farm nitrogen (N) balance was positive at 56.6, 67.4 and 56.4 kg farm$^{-1}$ yr$^{-1}$ for cGCL, cGscL and cLsC farm types, respectively. The same trend was observed for phosphorus (P) and potassium (K) in all the farm types except for cGCL where an annual negative K balance of 16 kg farm$^{-1}$ was found. Commercially-oriented livestock keeping (cLsC) was economically more viable than the other farm types with average annual positive gross margin (GM) and net cash flow (NCF) of $9033 and $935, respectively. Cropping activities within cGCL and cGscL had positive GMs ($1059 and $194) and NCFs ($757 and $206), but livestock activities in both farm types incurred financial losses. Using the same MONQI approach across vegetable production systems of the three cities, large amounts of nutrients were observed to be applied with large positive nutrient balances. Average annual N balances were positive for all gardens in the three cities: 279, 1127 and 74 kg N ha$^{-1}$ in Kano, Bobo Dioulasso and Sikasso, respectively. Phosphorus balance was positive in all cities except annual K deficits of 222 and 187 kg ha$^{-1}$ in Kano and Sikasso, respectively. Efficiencies were 63%, 51% and 87% for N; with poor P use efficiencies due to excess application in all three cities. K efficiency of 85% was observed in Bobo Dioulasso while in Kano and Sikasso's gardens, it was 120% and 110% respectively, indicating K mining. The average annual gross margins/benefits from gardening indicate a higher return of \$3.83 m$^{-2}$ in Bobo Dioulasso and differs statistically ($P<0.05$) from returns obtained in Kano (\$0.92 m$^{-2}$) and Sikasso (\$1.37 m$^{-2}$). Results show that UPA is an important economic livelihood strategy for urban and peri-urban farmers because of positive economic returns but with huge environmental trade-offs as a consequence of excess nutrient application. Efforts to better integrate resource management with measures to improve environmental and food safety are required of UPA stakeholders. Achieving this will require the formal recognition of the UPA sector by city officials, along with formulating realistic strategies for effective nutrient and water management for a more sustainable UPA operation in West Africa. The consistent and replicable typology developed in this study provides a basis to target system-specific technologies and appropriate recommendations to improve use efficiencies of resources as a whole.

**Key words**: Sustainability, CATPCA, two-step cluster analysis, farm types, nutrient balances, West Africa, gross margin, NUTMON/MONQI.

# Contents

# Chapter 1

# General introduction

## Background

The 21st century has witnessed a rapid urban population growth that by the year 2020 and beyond suggests that 85% of the poor in Latin America and 40–45% of the African and Asian poor will be concentrated in cities (RUAF, 2009)[1]. According to the World Urbanization Prospects[2], more than 50% of the population in developing countries is projected to live in the cities by 2030 (Fig. 1). This poses a great challenge on food security especially in sub-Sahara African countries with an urban population growth rate of 3.5% (UNDP, 2009), where 50% of the population lives on less than \$1.25 per day (UN, 2009). With a decline in the rural population that produces a large proportion of the consumed staple foods (Fig. 2), the consequence is that the increasing demand for food may not be met. Urban and peri urban agriculture (UPA) is a common practice of cultivating crops and keeping animals in and around the cities with a well-documented positive impact on livelihoods. Peri-urban agriculture is often comprised of systems within 30–40 km from the city, presenting a dynamic interface, having characteristics of both the urban and rural areas without a fixed geographical boundary (Mortimore and Wilson, 1993). The spatial dimension of this definition is unclear and depends upon the location of study. Most importantly, this study only covers the built-up area of the city plus a buffer of 10 km around its outer borders. In a 1996 global survey by the United Nations Development Programme (UNDP), it was estimated that 800 million people are engaged in urban and peri-urban agriculture. The vital contribution of UPA to African food security has been well documented. The continuing rural migration to urban areas (Schnitzler et al., 1998) has led to a strong increase in the number of urban poor that depend on UPA as a source of income and food (DESA, 2000). In sub-Saharan Africa (SSA) for example, it offers a complementary strategy to curb urban poverty and food insecurity and contributes to about 25% of the world's food supply (Schnitzler et al., 1998; Armar-Klemesu, 2000; FAO, 2005a). It also acts as an income-generating activity for the urban poor (Gundel, 2006) and raises the nutritional status of the urban diet, thus reducing urban malnutrition (Egziabher et al., 1994; Maxwell, 1998). In addition to UPA contribution to food demand of the increasing urban population, it offers a fresh supply of high value vegetables and livestock products for the urban populace. The changing diets of many urban dwellers, associated with economic growth, towards better quality food such as vegetables, fruits and animal products, has led to the intensification of UPA activities.

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[1] Resource Centres on Urban Agriculture and Food security

[2] http://esa.un.org/unpd/wup/index.htm.

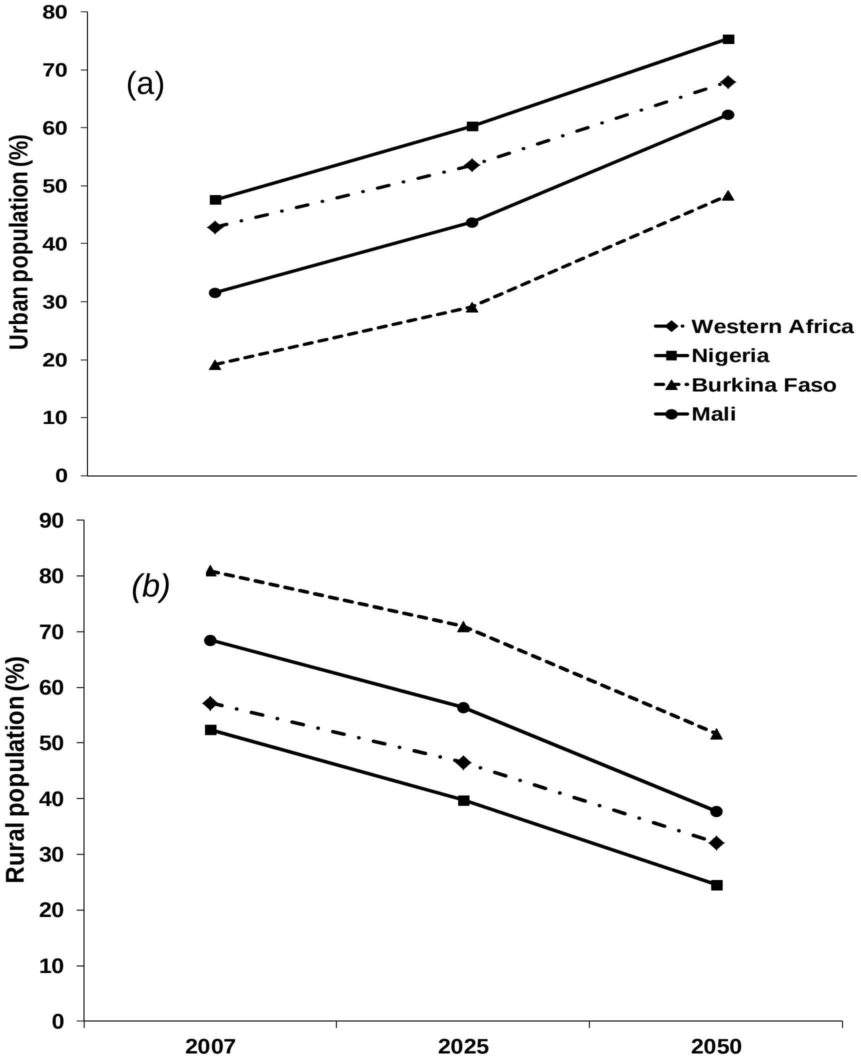

Fig. 1: Projected trends in (a) urban and (b) rural population of the West African region and countries. Source: UNDP 2009.

In response to this development, UPA systems have continued to expand. It is therefore necessary that research on UPA systems focuses on food security, but also on food and environmental safety.

## UPA in sub-Saharan Africa, characteristics, potentials and externalities

UPA operates mainly under the informal sector and is dominated by people with little education who are mainly migrants (Drechsel et al., 2006), although retired civil servants are also known to engage in such activities (Asomani-Boateng, 2002). It is practiced among diverse age groups but mainly within the middle-aged groups

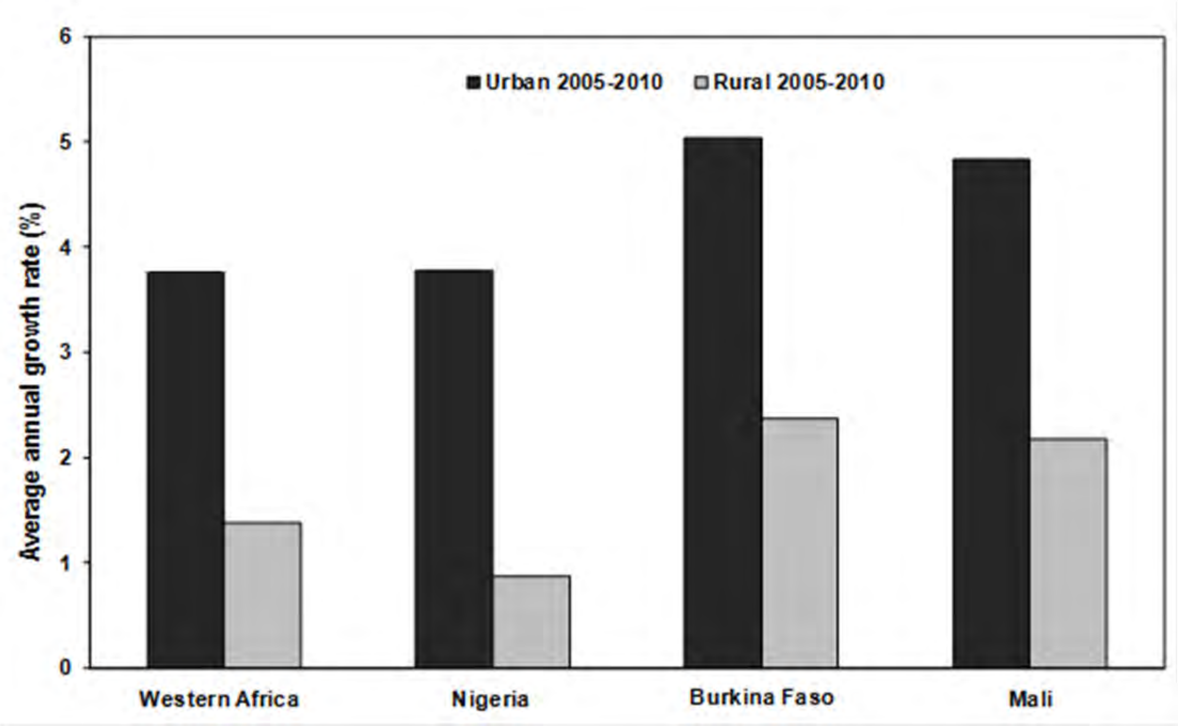

Fig. 2: Average annual growth rate of urban and rural population in West Africa. The three study locations are secondary cities in the presented West African countries. Source: UNDP.

of 31–50 years (Chah et al., 2010). Open space cultivation is usually practiced on undeveloped city plots illegally occupied without proper tenure rights (Lynch et al., 2001; Drechsel and Dongus, 2010). Vegetable production is market-oriented and a year-round activity that operates under dry season irrigation whereas crops such as rain-fed maize and cassava are only partly produced for sale (Obuobie et al., 2006).

For example, in Kumasi and Accra (Ghana), irrigation is commonly used to support dry season cultivation either from dug-up wells or city stream flows that may be fresh or loaded with city's waste (Keraita et al., 2002; Drechsel et al., 2006). Wastewater irrigation is common in other African and Asian cities under market-oriented UPA vegetable production. Irrigation constitutes the major labour demand of UPA cultivation and is done with watering cans or irrigation pumps. Because of the diversity of cultures in West Africa, gender participation in UPA varies. While it is a male dominated activity in Benin, Nigeria, Ghana, Cote d'Ivoire, Mali and Burkina Faso, about 90% of vegetable cultivation in Banjul (Gambia) is done by female farmers (Smith, 2001). Marketing of UPA products is dominated by females in most parts of West Africa (Drechsel and Varma, 2007).

Livestock is kept in many households in West African cities and ranges from poultry, goats, sheep and pigs to cattle. Furthermore, it contributes to food and offers employment, immediate financial security as well as insurance (Thys et al., 2005). About 64% of households in Niamey, Niger, keep sheep, while cattle keeping is dominant in the peri-urban areas under different scales of production and orientation ranging from small to large scale and commercial or semi-commercial to subsistence (Graefe et al., 2008). Livestock are kept by over 20,000 urban households in Mali (Schiere and van der Hoek, 2001, cited by Diogo et al., 2010b) and in 26% of 1,979 surveyed households in Ouagadougou (Burkina Faso) (Thys et al., 2005).

In a study on typical UPA livestock keeping in West Africa, systems were found to have poor feeding strategies and inappropriate manure handling, resulting in low efficiencies in nutrient use and consequently adverse environmental effects (Diogo et al., 2010b).

UPA gardening activities are characterized by heavy nutrient inputs from organic municipal waste and untreated wastewater. The use of this untreated water in UPA is inevitable for year-round crop cultivation, especially in dry periods. Contamination of vegetable produce in UPA with heavy metals and pathogens from livestock faeces and human excrements is likely to occur through the use of untreated wastewater to irrigate fields. Keraita et al. (2002) reported for Kumasi (Ghana) contamination of irrigation water with over 1000 microbial cells per litre of water while the permitted maximum is 103 coliforms per litre (WHO, 1989). High concentrations of heavy metals were detected in wastewater used for irrigation in Kano, Nigeria (Binns et al., 2003; Abdu et al., 2010).

Vegetable and crop production is also often accompanied by organic and inorganic inputs such as manure and mineral fertilizers. Up to 100 t $ha^{-1}$ $yr^{-1}$ of manure were applied to UPA vegetable cultivation in Ghana (Drechsel et al., 2005a) whereas >600 kg $ha^{-1}$ $yr^{-1}$ of mineral fertilizers were applied to African eggplant (*Solanum aethiopicum* L.) in the South of Benin (Assogba-Komlan et al., 2007, cited by Diogo et al., 2010a). These nutrient inputs far exceed the recommended nutrient supply to crops (Ensink et al., 2002; Van der Hoek et al., 2002), with the consequence of unavoidable and excessive nutrient leaching to the groundwater, as well as gaseous N losses due to denitrification and volatilization.

In addition to poor livestock dung management, the application of inorganic fertilizers and the heavy use of urban waste and wastewater to irrigate vegetable gardens are common features of most UPA systems in the three cities (Binns et al., 2003; Kimané, 2008). While waste and wastewater use may be important from the economic point of view to invest little in organic or inorganic fertilizer input, they are critical to ecological and human health risks. Under intensive UPA crop or vegetable production, nitrate leaching to the ground water constitutes a serious health concern owing to the critical role of groundwater in domestic water supply of surrounding communities (Dabi and Anderson, 1999). The increasing dependence of many SSA cities on groundwater exploration is evident from the presence of dug-up wells or constructed boreholes in almost every dwelling in Kano and Sikasso, with 60% of the urban area relying on these groundwater aquifers (Masiyandima and Giordano, 2007; Binns et al., 2000; Cissé and Mao, 2008). Nitrate concentrations in drinking water in excess of 50 mg $l^{-1}$ can result in methaemoglobinaemia (blue-baby syndrome) in children, which occurs when nitrate is reduced to nitrite in the stomach of infants and oxidizes haemoglobin which is then unable to transport oxygen (WHO, 2004). Agricultural activities strongly contribute to the high nitrate concentrations observed in groundwater (Uma, 1993). In their study, Cissé and Mao (2008) found that the Sikasso region had the highest concentrations of nitrate in well water compared with the other parts of the country as a result of agricultural practices.

## Current status of UPA in Kano, Bobo Dioulasso and Sikasso

In Nigeria, urban crop cultivation is common in major cities, such as in Kano, which is regarded as an important centre for commercial vegetable and food crop production (Binns and Lynch, 1998). The city’s multicultural setting and presence of foreign investors, influence the current changes of urban diets including fast-foods which make use of high-value vegetables and livestock products. Market price indices for meat, milk, fish, seafood and fruits rise with an accompanied decline in prices of staple foods (National Bureau of Statistics, 2009), and further drives intensification of UPA production to sustain or increase the accompanied economic gains. Already in 1992, large numbers of livestock ranging from cattle (12,910), sheep and goats (665,000), chicken and ducks (319,570) and pigeon (756,170) were kept in and around urban areas of Kano (National Livestock Survey in 1992, cited by Lewcock, 1995). These numbers must have increased because the survey was conducted when the municipal population was approximately 1.4 million compared with the recent population of approximately 3.14 million (UNUP, 2009). There has been no recent survey, however, providing data to assess the actual numbers of livestock in the urban and peri-urban areas of Kano.

In Bobo Dioulasso, cereal, vegetable and livestock production is present in 33% of the urban area and 67% of the peri-urban area (RUAF, 2010). Market gardening represents the major UPA activity and the city provides 15% of the total vegetables produced in Burkina Faso (Traore and Kone, 2009). Recently, an initiative is taken by the Municipal Environment Commission and Rural Development Institute to stimulate a multi-stakeholder policy development to enhance UPA in Burkina Faso.

In Sikasso, livestock and cotton production (Toulmin and Guèye, 2003) occur besides lowland food production which are major income generating activities for the UPA dwellers (Erenstein et al., 2006).

## Justification of research

To achieve the millennium development goal (MDG)[3] of reducing poverty and hunger (MDG 1), as well as attaining environmental sustainability (MDG 7), increased knowledge and understanding is needed on the manner in which UPA is conducted. Earlier research has focused mainly on the role of UPA in the livelihoods of the urban poor (Egziabher et al., 1994; Binns and Fereday, 1996; Bryld, 2003), their economic benefits (Freidberg, 1996; Kintomo et al., 1997; Ezedinma and Chukuezi, 1999) and on the health risks associated with heavy metals and pathogens, introduced in the food chain. In addition to human health implications, the generally low nutrient use efficiencies in these systems have been well documented for vegetable and livestock production (Diogo et al., 2010a, 2010b).

Published assessments of nutrient flows in UPA systems have been based on estimated input and outputs. However, there is little quantitative information on the use efficiencies of internal and external inputs as well as outputs as drivers of environmental pollution. An in-depth analysis of nutrient flows was advocated to monitor the contribution of UPA to environmental sustainability and the possibility to improve resource use efficiencies (Drechsel, 1999). Such comprehensive studies are still lacking in the existing integrated garden-crop-livestock systems.

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[3] www.un.org/milleniumgoals.

## Hypotheses

In view of the mentioned externalities and because only qualitative information of current UPA practices is available, two research hypotheses have been formulated:

(1) Current UPA systems operate under economically viable but ecologically critical conditions.

(2) Urban and peri-urban agriculture is characterized by heavy nutrient inputs and inefficient nutrient use.

## Study objectives and methodology

The study aimed at improved understanding of nutrient management, economic benefits and associated environmental risks of current UPA systems in West Africa. This will provide a basis for designing management strategies to improve nutrient use efficiencies of the UPA system. The specific objectives were to:

1. Attempt a regional typology of UPA production systems across three West African cities.
2. Characterize the identified UPA systems across West African cities and the socio-economic drivers for diversification into the different UPA activities along with their production constraints.
3. Quantify nutrient flows in the UPA systems of Kano (Northern Nigeria) and analyse nutrient use efficiencies and economic performances of the different systems.
4. Quantify nutrient flows in vegetable-based systems to assess similarities and differences across the three West African cities of Kano, Bobo Dioulasso and Sikasso with the aim to draw conclusions on their nutrient use efficiencies and sustainability.

## Methodology

### *A brief description of the study cities*

Kano, the capital and administrative centre of the state of Kano, is located at 12$^{o}$00’ N and 8$^{o}$31’ E (Fig. 3) and has a municipal area of 550 km$^{2}$ (Tiffen, 2001) that harbours an estimated human population of 3.14 million (UNUP, 2009). Population growth is

Fig. 3: Map of the study locations in West Africa.

largely related to immigration, catalysed by the commercial and political attraction of the city, and additionally to natural increase (Mortimore and Wilson, 1993). Average annual rainfall is approximately 786 mm and occurs between May and September (IAR Kano Meteorological Station, 2009).

Bobo Dioulasso is the second largest city in the southern part of Burkina Faso, located at latitude 11°11’ N and longitude 4°17’ W. With a total surface area of 137 km$^2$, it has a population of approximately 0.4 million (Commune de Bobo Dioulasso, 2007). Average annual rainfall is 1143 mm which occurs between May and October (Abdel-Rahman et al., 2008).

Sikasso (11°19’ N, 5°40’ W) lies in the northern Guinea Savannah zone and currently stands as the second largest city in Mali with an estimated population of 0.2 million (Erenstein et al., 2006). Average rainfall is approximately 1050 to 1100 mm (Kante, 2001; Erenstein et al., 2006) and occurs between May and September. The whole Sikasso region has a surface area of 70,280 km$^2$ (INSTAT, 2009), while Sikasso town only covers a land area of 37.45 km$^2$ (Ministère de l’Habitat et de l’Urbanisme, 2005).

This study focused on the urban and the peri-urban areas; peri-urban was defined as a band of land about 10 km width extending from the city borders for all three locations.

### *Nutrient balance concept*

The concept of nutrient balance is widely applied as a sustainability indicator of different farming systems. Nutrient balance studies can be set up for different scales and are defined as the difference between nutrient inputs and outputs in a production system. At farm-level, the balance is defined as the change in the state of various pools at the farm as a result of inflows and outflows of nutrients. This determines whether the production system of a farm in terms of nutrient status is positive or negative. It is positive if the total inflow of nutrients into the farm is larger than the outflow, and the reverse is the case for a negative balance. Using the approach developed by Stoorvogel and Smaling (1990), farm balances can be calculated for different integration levels (farm, field or livestock). This approach distinguishes inflows and outflows of major nutrients (nitrogen, N; phosphorus, P; potassium, K) with respect to the production units or components. Partial balances result from processes and flows that are managed by the farmer and calculated as the difference between mineral and organic inputs (fertilizers and feeds) as well as outputs via farm products. Full balances include both the manageable flows and those that the farmer cannot directly manipulate (also referred to as environmental or hard-to-quantify flows, and usually obtained from literature). This concept forms the basis for nutrient balance studies with the application of NUTMON/MONQI toolbox (De Jager et al., 1998; Van den Bosch et al., 1998a, 1998b; Vlaming et al., 2001).

Fig. 4 describes the methodological approach adopted in the current study according to the preceding chapters. In the beginning of the study (2007), a training workshop was organized by the Urban Food Project in Bobo Dioulasso, Burkina Faso, to assure an identical methodological approach of data collection across the study locations. A baseline survey of UPA households was conducted in the three West African cities with a semi-structured questionnaire that covered a wide range of information on socio-economic structure and farm management in the same year. This was followed by on-farm monitoring, regular surveys, sampling and meteorological data collection over two consecutive years during 2007–2009. The baseline data was used to typify UPA households using statistical approaches. In-depth farm-monitoring data from surveys and measurements, weather and literature data were used in the MONQI model to quantify nutrient flows and balances and calculate the economic performance of the farming systems in Kano, and the urban vegetable production systems across the three West African cities.

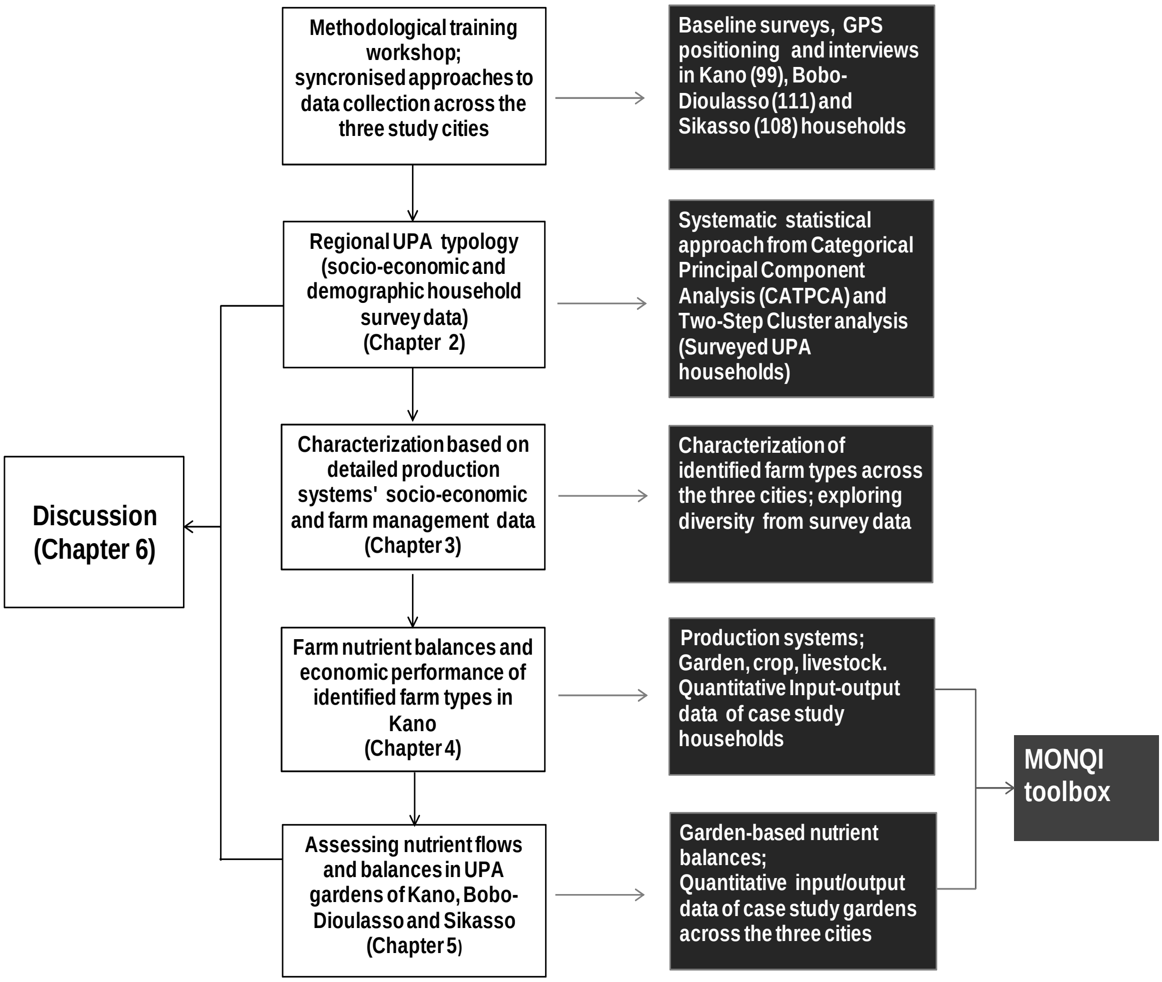

Fig. 4: Outline of study methodology used in this study. White boxes represent a description of the chapters (except for the first box) while the black boxes indicate the methods and tools applied to achieve the objectives in the respective chapters.

## Outline of thesis chapters

In Chapter 2, statistical techniques (Categorical Principal Component Analysis and Two-Step Cluster analysis) are applied on collected socio-economic data to cluster the UPA households in the three study cities. The techniques attempt to group farms with similar characteristics in order to facilitate further statistical analysis such as means and mean difference of resource endowments, demographics and personal attributes of UPA households in the identified farm types, with the aim to target the implementation of policies to farm groups rather than to individual farms.

The characterization of identified UPA farm types in the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali) is presented in detail in Chapter 3. In that chapter, an analysis of the socio-economic characteristics of the households, and the similarities and differences between farm types within and across the cities is presented, along with general farm management practices and production constraints.

Chapter 4 attempts the quantification of farm-level nutrient flows and balances in the urban and peri-urban agricultural systems of Kano city (Nigeria). For three farm types/production systems in Kano, nutrient inputs and outputs of the garden, field, and livestock components are analysed to assess the efficiencies of nutrient uses as well as the financial performance within each farming system, using the static model NUTMON/MONQI.

In Chapter 5, nutrient flows and balances in vegetable gardens across the West African cities of Kano, Bobo Dioulasso and Sikasso are analysed for similarities and differences in production management and resource use efficiencies.

Chapter 6 discusses the general findings from the research, addressing the research questions and hypotheses, and the possible impacts and implications for further research.

# Chapter 2

# Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology

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This chapter is published in a slightly modified version as:
Dossa, L.H., A. Abdulkadir, H. Amadou, C. Sangare, and E. Schlecht. 2011. Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. Landscape and Urban Planning 102: 197-206.

## *Abstract*

Developing appropriate and innovative technologies and policies to respond to the challenges that urban and peri-urban agriculture (UPA) faces in West Africa requires a better understanding of the existing production systems. Although there is an increasing recognition of the importance of UPA in the region, its extent, forms and related practices may vary across countries and cities because of different socio-economic conditions and urbanization patterns. A systematic classification of the regional UPA systems is lacking but is necessary to allow for meaningful comparisons between cities and avoid misleading generalizations. The purpose of this study was to develop a typology of UPA households across three selected West African cities. Survey data from 318 UPA households (Kano: 99, Bobo Dioulasso: 111, Sikasso: 108) were submitted to principal components analysis for categorical variables (CATPCA). Next, the Two-Step cluster method was used to classify the households using object scores obtained from the CATPCA. Diversification of farm activities, farm resource endowment and production orientation were the major discriminating variables. In each city, four distinct UPA systems were identified, of which three were common to Kano, Bobo Dioulasso and Sikasso: commercial gardening plus field crops and livestock (59%, 18%, and 37%), commercial livestock plus subsistence field cropping (14%, 41%, and 7%), and commercial gardening plus semi-commercial field cropping (14%, 28%, and 30%). The fourth group was different at each location and was characterized as follows: commercial gardening plus semi-commercial livestock in Kano (13%), commercial field cropping in Bobo Dioulasso (13%) and commercial gardening in Sikasso (26%).

**Keywords**: Urban land uses, Gardening, Animal husbandry, Field crop cultivation, Multivariate analysis, Farm classification

# 1. Introduction

## 1.1. Importance of urban and peri-urban agriculture in West Africa

Urban and peri-urban agriculture (UPA), which can be defined as the cultivation of crops and rearing of animals for food and other uses within and around cities (Mougeot, 2000), is not a new phenomenon in West Africa (Rakodi, 1988; Kironde, 1992) and has continued to rise as a consequence of rapid urbanization associated with high levels of under- and unemployment and increasing food demand of urban dwellers (Drechsel and Dongus, 2010). There is a wealth of literature that describes the social roles of UPA, its economic functions and its potentials to sustain the livelihoods of urban dwellers in West African countries, along with its environmental benefits (Smit et al., 1996; Asomani-Boateng, 2002; Danso et al., 2002; Cissé et al., 2005; Graefe et al., 2008; De Bon et al., 2010). On the other hand, a number of UPA practices raised concerns about associated negative side-effects on human health and environmental quality. The potential risks ensuing directly or indirectly from UPA are linked to inappropriate use of agro-chemicals in plant and animal production, over-application of mineral fertilizers, use of untreated livestock and human excreta as well as household wastes as manure, use of untreated wastewater for irrigation of vegetables, and inappropriate or inadequate food handling, processing and storage (Binns et al., 2003; Amoah et al., 2006; Brock and Foeken, 2006). Within the large number of available scientific and ‘grey’ publications on UPA crop and animal production in West Africa, each study presents a particular set of data for a well-defined production context and for specifically defined research questions. These cover practically all aspects of UPA, such as appropriate dosing of mineral fertilizers (Drechsel and Zimmermann, 2005), targeted application of organic manure to vegetable gardens (Drechsel et al., 2000), improved urban milk production (Sidibe et al., 2004; Millogo et al., 2008) and the externalities linked to wastewater reuse in vegetable cultivation (Sonou et al., 2001; Niang et al., 2002; Eaton and Hilhorst, 2003). However, these individual case studies often ignored the interdependencies of bio-physical and socio-economic conditions at the scale of a farm and a town, and the interrelatedness of plant and animal production as well as the interrelatedness of resource use efficiencies and externalities in production processes. Because these case studies lack a proper typology and systems research approach, only very limited broader conclusions and policy recommendations can be drawn from their findings. There is thus a need to scale up the findings from case studies (Pearson et al., 2010a) while taking into account the specific socio-economic, environmental and institutional context within which urban agriculture is taking place in each country (Bryld, 2003).

## 1.2. Classification of urban and peri-urban farming systems in West Africa

Several studies have used various criteria to describe local urban farming systems in different West African countries. Often, these criteria varied according to authors' discipline and the purpose of the classification, and some authors used only one criterion. For example, Schilter (1991) used time allocation to classify urban farmers in Lomé, Togo, and distinguished between full-time, part-time and temporary urban farmers. Based on the location where the activity is carried out, three major UPA systems were identified in Accra, Ghana (Asomani-Boateng, 2002) and in the metropolis of Katsina, Northern Nigeria (Ruma and Sheikh, 2010). These were: peri-urban, vacant/open space and household farming systems. Other studies used a combination of criteria to differentiate among urban farming systems. Kessler (2003) used the type of crop grown and the cultivation practices to describe different farming systems in Lomé (Togo), Cotonou (Benin), Bamako (Mali) and Ouagadougou (Burkina-Faso). Danso et al. (2002) used similar criteria to distinguish four crop production systems in Accra, Ghana. Drechsel et al. (2006), using production systems and product destination next to location, distinguished between open space market gardening, subsistence backyard gardening and livestock husbandry and aquaculture systems. Most of the studies focused on crop and vegetable production sub-systems and lacked a systems approach. Moreover, the results of these studies are hardly comparable, since the criteria used are generally qualitative and vary greatly among authors. Research on farming systems that rely on purely qualitative methods can produce useful typologies but quantitative comparison of the results is not possible without using any appropriate quantitative classification methods (Kostrowicki, 1977).

## 1.3. Multivariate approaches for classification

Several statistical methods exist and have been widely used in different disciplines for classification purposes. The most frequently applied methodology is based on multivariate techniques, such as Factor Analysis (FA), Discriminant Analysis (DA), Multidimensional scaling (MDS), Principal Component Analysis (PCA) and Cluster Analysis (CA). Like FA, DA and MDS, PCA is a method to reduce the dimensionality of data by transforming the original set of correlated variables into a smaller and more understandable set of uncorrelated variables (Jolliffe, 2002) whereas CA is used to create homogeneous groups of objects based on the characteristics of these objects as described in the data set (Everitt et al., 2001; Hair et al., 2006). There are many clustering methods, and each of them may give a different grouping of a dataset (Gelbard et al., 2007). The two most widely used clustering methods are the hierarchical and the K-means clustering methods. In the hierarchical procedure, a tree-like structure is built to see the relationship among entities whereas in the K-means procedure a position in the measurement is taken as central place and distance is measured from such central point.

PCA and CA have been used to identify farm types worldwide (Gebauer, 1987; Siegmund-Schultze and Rischkowsky, 2001; Köbrich et al., 2003; Maseda et al., 2004; Somda et al., 2005; Kostov and McErlean, 2006; Bidogeza et al., 2009; Joffre and Bosma, 2009). However, although commonly used, these techniques are often not the most appropriate methods in a good number of farming systems studies. For example, the appropriate use of the standard PCA, like FA, DA and MDS techniques, is based on the powerful assumptions that all variables are continuous and that the relationships between them are linear (Jolliffe, 2002). Since the complexity of farming systems requires an interdisciplinary research approach (Collinson, 2000; Zandstra, 2006), many variables used to describe local farming systems are nominal and relationships between them are frequently nonlinear. Similarly, each of the two traditional techniques of K-means and hierarchical clustering widely used in the above mentioned studies has its limitations. An important step in any of these two procedures is to select a distance measure that determines how the similarity of two objects is calculated. Unfortunately, none of the distance measures in hierarchical clustering or K-means are suitable for use with variables of mixed measurement levels (Huang, 1998).

To overcome the limitations of standard PCA, a nonlinear PCA has been developed (Gower and Blasius, 2005) and is available as Categorical Principal Component Analysis program (CATPCA) in the Categories Module of SPSS® (Meulman et al., 2004; Linting et al., 2007). CATPCA is a multivariate technique intermediate between standard (linear) PCA and nonlinear multiple correspondence analysis (Blasius and Greenacre, 2006). In contrast to linear PCA, CATPCA can handle variables of different analysis levels (nominal, ordinal, and numerical) simultaneously, and can deal with nonlinear relationships between variables (Linting et al., 2007). It is therefore adapted for use in social and behavioural science (Meulman et al., 2004), but also in cross-disciplinary research like farming systems research where variables resulting from surveys are often non-numeric. Similarly, to overcome the major of the above-mentioned limitations of K-means and hierarchical clustering methods, a Two-Step clustering method was developed based on the Balance Iterative Reducing and

Clustering using Hierarchies (BIRCH) algorithm (Zhang et al., 1997) and implemented in SPSS (Meulman et al., 2004). The Two-Step cluster procedure of SPSS possesses two very important features that distinguish it from traditional clustering techniques (Bacher et al., 2004). First, it permits the use of categorical variables along with continuous variables and reduces the size of the data set by generating a fairly large number of pre-clusters. Second, it can automatically determine the optimal number of clusters but also gives the opportunity to the user to pre-specify the numbers of clusters required. As prerequisites for a Two-Step cluster analysis, continuous variables must be normally distributed and categorical ones multi-nominally distributed; moreover, the variables must be independent of each other (SPSS Inc., 2001). Fortunately, the procedure is fairly robust to violations of both assumptions (Chan, 2005), making it therefore a suitable clustering technique for multi-dimensional data sets (Meulman et al., 2004; Linting et al., 2007). In a comparative study of 11 clustering methods applied on four known data sets, Gelbard et al. (2007) highlighted the superiority of the Two-Step Clustering method over the Hierarchical and K-means algorithms. Yet, the Two-Step cluster algorithm has also shown some limitations. Differences in categorical variables may be given a higher weight than differences in continuous variables, and the method is not able to correctly detect models with no cluster solutions (Bacher et al., 2004). Other alternative clustering approaches such as the Latent Class Models (Magidson and Vermut, 2002) and the Mixtures of Distributions Model MDM (Kostov and McErlean, 2006) have been developed to allow the inclusion of variables of mixed scale types and to overcome the shortcomings of the classical clustering methods. However, unlike for the classical and Two-Step cluster methods, tools for these alternative methods are not available in most of the established econometrical or statistical packages.

The purpose of this study was to apply multivariate analysis techniques so as to develop a common typology of urban households participating in UPA in three selected West African cities located in three different countries. If successful, such a typology can provide the basis for in-depth characterization of existing UPA systems and the identification of their (production) opportunities and challenges and the subsequent development of recommendation domains at local and regional scales.

## 2. Materials and methods

The dataset used in this study was derived from a baseline survey of a larger ongoing study aiming at a consistent quantitative characterisation of resource use efficiencies and environmental externalities of UPA in the three secondary West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali).

With a population estimated at 3.14 million inhabitants in 2007 (UNUP, 2009), Kano in northern Nigeria is the country's second largest city after Lagos. It covers a total area of 550 km$^2$ (Tiffen, 2001). Bobo Dioulasso, located in the south-western part of the country, is the second largest city in Burkina-Faso after Ouagadougou. With an estimated population of 0.4 million inhabitants in 2007, it covers a land area of 137 km$^2$ (Commune de Bobo Dioulasso, 2007). Located in the south-east of Mali, Sikasso is the third largest city of this country after Bamako and Segou. It covers a land area of 37.45 km$^2$ (Ministère de l'Habitat et de l'Urbanisme, 2005) and has an estimated population size close to 0.2 million inhabitants. While Kano is located in the Sudano-Sahelian agroecological zone, Bobo Dioulasso and Sikasso are situated in the Sudanian zone of West Africa.

## 2.1. Data collection

A snowball sampling procedure (Babbie, 2009) was used to randomly select and interview 99 households in Kano, 111 in Bobo Dioulasso and 108 in Sikasso. The interviews were performed from March to June 2007 using a standardized semi-structured questionnaire. The variables selected for our typology are shown in Table 1 and are derived from the information recorded from heads of households or their representative. This information included the demographic and socio-economic characteristics of households, the resources owned, their involvement in different agricultural activities in and around the respective city, their production constraints, access to UPA supporting institutions and contribution of UPA activities to household income.

## 2.2. Statistical analyses

After data cleaning (removal of incomplete household data sets), a manual expert classification of the households was performed based on the assets (land, namely gardens and fields) and livestock managed by the households, leading to the categories garden (G), field crop (C), livestock (L), garden and field crop (GC), garden and livestock (GL), livestock and field crop (LC) and garden-field crop and livestock (GCL) households. These categories were subsumed under the variable UPATYP, which indirectly describes the level of diversification of UPA activities. The total active family work force in man-day equivalents was calculated by applying

Table 1: Description of household socio-economic variables used in the categorical component analysis (CATPCA) on 99, 111 and 108 households (HH) in the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali), respectively.

| **Variables** | **Description** |
|---|---|
| **Nominal** | |
| SEX | Gender of HH head (male, female) |
| M_Status | Marital status of HH head (married, unmarried, divorced/widowed) |
| MIGR | Migration status of HH head (immigrant, native) |
| EDUC | Formal education level of HH head (none, primary, secondary, university) |
| LIVH | Is the HH involved in (peri) urban animal husbandry? (yes, no) |
| GARDH | Is the HH involved in (peri) urban gardening? (yes, no) |
| CROPH | Is the HH involved in (peri) urban field crop cultivation? (yes, no) |
| INC_GAR | Contribution of gardening to total HH income (highest, moderate, low, none) |
| INC_FIEL | Contribution of field cropping to total HH income (highest, moderate, low, none) |
| INC_LIV | Contribution of animal husbandry to total HH income (highest, moderate, low, none) |
| INC_REGSAL | Contribution of regular salary to total HH income (highest, moderate, low, none) |
| INC_OCCW | Contribution of occasional work to total HH income (highest, moderate, low, none) |
| UPATYP | Type of UPA enterprise (G, C, L, GC, GL, LC, GCL) |
| **Metric** | |
| AGE | Age of HH head (in years) |
| HHSIZE | Total household size, defined as total numbers of permanent family members |
| EXP_UPA | Number of years of experience in UPA |
| NGAR | Number of gardens cultivated |
| GARSIZ | Total garden size (in $m^2$) |
| NFIELD | Number of crop fields cultivated |
| FIELSIZE | Total field size (in ha) |
| NPOULTRY | Total number of poultry reared |
| TLU_Total | Total number of animals reared, expressed in TLU[a] |
| R_LABOR | Total active family work force in man-days as a proportion of HHSIZE |
| R_EDUCM | Total educated HH members as a proportion of HHSIZE |
| R_REGSAL | Total HH members with regular salary as a proportion of HHSIZE |
| R_TEMPSAL | Total HH members with temporary salary as a proportion of HHSIZE |

[a] TLU: tropical livestock unit, hypothetical animal of 250 kg live weight; TLU conversion factors used: camel = 1, cattle = 0.80, sheep and goats = 0.10, donkey = 0.5; pigs = 0.20, poultry and rabbit = 0.01.

conversion factors to male and female household members in different age groups as follows: 1.0 for males aged between 15 and 55 years; 0.75 for females between 15 and 55 years; 0.75 for males above 55 years and 0.5 for females above 55 years. Household members below 15 years of age were not considered in workforce calculations.

The clustering procedures were performed separately for each city. As the dataset contained nominal and metric variables, we used the Categorical Principal Component Analysis (CATPCA) implemented in the Categories Module of SPSS/PASW 18 (SPSS Inc., 2010), to explore the relationships between the variables and to reduce the original set of 26 variables into a smaller number of components.

We first performed the CATPCA analysis with all 26 variables listed in Table 1. Regardless of city, sex and marital status of the household heads were alike. Almost all household heads were male and married. There was therefore almost no variability to capture for the variables sex and marital status which were removed from the analysis.

The CATPCA was thus performed again with the 24 remaining variables. The grouping variable (UPATYP) was fitted in the CATPCA solution by choosing a "multiple nominal" scaling level and treating the variable as supplementary. A supplementary variable has no influence on the actual analysis, but its quantifications are computed afterwards to establish its relationship with the solution obtained (Meulman et al., 2004). The rule of thumb of retaining the components that contain a minimum of four variables having a loading score > 0.60 (Stevens, 1992) was applied to choose the number of reliable principal components. The higher the loading of a variable on a given principal component, the more that variable contributes to the variation accounted for by this component. Therefore, in this study, we selected only those variables that loaded greater than 0.5 on one of the retained components for further analysis; a similar cut-off level was used by Dominguez-Rodrigo et al. (2009) and Costantini et al. (2010) for significant indicator loadings. The perceptual maps yielded in the CATPCA were used to predict a priori the number of homogeneous groups in the data sets. The extracted component scores were subsequently used as inputs in the cluster analysis. Two clustering approaches were explored: the non-hierarchical Two-Step and the classical hierarchical approach using the Ward's method. In the Two-Step cluster analysis, the higher weighting of categorical variables at the expense of the continuous variables in the clustering process may be an important issue (Bacher et al., 2004). Therefore we used the visual binning procedure to convert the selected continuous variables into nominal variables before their submission to the algorithm. Furthermore, since the Two-Step clustering result is influenced by the order in the records of the data set (Bacher et al., 2004), we ran the analysis four times for each country with random orders of variables.

The number of clusters to fix was determined on the basis of the Bayesian Information Criterion (BIC). Several cluster solutions were then explored and the overall silhouette measure of cluster cohesion and separation (Rousseeuw, 1987; Jain and Korionos, 2008) was used to evaluate the goodness of the cluster solution. A silhouette is a graphical aid to the interpretation and validation of cluster analysis that provides a measure of how well a subject is classified when it is assigned a cluster membership. A cluster cohesion and separation value > 0.7 indicates an excellent separation between the clusters, a value between 0.5 and 0.7 indicates a clear assignment of data points to cluster centers, values between 0.25 and 0.5 indicate that there are many data points that cannot be clearly assigned and values < 0.25 indicate that it is practically impossible to find significant clusters (Kaufman and Rousseeuw, 1990). For the sake of comparison, the same variables used in the Two-Step cluster algorithm were also submitted to hierarchical cluster analysis using the Ward's method and the squared Euclidean distance, and the resulting Elbow diagram was used to derive the number of clusters.

The final clusters obtained were profiled and a cluster name was assigned to each. Cross tabulations were used to show the distribution of each UPA activity and its households' income contribution across clusters. Differences between clusters in households' resources endowments were explored using the Kruskal-Wallis test. Next, an internal cross-validation of the identified groups was performed using multinomial regression analysis. Finally, a cross-tabulation of the final clusters with the supplementary variable representing the expert's manual classification (UPATYP) was used as a validity check.

## 3. Results

The variables related to UPA activities were distributed into two components by CATPCA (Table 2). The introduction of a third component increased the total variance accounted for by approximately 10% in each city; however, only two variables related to household socio-economic characteristics were placed into this additional dimension: R_EDUCM and R_REGSAL in Kano; INC_OCCW and R_REGSAL in Bobo Dioulasso; R_TEMPSAL and INC_OCCW in Sikasso. Therefore, we decided to continue the exploration of data with the two-component solution. Variables that scored more than 0.5 in at least one of the two components were used in the classification of households. Fig. 1 shows the two-dimensional component loading plots obtained with CATPCA, summarizing the relationships between the different variables. These relationships, represented by their correlations with the principal components, are displayed by vectors pointing towards the category with the highest score. Regardless of the city, the most influential variables as reflected by the length of the vectors were identified as those related to diversification of UPA activities (GARDH, LIVH and CROPH), to income contribution of different UPA activities (INC_GAR, INC_LIV and INC_FIEL) and to resource endowment (NGAR, NFIELD, FIELSIZE, TLU_Total).

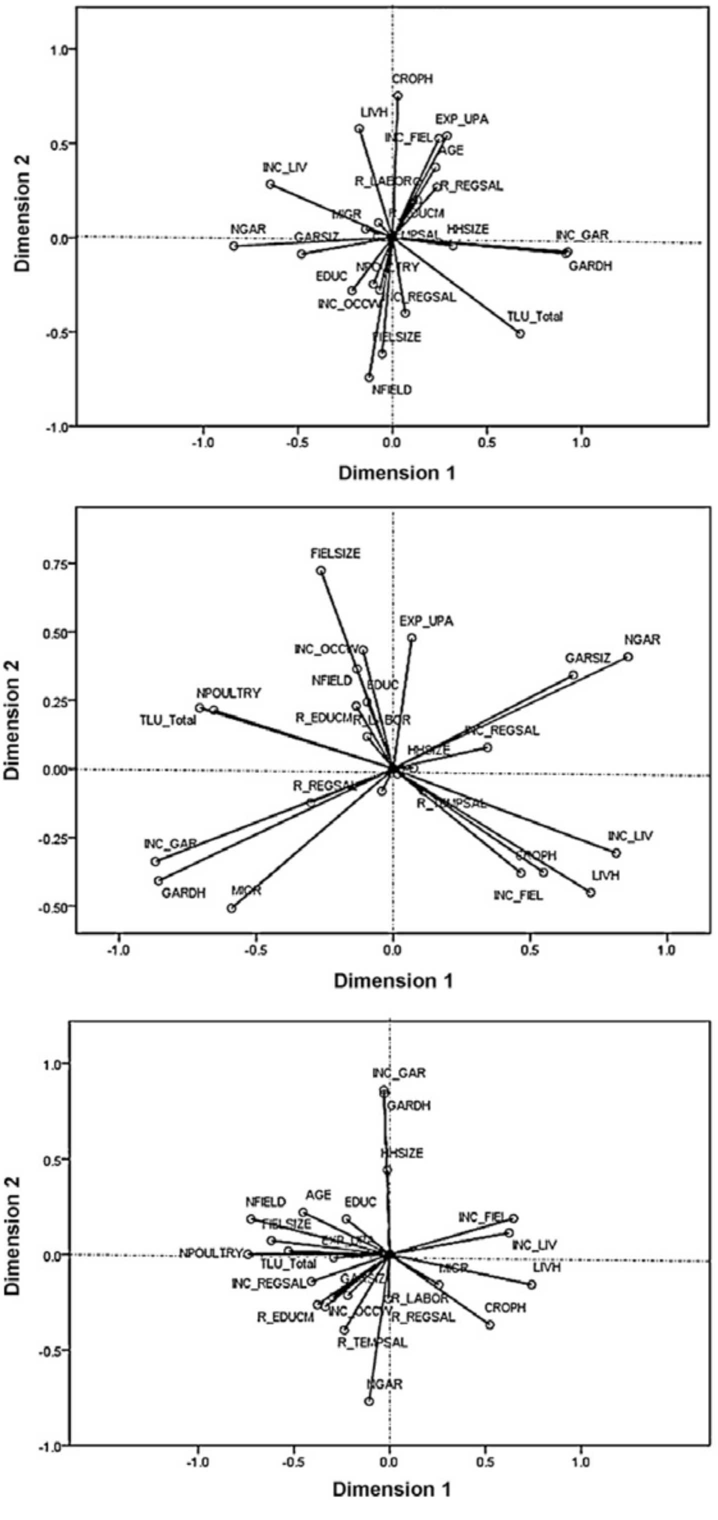
Fig. 1 suggests that a priori four groups of households can be identified in each city, as a result of the relationships among the most influential variables. The automatic clustering procedure of the Two-Step cluster algorithm suggested a four-cluster solution for each city. The quality of the clustering solution was good with an overall silhouette measure of 0.6 for each city. However, given the fact that the supplementary variable (UPATYP) used in the CATPCA had seven levels of measurements reflecting the different combinations possible of UPA activities, a number of possible cluster solutions, ranging from three to seven, were considered.

The three- and five-cluster solutions were both plausible but the overall silhouette measure of cluster cohesion and separation was lower than 0.6, indicating poorer cluster quality. Therefore, a final four-cluster solution that confirmed the four a priori groups suggested by the CATPCA was adopted for all cities. The distribution of the final clusters is shown in Table 3.

Table 2: CATPCA model summary and component loadings for the three West African cities of Kano, Bobo Dioulasso and Sikasso.

| | Kano | | Bobo Dioulasso | | Sikasso | |
|---|---|---|---|---|---|---|
| | (n = 99) | | (n = 111) | | (n = 108) | |
| Total Cronbach's Alpha[a] | 0.906 | | 0.926 | | 0.905 | |
| Total Eigenvalue | 7.523 | | 8.719 | | 7.461 | |
| Total % variance | 32.708 | | 37.909 | | 32.439 | |
| | Dimension | | | | | |
| | 1 | 2 | 1 | 2 | 1 | 2 |
| Cronbach's Alpha | 0.786 | 0.746 | 0.871 | 0.662 | 0.808 | 0.704 |
| Total Eigenvalues | 4.037 | 3.486 | 5.991 | 2.728 | 4.396 | 3.065 |
| % of total variance | 17.551 | 15.157 | 26.048 | 11.861 | 19.113 | 13.326 |
| Label | Component Loadings | | | | | |
| AGE | 0.228 | 0.373 | -0.030 | -0.055 | -0.452 | 0.221 |
| MIGR | -0.143 | 0.045 | -0.590 | -0.508 | 0.257 | -0.158 |
| EDUC | -0.215 | -0.282 | -0.094 | 0.243 | -0.227 | 0.186 |
| HHSIZE | 0.320 | -0.044 | 0.074 | 0.003 | -0.013 | 0.443 |
| R_LABOR | 0.132 | 0.297 | -0.095 | 0.117 | -0.008 | -0.232 |
| R_EDUCM | 0.132 | 0.199 | -0.135 | 0.228 | -0.377 | -0.263 |
| R_REGSAL | 0.235 | 0.268 | -0.301 | -0.122 | -0.298 | -0.225 |
| R_TEMPSAL | -0.074 | 0.078 | 0.109 | -0.081 | -0.237 | -0.396 |
| LIVH | -0.176 | 0.578 | 0.720 | -0.451 | 0.741 | -0.158 |
| GARDH | 0.917 | -0.086 | -0.856 | -0.408 | -0.028 | 0.842 |
| CROPH | 0.028 | 0.751 | 0.466 | -0.379 | 0.523 | -0.368 |
| EXP_UPA | 0.288 | 0.540 | 0.067 | 0.477 | -0.292 | -0.015 |
| NGAR | -0.839 | -0.046 | 0.856 | 0.408 | -0.107 | -0.769 |
| GARSIZ | -0.481 | -0.087 | 0.657 | 0.341 | -0.219 | -0.214 |
| NFIELD | -0.124 | -0.742 | -0.132 | 0.364 | -0.724 | 0.186 |
| FIELSIZE | -0.055 | -0.617 | -0.264 | 0.723 | -0.618 | 0.073 |
| TLU_Total | 0.675 | -0.510 | -0.706 | 0.222 | -0.529 | 0.018 |
| NPOULTRY | -0.102 | -0.247 | -0.654 | 0.213 | -0.740 | 0.001 |
| INC_GAR | 0.926 | -0.076 | -0.868 | -0.337 | -0.030 | 0.861 |
| INC_FIEL | 0.245 | 0.525 | 0.548 | -0.377 | 0.646 | 0.189 |
| INC_LIV | -0.646 | 0.282 | 0.813 | -0.307 | 0.623 | 0.113 |
| INC_REGSAL | 0.068 | -0.401 | 0.344 | 0.077 | -0.408 | -0.142 |
| INC_OCCW | -0.067 | -0.279 | -0.110 | 0.433 | -0.336 | -0.273 |
| UPATYP[b] | -0.889 | 0.326 | 0.964 | 0.105 | 0.683 | -0.650 |

[a] Total Cronbach's Alpha is based on the total Eigenvalue.
[b] Supplementary variable.



*Kano (n=99)*

*Bobo Dioulasso (n=111)*

*Sikasso (n=108)*

Fig. 1. Plots of component loadings obtained from CATPCA for Kano, Bobo Dioulasso and Sikasso describing the relationships among household socio-economic characteristics.

Table 3: Distribution of households across the final clusters derived from the Two-Step cluster analysis for the three West African cities of Kano, Bobo Dioulasso and Sikasso.

| | Percentage of households | | |
|---|---|---|---|
| | Kano<br>(n = 99) | Bobo Dioulasso<br>(n = 111) | Sikasso<br>(n = 108) |
| Cluster 1 | 58.59 | 41.44 | 25.93 |
| Cluster 2 | 14.14 | 12.61 | 37.04 |
| Cluster 3 | 14.14 | 27.93 | 7.40 |
| Cluster 4 | 13.13 | 18.02 | 29.63 |
| Total | 100.00 | 100.00 | 100.00 |

In the hierarchical clustering analysis, using the same influential variables obtained from the CATPCA, the curve of the Elbow diagram inflected at a 13–15 cluster-solution for Kano, a 11–13 cluster-solution for Bobo Dioulasso and a 16–18 cluster-solution for Sikasso. These solutions resulted in very small numbers of households per group, which were very difficult to characterize unanimously.

In the Two-Step cluster analysis, a variable cluster member was created that identified which household belongs to which cluster. A profiling of the clusters was performed by crossing the variable cluster membership with both qualitative (Table 4) and quantitative (Table 5 and Fig. 2) variables that were used in the clustering algorithm. A closer look at the clusters across countries revealed strong similarities between cluster 1 of Kano, cluster 4 of Bobo Dioulasso and cluster 2 of Sikasso. Likewise, cluster 3 of Kano was similar to cluster 3 of Bobo Dioulasso and cluster 4 of Sikasso, whereas cluster 4 of Kano was similar to cluster 1 of Bobo Dioulasso and cluster 3 of Sikasso. Consequently, cluster names for six different UPA production systems were specified (Table 6). These final groups had correct classification rates of 100% overall, whereas overall correct classification of the initial pre-defined groups (UPATYP) in the final groups was 98% in Kano and Sikasso and 100% in Bobo Dioulasso (Table 7).

**Table 4:** Frequency distribution of gardening, animal husbandry and field crop cultivation activities and their relative contribution to households' income across the final four clusters in the West African cities of Kano, Bobo Dioulasso and Sikasso.

| | Clusters Kano | | | | Clusters Bobo Dioulasso | | | | Clusters Sikasso | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | K1 (n=58) | K2 (n=13) | K3 (n=14) | K4 (n=14) | B1 (n=46) | B2 (n=14) | B3 (n=31) | B4 (n=20) | S1 (n=28) | S2 (n=40) | S3 (n=8) | S4 (n=32) |
| *Percentage of households* | | | | | | | | | | | | |
| Gardening | | | | | | | | | | | | |
| Yes | 100 | 69 | 100 | 0 | 0 | 0 | 100 | 100 | 100 | 100 | 0 | 100 |
| No | 0 | 31 | 0 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 100 | 0 |
| Animal husbandry | | | | | | | | | | | | |
| Yes | 100 | 100 | 0 | 93 | 100 | 0 | 0 | 100 | 0 | 100 | 63 | 0 |
| No | 0 | 0 | 100 | 7 | 0 | 100 | 100 | 0 | 100 | 0 | 37 | 100 |
| Field crop cultivation | | | | | | | | | | | | |
| Yes | 100 | 0 | 43 | 79 | 96 | 100 | 65 | 100 | 0 | 83 | 100 | 100 |
| No | 0 | 100 | 57 | 21 | 4 | 0 | 35 | 0 | 100 | 17 | 0 | 0 |
| Income gardening | | | | | | | | | | | | |
| Highest | 91 | 61 | 93 | 0 | 0 | 0 | 84 | 50 | 75 | 65 | 0 | 75 |
| Moderate | 7 | 8 | 7 | 0 | 0 | 0 | 16 | 40 | 25 | 28 | 0 | 19 |
| Low | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 6 |
| None | 0 | 31 | 0 | 100 | 100 | 100 | 0 | 10 | 0 | 0 | 0 | 0 |
| Income livestock | | | | | | | | | | | | |
| Highest | 7 | 15 | 0 | 72 | 52 | 0 | 0 | 20 | 0 | 0 | 12 | 0 |
| Moderate | 29 | 39 | 0 | 14 | 39 | 0 | 0 | 20 | 0 | 13 | 13 | 0 |
| Low | 16 | 0 | 0 | 0 | 7 | 0 | 0 | 25 | 0 | 30 | 0 | 0 |
| None | 48 | 46 | 100 | 14 | 2 | 100 | 100 | 35 | 100 | 57 | 75 | 100 |
| Income crop cultivation | | | | | | | | | | | | |
| Highest | 0 | 0 | 0 | 14 | 48 | 71 | 13 | 35 | 0 | 25 | 0 | 25 |
| Moderate | 41 | 0 | 7 | 22 | 42 | 29 | 49 | 40 | 0 | 35 | 13 | 34 |
| Low | 14 | 0 | 0 | 0 | 8 | 0 | 0 | 25 | 0 | 10 | 0 | 3 |
| None | 45 | 100 | 93 | 64 | 2 | 0 | 38 | 0 | 100 | 30 | 87 | 38 |

**Table 5:** Mean values for households' resource endowment variables across the final four clusters in the West African cities of Kano, Bobo Dioulasso and Sikasso.

| | Clusters Kano | | | | Clusters Bobo Dioulasso | | | | Clusters Sikasso | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | K1 | K2 | K3 | K4 | B1 | B2 | B3 | B4 | S1 | S2 | S3 | S4 |
| *Resource endowment profile* | | | | | | | | | | | | |
| Total garden size ($m^2$) | | | | | | | | | | | | |
| *n* | 58 | 9 | 14 | 14 | 46 | 14 | 31 | 20 | 28 | 40 | 8 | 32 |
| Mean | $1236^a$ | $1004^a$ | $841^a$ | 0 | 0 | 0 | $737^a$ | $797^a$ | $2257^a$ | $4145^a$ | 0 | $2647^a$ |
| SD | 1160 | 791 | 843 | 0 | 0 | 0 | 598 | 744 | 2716 | 4985 | 0 | 2810 |
| Total crop field size (ha) | | | | | | | | | | | | |
| *n* | 58 | 13 | 6 | 14 | 44 | 14 | 20 | 20 | 28 | 38 | 8 | 32 |
| Mean | $1.3^a$ | 0.0 | $0.8^a$ | $1.1^a$ | $3.3^{ad}$ | $1.8^{bc}$ | $2.4^{ac}$ | $4.6^d$ | 0.0 | $2.8^a$ | $1.7^a$ | $2.0^a$ |
| SD | 1.2 | 0.0 | 0.4 | 0.5 | 2.3 | 1.2 | 1.6 | 3.1 | 0.0 | 3.1 | 1.5 | 2.5 |
| Total TLU (n) | | | | | | | | | | | | |
| *n* | 58 | 13 | 14 | 13 | 46 | 14 | 31 | 20 | 28 | 40 | 5 | 32 |
| Mean | $2.3^a$ | $2.5^a$ | 0.0 | $40.1^b$ | $21.4^a$ | 0.0 | 0.0 | $4.4^b$ | 0.0 | $7.5^a$ | $21.5^a$ | 0.0 |
| SD | 3.5 | 3.8 | 0.0 | 35.5 | 30.5 | 0.0 | 0.0 | 8.8 | 0.0 | 10.8 | 42.3 | 0.0 |
| Total active family work force in man-equivalent (n) | | | | | | | | | | | | |
| *n* | 58 | 13 | 14 | 14 | 46 | 14 | 31 | 20 | 28 | 40 | 8 | 32 |
| Mean | $4.5^a$ | $4.4^a$ | $5.9^a$ | $8.8^a$ | $3.6^a$ | $3.9^a$ | $3.9^a$ | $3.5^a$ | $5.8^a$ | $10.6^a$ | $8.9^a$ | 6.6 |
| SD | 3.9 | 1.6 | 3.9 | 7.5 | 2.5 | 2.6 | 2.3 | 1.7 | 4.4 | 10.1 | 8.3 | 4.6 |

$^{abcd}$ Means with different superscripts differ significantly (Kruskal-Wallis test, $P \leq 0.05$).

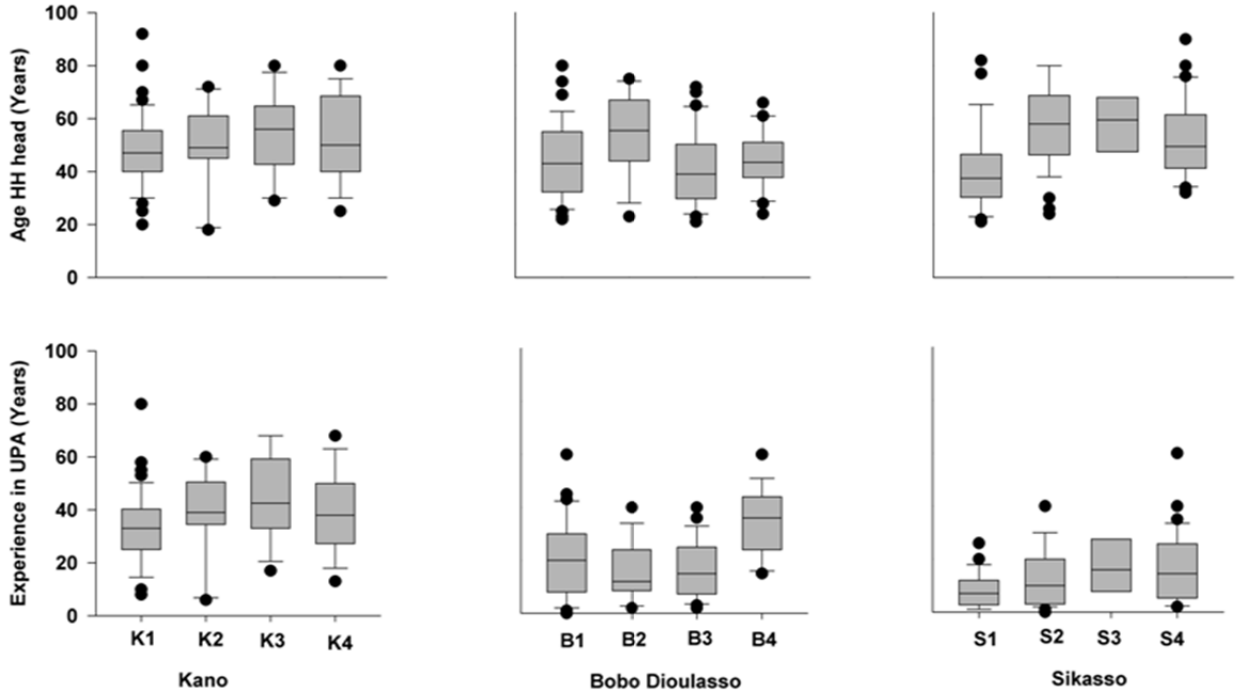


Fig. 2: Mean values for the age of head of households and households' experience in UPA across the final four clusters in Kano, Bobo Dioulasso and Sikasso.

**Table 6:** Major UPA systems obtained from the cluster analysis and their similarities across the three West African cities of Kano, Bobo Dioulasso and Sikasso.

| UPA system | Clusters | | | |
|---|---|---|---|---|
| | Kano | Bobo Dioulasso | Sikasso | Cross-location cluster number |
| Commercial gardening plus field crop-livestock (cGCL) | K1 | B4 | S2 | 1 |
| Commercial gardening plus semi-commercial livestock (cGscL) | K2 | - | - | 2 |
| Commercial livestock plus subsistence field cropping (cLsC) | K4 | B1 | S3 | 4 |
| Commercial gardening plus semi-commercial field cropping (cGscC) | K3 | B3 | S4 | 3 |
| Commercial field cropping (cC) | - | B2 | - | 5 |
| Commercial gardening (cG) | - | - | S1 | 6 |

**Table 7:** Congruency (%) between the manual expert classification and the classification obtained from the cluster analysis.

| Groups based on manual expert classification | Groups based on cluster analysis | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cGCL[a] | | | cGscL | | | cGscC | | | cLsC | | | cC | | | cG | | |
| | K[b] | B | S | K | B | S | K | B | S | K | B | S | K | B | S | K | B | S |
| GCL[c] | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| GC | 25 | 0 | 6 | 0 | 0 | 0 | 75 | 100 | 94 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GL | 0 | 0 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |
| C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 100 | 0 | 100 | 0 | 0 | 0 | 0 |
| L | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[a] cGCL = commercial gardening + field crop livestock; cGscL = commercial gardening + semi-commercial livestock; cGscC = commercial gardening + semi-commercial field cropping; cLsC = commercial livestock + subsistence field cropping; cC = commercial field cropping; cG = commercial gardening.

[b] K = Kano; B = Bobo Dioulasso, S = Sikasso.

[c] GCL = garden + crop+ livestock; LC = livestock + crop; GC = garden + crop; GL = garden + livestock; G = garden only; C = field crop only and L = livestock only.

# 4. Discussion

## 4.1. Methodology

The decision to apply multivariate methods or to simply stratify using a single criterion (e.g. location) is determined by the quality of the available data set (Selter et al., 2009). Likewise, the quality of a typology depends on the choice of the appropriate clustering method and on the quality of the data (Emtage et al., 2006; Gelbard et al., 2007). The two crucial issues in using classical cluster analysis techniques are the selection of the variables to be submitted to the cluster algorithm and deciding the most suitable number of clusters. In our study, the use of the CATPCA as data reduction technique permitted to integrate variables of different measurement levels in the analysis and provided an a priori idea about the number of groups. The four groups of UPA farmers for each city suggested by the CATPCA were then confirmed by the Two-Step cluster analysis, while the hierarchical clustering approach using the Ward's method and the squared Euclidean distance suggested for each city at least 10 groups of small sizes and of low interpretability. Different and varied cluster solutions were also reported by Gelbard et al. (2007) when applying 11 common clustering algorithms, including the Two-Step and the hierarchical clustering approach using the Ward's method that we used in our study, to the same dataset. Similar to our results, this study strongly supported the advantages of the Two-Step cluster approach over the classical clustering methods.

However, although the Two-Step cluster approach automatically detects the optimal number of clusters, like the classical hierarchical approach, it provides opportunities for the researcher to subjectively affect the final classification. In our study, we explored up to seven-cluster solutions for each city and finally decided to retain the four-cluster solution. Köbrich et al. (2003) and Rischkowsky et al. (2006a) demonstrated that in the hierarchical approach, objective numbers of clusters could be obtained by using the researcher's subjective judgment to rationally cut the hierarchical tree. We therefore agree with Kostov and McErlean (2006) and Emtage et al. (2007) that some degree of subjectivity is always present in typology research. As shown in Table 7, the pre-grouping, based on the expert evaluation, was very close to the final outcome of the cluster analysis.

This expert classification used the asset-based (garden size, field area and livestock numbers) criteria of diversity of UPA activities. Our results thus confirm that under certain circumstances, for instance when it is not possible to use cluster analysis, an expert's manual classification may be very useful.

## 4.2. Main findings

By applying multivariate analysis techniques, we were able to identify six different UPA farming systems across the three West African cities investigated. Three were common to all three cities: commercial gardening plus field crop-livestock, commercial livestock plus subsistence field cropping, and commercial gardening plus semi-commercial field cropping. The commercial gardening plus field crop-livestock system was predominant in Kano, the commercial livestock plus subsistence field cropping was predominant in Bobo Dioulasso whereas the commercial gardening plus semi-commercial field cropping was the prevailing system in Sikasso. The other identified UPA systems were location-specific and were characterized as commercial gardening plus semi-commercial livestock in Kano, commercial field cropping in Bobo Dioulasso and commercial gardening in Sikasso. These findings provide evidence that, beyond the previous site-specific classifications (Danso et al., 2002; Kessler, 2003; Drechsel et al., 2006), a regional approach may be successfully applied to deal with the complexity of the UPA farming systems.

Since it is based on multiple criteria, the typology developed in this study depicts much better UPA systems with respect to the diversity of the UPA activities and the relative contribution of each activity to the participant household's income than do the various single criterion classifications provided in previous studies (Schilter, 1991; Asomani-Boateng, 2002; Danso et al., 2002; Kessler, 2003; Ruma and Sheikh, 2010). Out of the six UPA farming systems identified in the present study, only the commercial gardening system was included in the three major categories of urban agriculture in West Africa as described by Drechsel et al. (2006). This system is considered as a typical feature of many West African cities and has been previously described for Bobo Dioulasso, Burkina-Faso (Centrès, 1996; Freidberg, 1997), for Cotonou, Benin (Brock and Foeken, 2006), for Lagos and Port-Harcourt, Nigeria (Ezedinma and Chukuezi, 1999), and for Accra, Ghana (Etuah-Jackson et al., 2001) where it has been identified as the dominant system (Danso et al., 2002). The commercial gardening plus semi-commercial field cropping was previously reported from Bamako (Eaton and Hilhorst, 2003). However, the different mixed systems identified in our study, which disclose the strong tendency for diversification of agricultural activities among West African UPA households, were poorly identified in previous studies and are not in agreement with the general perception that vegetable growing, field cropping and livestock keeping activities are undertaken by separate urban and peri-urban households (Veenhuizen and Danso, 2007). Similar combinations of UPA activities as obtained in our typology were recently reported in Niamey (Graefe et al., 2008). It is worth noting that, although small stock (e.g. chicken) was raised and staple crops (e.g. maize and millet) were grown mainly for home-consumption, the majority of the farms in our study were to some extent market-oriented. These findings are in agreement with Cour (2001) who argued that with the rise of food demand in cities, small scale farming in the West African Sahel will gradually shift from subsistence farming to commercial farming.

In their typology of rural farm households in Rwanda, Bidogeza et al. (2009) found that the age of the household head was a significant predictor of cluster membership. In a similar study in Kenya, Tittonell et al. (2010) also reported age of household head and size of the household as influential variables in cluster membership prediction. Interestingly, in our study, none of the variables related to personal attributes of the household head and to the household's socio-demography was found to be significantly predicting cluster membership. This may be explained by the fact that people involved in urban agriculture are more diverse in their origin and socio-economic conditions than rural farmers (Prain and Zeeuw, 2007).

### 4.3. Implications for further research

Our typology enabled group membership identification and the statistical tests showed that most variables representing diversification of UPA activities had high discriminating power. This indicates that the identified groups were distinct and that our typology can be useful in further studies aiming at exploring differences in challenges, opportunities, resource use efficiencies and innovation process among them and at identifying areas of potential cooperation between them. Furthermore, since it was based on a reduced set of household's socio-economic variables that can be easily and rapidly collected through a survey questionnaire with a limited set of questions, our typology is open to the inclusion of new households – within the three cities and beyond – into the identified groups.

## 5. Conclusions

Across the studied three West African cities, UPA households were classified into six different UPA farming systems using multivariate analysis techniques. Differences between the farming systems were determined largely by the diversity of the UPA activities, their individual contribution to the households' income and the households' resource endowments. Three of the identified UPA systems were common to the three cities. These findings confirm our hypothesis that a regional typology of UPA systems can be developed. This should serve as a starting point for in-depth analysis of characteristics, opportunities and problems of such livelihood systems, and form the basis for regional as well as location-specific recommendation domains. Our study thus provides a framework for further comprehensive bio-economic evaluation of the identified UPA systems and the development of appropriate technologies and policies that foster an ecologically sustainable, socially acceptable and economically profitable UPA in the Sudano-Sahelian zone of West Africa.

## *Acknowledgements*

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# Chapter 3

# Characterization of urban and peri-urban agroecosystems in three West African cities

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## *Abstract*

Systems of Urban and Peri-urban Agriculture (UPA) take many forms in terms of integration of different activities, production intensities and production orientations. The present study aimed at a refined characterization of the diversity in terms of production orientation, resource endowments and production strategies of the different types of farm households involved in urban and peri-urban agriculture in three West African cities. A total of 318 UPA households were surveyed using a standardized semi-structured questionnaire in the West African cities Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). Through Categorical Principal Component Analysis (CATPCA) and Two-Step Cluster analysis, six distinct household clusters were identified based on resource endowments and the degree of integration of vegetable, field crop and animal production. Three clusters appeared in all three cities, the remaining three were specific for one of the cities each and comprised (i) Commercial gardening plus field cropping and livestock keeping (cGCL), (ii) Commercial livestock plus subsistence field cropping (cLsC), (iii) Commercial gardening plus semi-commercial field cropping (cGscC), (iv) Commercial gardening plus semi-commercial livestock keeping (cGscL), (v) Commercial field cropping (cC), and (vi) Commercial gardening (cG). Production constraints were similar across the cities, i.e. high costs of inputs, water shortages and lack of fertilizers in the garden and field crop production systems, while feeding constraints and animal diseases were the main constraints in livestock production. UPA remains an important economic activity to livelihood strategy for urban and peri-urban farmers. Appropriate policies should be formulated that efficiently target the site-specific constraints for improving the quality and sustainability of UPA production systems.

**Keywords**: CATPCA, Two-step Cluster analysis, sub-Saharan Africa, diversification, semi-structured questionnaire

## 1. Introduction

Urban and Peri-Urban Agriculture (UPA) is defined as the growing of crops and rearing of livestock in and around cities, a common practice in Africa, Asia and Latin America. These activities offer a coping strategy to curb urban poverty and food insecurity and are estimated to contribute currently about 15–20% to the worldwide food supply (Schnitzler et al., 1998; Armar-Klemesu, 2000). Urbanization is taking place at a rapid pace in developing countries of Africa, Asia and Latin America, leading to an increase in urban poverty and urban food insecurity. Projections suggest that by the year 2020, 85% of the poor in Latin America, and 40–45% of the African and Asian poor will be concentrated in cities (RUAF, 2009). In West Africa, the city population grows by 6% each year (FAO, 2010a). With an annual population increase of 2% (FAO, 2009) and an urbanization rate of 4% (World Bank, 2009), 60% of the population of sub-Saharan Africa will live in cities by the year 2050 (UN, 2006), compared to the current 37% (UN-HABITAT, 2010). The vital contribution of UPA to African food security has been well documented (Mwangi, 1995; Cofie et al., 2003; ADRA, 2004) and the continuing rural migration to urban areas leads to a strong increase in the number of urban poor depending on UPA as a source of income and food (DESA, 2000). To meet this challenge, the Food and Agriculture Organisation (FAO) of the United Nations, in the years 1998/1999, established a special programme on food security “Food for the cities” (http://www.fao.org/fcit/en), to improve access to food and enhance the livelihood of the urban poor.

A wide variety of farming systems and modes of production exist in sub-Saharan Africa, the most common being the mixed crop-livestock system (Seré et al., 1995). In many UPA households, vegetable, food crop and livestock production co-exist at varying intensities, under different management practices and with varying production orientations (Veenhuizen and Danso, 2007). A common feature of these UPA activities in West Africa is a combination of intensive vegetable production within the cities along rivers or streams that are loaded with municipal waste and wastewaters, and livestock production in urban centres in close proximity to living quarters, combined with field crop cultivation in the peri-urban areas (De Bon, 2001). Similar features have been described for vegetable or crop-based urban and peri-urban agriculture in cities such as Kumasi (Ghana), Nairobi (Kenya), Harare (Zimbabwe) and Dar es Salaam (Tanzania) (Binns and Lynch, 1998; Keraita et al., 2002; Cofie, 2010), where wastewater, used for irrigation, serves as a source of nutrients for sustaining these intensive systems.

Livestock keeping in urban areas comprises semi-intensive or extensive systems with small ruminants roaming the living quarters and streets, scavenging for food (Rischkowsky et al., 2006b). These systems have been shown to play an important role in supplementing household income and they represent part of the livelihood strategy for many of the urban poor (Schiere and Van der Hoek, 2001; Thys et al., 2006). About two-thirds of the poor urban households are directly or indirectly involved in UPA (FAO, 2009), either in the cultivation of crops and/or vegetables and in livestock keeping or in their marketing. Improved nutrition of the poor urban residents through UPA further highlights its important role for urban livelihoods (Maxwell et al., 1998; Kushwaha et al., 2007). This indicates the long-term benefits of these systems with respect to the extensive use of urban resources to sustain both economic and agricultural productivity.

Research on UPA has so far focused mainly on its role for the livelihoods of the urban poor (Chadegesin, 1991; Egziabher et al., 1994; Atkinson, 1995; Binns and Fereday, 1996; Binns and Lynch, 1998; Bryld, 2003; Cofie, 2010), on its economic benefits (Freidberg, 1996; Kintomo et al., 1997; Ezedinma and Chukuezi, 1999; Obuobie et al., 2006) and on the health risks associated with heavy metals and pathogens, introduced in the food chain as a result of the use of organic municipal waste and sewage water in crop production (Binns et al., 2003; Eaton and Hilhorst, 2003; Amoah et al., 2007). Although there is no single approach to describe agricultural sustainability, it could be viewed from social, economic, environmental and institutional perspectives for the different UPA sectors (Pearson et al., 2010b). The multi-functionality of UPA has been elaborated in a review by De Bon et al. (2010) on these different aspects of sustainability and stressed the need for documenting UPA in urban development plans.

UPA systems are heterogeneous, especially with respect to household livelihood strategies, resource allocation and farm management (De Bon, 2001; Tittonell et al., 2005) which imply that individual farm households are unique in terms of their farming system. As it is not realistic to formulate policies for each of these ‘unique’ households, they need to be grouped, based on relevant characteristics that substantiate their identity, i.e. ‘representative’ farms need to be identified. Hence, an appropriate method of classification is necessary for objective grouping. Farm households have been classified based on socio-economic characteristics and livelihood strategies, such as wealth classes and resource flow maps, characterizing resource allocation and use in soil fertility and farm management strategies (Thuweba et al., 2005; Tittonell et al., 2005). A more systematic approach is based on the use of multivariate techniques, as have been applied to identify homogenous groups of farms or farming systems using clustering analysis (Hardiman, 1990; Ogungbile et al., 1998; Köbrich et al., 2003; Somda et al., 2005; Rischkowsky et al., 2006b; Schippers et al., 2007). Based on a farm classification derived from an appropriate clustering approach (Dossa et al., 2011), the present study aimed at a refined characterization of the diversity in terms of production orientation and resource endowments and production strategies of the different types of farm households involved in urban and peri-urban agriculture in three West African cities. Based on this characterization, system- and site-specific constraints to and operations of urban and peri-urban agricultural production in West Africa are identified and approaches towards problem solutions are suggested to ensure sustainable production.

## 2. Material and methods

### 2.1. Study sites

The study was conducted in three West African cities (Fig. 1) having different ecological, social and economic characteristics. Kano city ($12^{o}00'$ N and $8^{o}31'$ E) in the northern part of Nigeria, is located in the most populated state of the country (NPC, 2006) in the Sudano-Sahelian agroecological zone with an average annual rainfall of approximately 800 mm (810 mm during 1990–1999, 786 mm during 1999–2009; IAR Kano Meteorological Station, 2009; Ahmed, 2007). Mean daily temperatures range between 29 and 38 °C, but can be as low as 15 °C in the cool dry season. Soils are well drained with predominantly sandy loam texture (Jibrin et al., 2008). The main economic activity in the region is production and marketing of agricultural produce (Binns and Lynch, 1998) and it is known for its historic trading and commercial activities (Mortimore and Wilson, 1993). Bobo Dioulasso ($11^{o}11'$ N and $4^{o}17'$ W) is located in south-western Burkina Faso and is the second largest city in the country. It is a significant economic centre for agricultural trade and the textile industry. Average annual rainfall was 1143 mm over the period 1964–2008 (Abdel-Rahman et al., 2008), and soils in the region are classified as ferruginous tropical soils of low fertility (Sidibé-Anago et al., 2009). Sikasso ($11^{o}19'$ N and $5^{o}49'$ W), Mali's third largest city, lies in the southeast of the country. Rainfall is similar to that of Bobo Dioulasso, and the soils are well drained and loamy sand to sandy loam in texture (Ramisch, 2005). The local economy is largely agriculture-based with emphasis on production and marketing of fruits and vegetables. Kano city has a population of 3.14 million (UNUP, 2009), Bobo Dioulasso and Sikasso have populations of 0.4 (Commune de Bobo Dioulasso, 2007) and 0.2 million (Ministère de l'Habitat et de l'Urbanisme, 2005).

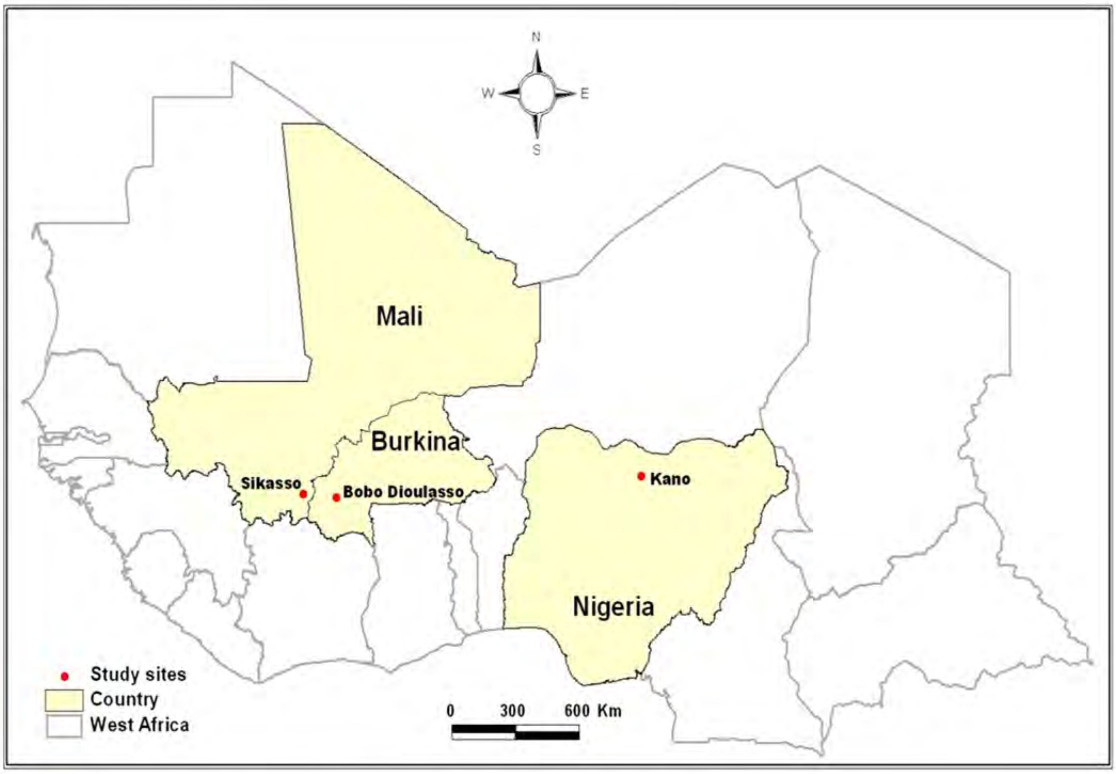

Fig. 1: Location of the three West African cities involved in the study.

A brief description of the agro-ecological and biophysical characteristics of the locations is given in Table 1, showing that they differ markedly in annual rainfall, altitude and population density.

## 2.2. Baseline interviews of UPA households

A baseline survey with a standardized semi-structured questionnaire was conducted with 99, 111 and 108 households involved in UPA activities in Kano, Bobo Dioulasso and Sikasso, respectively, between March and June 2007. Household selection followed a snowball approach where the first household per city was randomly selected at a location where UPA gardening and livestock keeping is practiced, after which the interviewed farmer was asked to identify three other farmers involved in similar urban and peri-urban agricultural activities from any part of the city; among these three, one was chosen at random for the subsequent interview. This procedure was followed until the required number of households was interviewed. The questionnaire covered household demographic structure, socio-economic characteristics, participation in UPA activities, numbers, sizes and production of gardens, fields and livestock herds, as well as the contribution of individual UPA

Table 1: Main characteristics of the three West African study locations.

| | Region | Northern Nigeria | Southern Burkina Faso | Southern Mali |
|---|---|---|---|---|
| | City | Kano | Bobo Dioulasso | Sikasso |
| Biophysical attributes | Altitude (a.s.l)[a] m | 487 | 445 | 410 |
| | Total annual rainfall (mm) | 786[b] (Unimodal) | 1143 (Unimodal) | 1150 (Unimodal) |
| | Rainy season | May - September | May - October | May - October |
| | Mean annual temperature ($^{o}$C) | 29-38 | 23-33 | 28 |
| | Common soil types (FAO) | Nitosols, Ultisols | Lithosols, Alfisols | Luvisols |
| | Agro-ecological zone | Sudano-Sahel Savanna | Sudanian Savanna | Sudanian Savanna |
| Economic[c] characteristics | City area ($km^2$) | 550 | 137 | 37.45 |
| | Population (Million) | 3.14 | 0.4 | 0.2 |

[a] Above sea level:

Sources: [b] Average over 10 years for Kano, Institute for Agricultural Research, Kano; [c] Tiffen, 2001; Ministère de l'Habitat et de l'Urbanisme, 2005; Commune de Bobo Dioulasso, 2007; RUAF, 2010.

activities and off-farm income to total household income. Different approaches have been used to estimate available family labour (Hardiman, 1990; Langyintou and Mungoma, 2008). In the present study, total available family labour was calculated on the basis of active household members (man-day equivalent), in which male members from 15–55 years were assumed to be fully active and those above 55 years for 75%. Each household requires at least one active adult female to carry out household activities for 75% of the working day, while females above 55 years were assumed to be active for 50%. Children below 15 years of age were assumed not to contribute to the work force in this study, even though in other studies children between the ages of 9 and 15 years have been assumed to take part in agricultural activities (Hardiman, 1990; Langyintou and Mungoma, 2008). Moreover, information was collected on use and application rates of organic and inorganic fertilizers, pesticide use, vegetable and field crop marketing, livestock feeding, livestock transactions and use of veterinary products.

## 2.3. Data analysis

Since socio-economic survey data do not assume a strictly uniform distribution, due to the nature of the data and the method of collection, a statistical technique that is more flexible in terms of data characteristics and distribution was selected to characterize farms. The dataset originating from the survey contained both categorical and numeric data (of nominal, ordinal and interval forms) on household socio-economic characteristics and on the number of tropical livestock units (TLU[1]) owned, the number of gardens and fields and their respective areas. Out of this dataset, a set of 26 variables was subjected to categorical principal component analysis (CATPCA), a procedure that simultaneously quantifies categorical and continuous variables while reducing the dimensionality of the data (Dossa et al., 2011). The approach reduces the original dataset to a smaller set of variables that represent the most relevant information from the original variables. Variables with object scores of at least 50% in either of the two principal dimensions were selected for the final grouping, using Two-Step Cluster Analysis. These were livestock keeping (yes/no), gardening activities (yes/no), field cropping activities (yes/no), number of gardens, number of cultivated fields, number of ruminant livestock units, total number of livestock units, garden contribution to income (highest, moderate, low, none), livestock contribution to income (highest, moderate, low, none), total garden area and total field area (Dossa et al., 2011). Classification was done separately for each city to reduce the need for aggregation, with the ensuing loss of information.

Based on the resulting farm types, subsequent characterization explored and compared their socio-economic and management-related variables, using the SPSS version 17.0 statistical package (SPSS, 2008). Where appropriate, Kruskal-Wallis and Mann-Whitney U non-parametric tests were conducted on the continuous variables for comparison of mean differences between the identified farm types at probability level of 5% and 95% confidence interval. Chi-square non parametric test was conducted on the categorical variables to test for frequencies and statistical differences between these farm types. Cross tabulations of ethnicity with the identified farm types were carried out to capture the ethnic background of the UPA households in the different farm groups.

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[1] TLU, Tropical Livestock Unit: a hypothetical animal of 250 kg live weight; used to standardize different livestock categories. TLU conversion factors used: camel = 1, cattle = 0.80, sheep and goats = 0.10, donkey = 0.50, pigs = 0.20, poultry and rabbit = 0.01.

# 3. Results

## 3.1. Cluster characterization and resource endowment

For each city, three common and one city-specific cluster resulted from the clustering analysis based on the combination of resource endowments, production orientation and resource allocation criteria. Six distinct production systems were thus defined across the three cities (Fig. 2), whereby three of the identified production systems were similar across the three cities and the other three systems each typical for one city only. Fig. 3 presents the three principal variables that segregate the clusters of the three cites under the different farming systems. Across all farm types, female-headed UPA respondents comprised 5% and 19% of the households in Bobo Dioulasso and Sikasso, with no female participation in gardening in Kano.

### *3.1.1. Commercial gardening plus field crop-livestock (cGCL)*

In the commercial gardening plus field crop-livestock system, combining vegetable gardens, field cropping and livestock production, represents the dominant cluster across the three cities. In this market-oriented system, most of the household income is generated from garden activities with moderate to low contributions from field crops and livestock, respectively. In Kano, households in this cluster cultivate on average 1236 $m^2$ of vegetable garden (Table 2). Average total field area is 1.3 ha (47% of the households cultivate between 0.1–0.5 ha) and the livestock herd, mainly consisting of small ruminants, averages 2.3 TLU, but 43% of the households own between 0.01–1.5 TLU. Food crop production is mainly for subsistence and 40% of the households in this cluster engage in occasional off-farm activities with moderate to low impact on household income.

In Bobo Dioulasso, these farms closely resemble the ones in Kano, except for their smaller garden size of 797 $m^2$ (Table 2). The field area is larger, averaging 4.6 ha, with 40% of the households in this group cultivating from 1–3 ha and 55% of the households cultivating areas exceeding 3 ha. With 4.4 TLU, average livestock number exceeds that of the Kano households, although 50% of the households own 1.5–3 TLU. Again, the vegetable garden contributes most to household income, with moderate to large contributions also from field crops and from livestock activities. Only 10% of the households earn a regular salary and 25% generate moderate to low earnings from occasional unskilled off-farm activities.

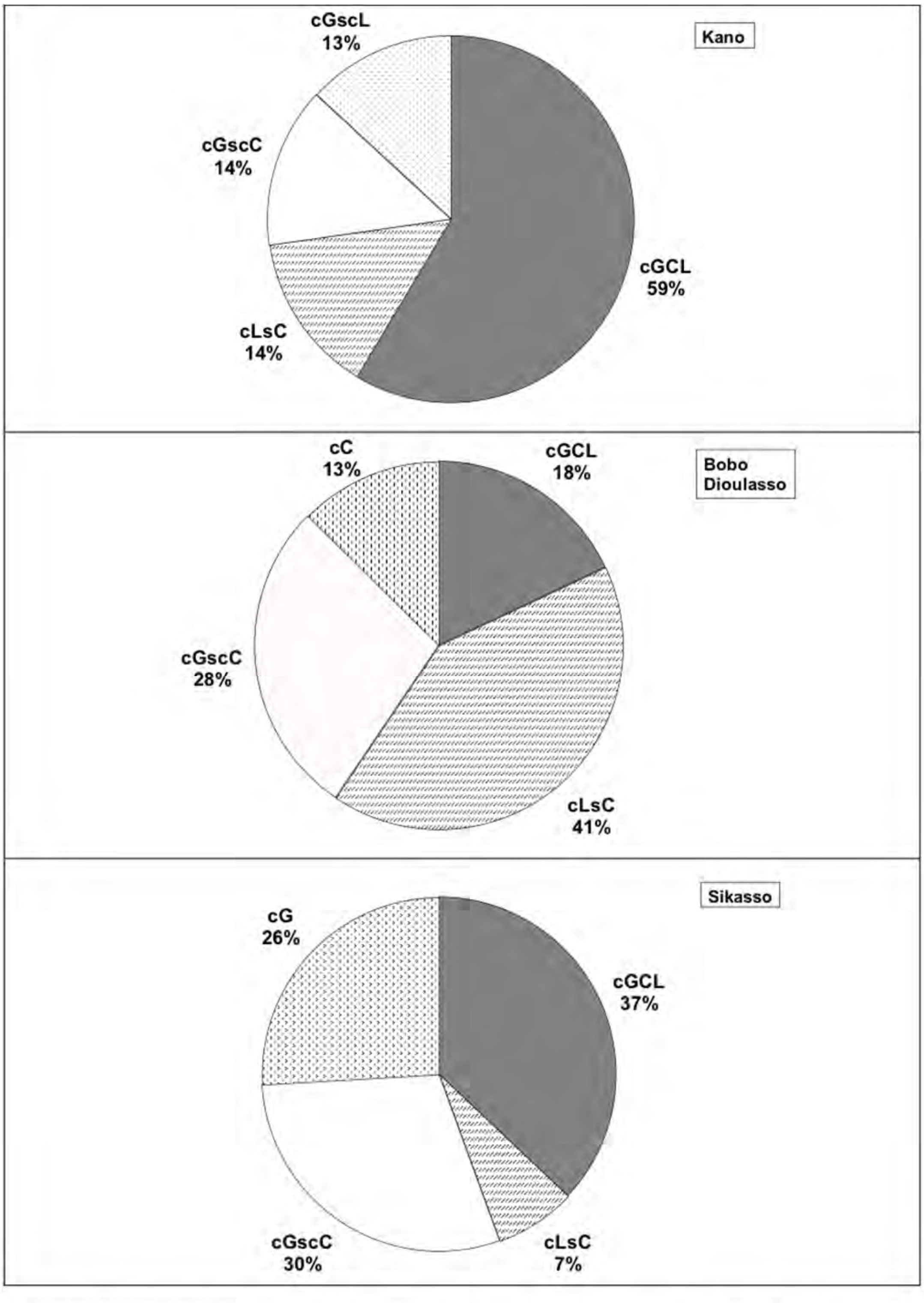

Fig. 2: Pie chart showing the six distinct clusters representing the farm types in Kano, Bobo and Sikasso. cGCL = commercial gardening plus field crop-livestock, cLsC = commercial livestock plus subsistence field cropping, cGscC = commercial gardening plus semi-commercial field cropping, cGscL = commercial gardening plus semi-commercial livestock, cC = commercial field cropping, cG = commercial gardening.

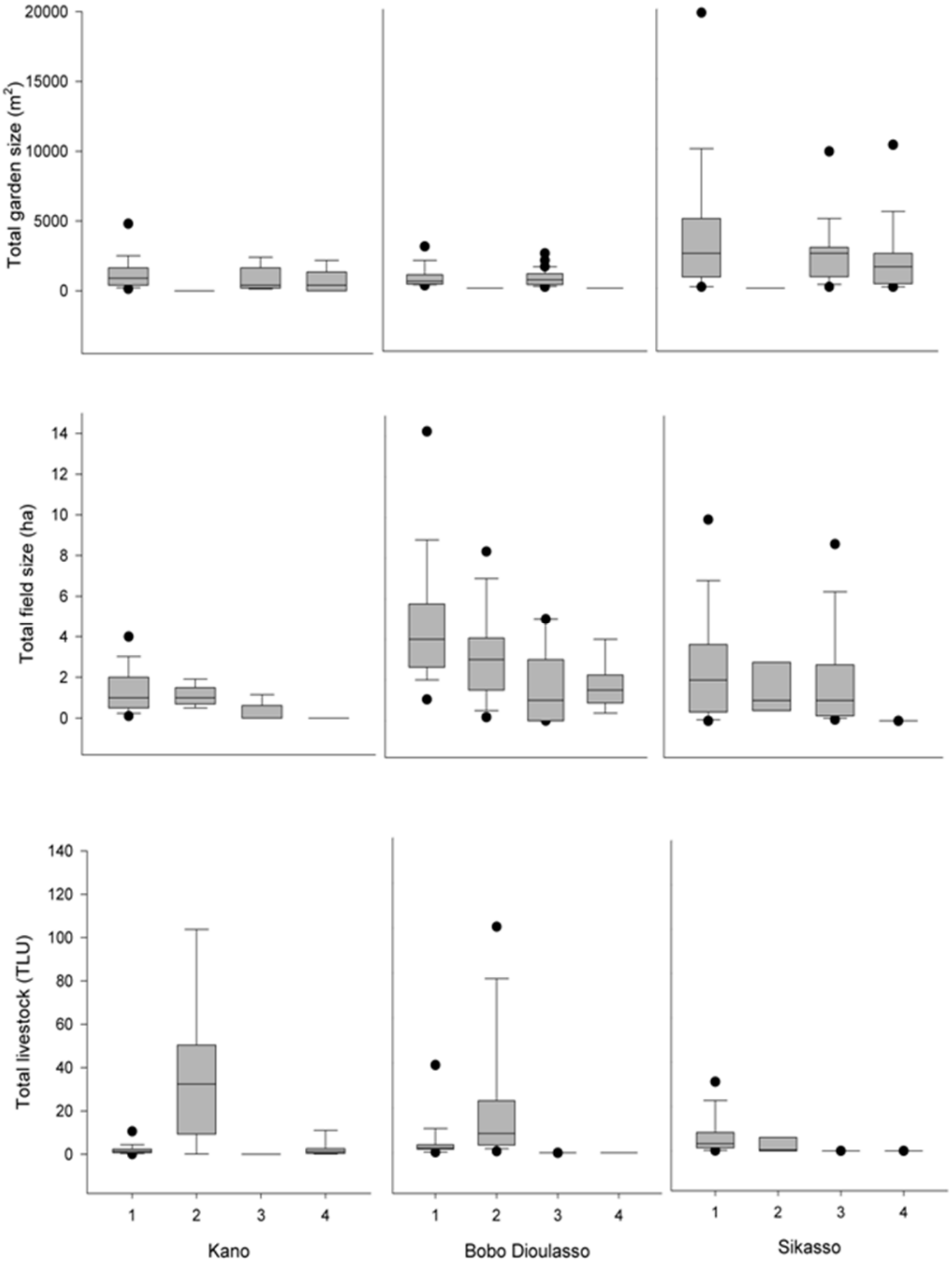

Fig. 3: Box-and-whisker plots showing the variation in ownership of total garden area (m$^2$), field size (ha) and total livestock number (TLU, see footnote 1) in the clusters of Kano, Bobo Dioulasso and Sikasso. Range (rectangle, from 25th to 75th percentile), median (cross bar) maximum and minimum values (lines above and below the box) and outliers (points). Clusters 1, 2, 3 represent farm types cGCL, cLsC, cGscC for the three cities; 4 represents cGscL, cC and cG for Kano, Bobo Dioulasso and Sikasso, respectively.

Table 2: Mean values of resource endowments of the different farm types in the three studied West African cities.

| City | Resource endowment | Farm types[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | cGCL | cLsC | cGscC | cGscL | cC | cG |
| Kano | n | 58 | 14 | 14 | 9 | - | - |
| | Total garden size (m$^2$) | 1236 $^{a}$ | 0.0 | 841 $^{a}$ | 1004 $^{a}$ | - | - |
| | Total field size (ha) | 1.3 $^{a}$ | 1.1 $^{a}$ | 0.8 $^{a}$ | 0.0 | - | - |
| | Total livestock number (TLU[2]) | 2.3 $^{a}$ | 40.1 $^{b}$ | 0.0 | 2.5 $^{a}$ | - | - |
| Bobo Dioulasso | n | 20 | 46 | 31 | - | 14 | - |
| | Total garden size (m$^2$) | 797 $^{a}$ | 0.0 | 737 $^{a}$ | - | 0.0 | - |
| | Total field size (ha) | 4.6 $^{ad}$ | 3.3 $^{a}$ | 2.4 $^{ac}$ | - | 1.8 $^{bc}$ | - |
| | Total livestock number (TLU) | 4.4 $^{b}$ | 21.4 $^{a}$ | 0.0 | - | 0.0 | - |
| Sikasso | n | 40 | 8 | 32 | - | - | 28 |
| | Total garden size (m$^{2)}$ | 4145 $^{a}$ | 0.0 | 2647 $^{a}$ | - | - | 2257 $^{a}$ |
| | Total field size (ha) | 2.8 $^{a}$ | 1.7 $^{a}$ | 2.0 $^{a}$ | - | - | - |
| | Total livestock number (TLU) | 7.5 $^{a}$ | 21.5 $^{a}$ | 0.0 | - | - | - |

[a,b,c,d] Means with different letters within the rows are statistically different (Kruskal-Wallis test, $P \leq 0.05$).

[1] cGCL = commercial gardening plus field crop-livestock, cLsC = commercial livestock plus subsistence field cropping, cGscC = commercial gardening plus semi-commercial field cropping, cGscL = commercial gardening plus semi-commercial livestock, cC = commercial field cropping, cG = commercial gardening.

[2] TLU, see footnote 1.

In Sikasso, households in this cluster cultivate larger gardens (mean 4145 $m^2$), with 60% of the households cultivating at least 2000 $m^2$. The field crop area is at least 1 ha (mean 2.8 ha) and for 58% of the households exceeds 3 ha. Livestock ownership varies between 3 and 10 TLU for 33% of the households with an average of 7.5 TLU (Table 2). Vegetable cultivation again contributes most to household income, supplemented by moderate to high contributions from field crops and relatively low contributions from livestock activities. Earnings from occasional off-farm activities are rather low, with 20% of the households earning a low income and another 10% sustaining their family through a regular salary. In summary, this cluster of the UPA sector can be referred to as the one that is highly endowed in terms of the various resources across typical West African cities.

### *3.1.2. Commercial livestock plus subsistence field cropping (cLsC)*

This cluster is again present in Kano, Bobo Dioulasso and Sikasso. In Kano, 79% of these households own a herd that exceeds 10 TLU, and livestock is the largest contributor to household income for 71% of the respondents. Average field size is 1.1 ha, with 50% of the households cultivating 0.5–1 ha, which moderately contributes to household income (for 21% of the respondents), but mainly serves the families' own food supply. Off-farm activities are important for income generation, as 57% of the households engage in occasional employment and 36% have earnings from regular employment, both contributing moderately to household income. In Bobo Dioulasso, 78% of the households in this cluster own herds exceeding 3 TLU. Although most households cultivate one field, field sizes (average of 3.3 ha) are larger than those of the Kano farms in this cluster, with 81% of the households cultivating at least 1 ha (Fig. 3). Both, livestock keeping and field cropping are important economic activities for 91% and 89% of the households, respectively, with moderate to high impact on household income, whereby most of the income is generated by the livestock activity. In Sikasso, average herd size in this group is 21.5 TLU, but only 25% of the households reported a moderate to high income from their livestock activity. At 1.7 ha, average field size is smaller than in Bobo Dioulasso and similar in size with those in Kano. Field crop production mainly serves home consumption, with little or no perceived contribution to the household economy. For income generation, 50% of Sikasso cLsC households rely on off-farm activities of both occasional and regular employment. This cluster thus represents rich livestock farmers that produce crops for home consumption.

### *3.1.3. Commercial gardening plus semi-commercial field cropping (cGscC)*

Like the previous two clusters, this cluster is also found in all three cities. In Kano, it comprises important market-oriented gardening activities combined with semi-subsistence field cropping. Average garden size is 841 $m^2$ (Table 2), but 57% of the households in this group cultivate smaller areas (100–500 $m^2$). Field size is rather small, with an average of 0.8 ha and 57% of the households in this group are not cultivating field crops at all. Garden activities are the main contributor to household income (93% of respondents), with no contribution from field cropping. Of the households, 43% obtain a low to moderate income from occasional off-farm employment and 14% from regular employment. In Bobo Dioulasso, this group cultivates gardens sized on average 737 $m^2$, but average field size is larger (2.4 ha) than in Kano. The largest contribution to household income originates from vegetable gardening activities, but unlike in Kano, a moderate to high contribution to income is obtained from field cropping activities. Only 3% of the households here earn a regular salary and 16% receive rather low earnings from occasional off-farm activities. The Sikasso households in this cluster cultivate on average larger gardens and crop fields than those in the other two cities, with areas averaging 2647 $m^2$ and 2.0 ha, respectively. In terms of income, market gardening contributes most for this group, supplemented by a moderate to high contribution from field cropping activities. Household involvement in occasional off-farm activities is moderate, but 25% of the households reported moderate to high income contributions from regular employment. In summary, this cluster comprises poor to well-off gardeners engaged in subsistence field cropping in Kano, and moderately resource-endowed gardeners engaged in semi-commercial field cropping in Bobo Dioulasso and in Sikasso, but the households in Bobo Dioulasso are more resource-limited than those in Sikasso.

### *3.1.4. Commercial gardening plus semi-commercial livestock (cGscL)*

This cluster is only found in Kano and can be characterized as a market-oriented garden cultivation system in which also some livestock is kept (69% of the households manage small ruminants, totalling 0.01–1.5 TLU). The average herd size of 2.5 TLU (Table 2) is not significantly different ($P>0.05$) from that of cGCL in Kano. Average garden size is 1004 $m^2$ and vegetable gardening contributes most to household income, supplemented by moderate to high contributions from livestock activities. Of the households in this group, 31% cultivate no garden, and 15% and 30% of the respondents reported to earn a regular salary and occasional off-farm income, respectively, which both provide a moderate contribution to household income.

This group represents resource-limited farmers, cultivating a small garden or none at all and keeping some livestock.

### *3.1.5. Commercial field cropping (cC)*

This cluster, cultivating only field crops, is only found in Bobo Dioulasso. Average field size is 1.8 ha (Table 2), with 64% of the households cultivating 1–3 ha. Field cropping evidently is an important source of income, providing the highest contribution to income for 71% of the households. Household income is supplemented by occasional off-farm employment (43% of the respondents) with a moderate to high contribution, but regular employment is found in 14% of the households only. This cluster thus comprises households endowed with a moderate area of crop land.

### *3.1.6. Commercial gardening (cG)*

Households in this group, found only in Sikasso, engage in market-oriented gardening. The vast majority (86%) cultivates one rather large garden, especially compared to households in the Kano cGscL cluster, with an average size of 2257 $m^2$. For 71% of the households the largest contribution to income originates from gardening, while 50% are engaged in occasional off-farm activities, generating moderate to high income contributions and 22% earn a moderate to high income from regular off-farm work.

This cluster may be classified as a moderately resource-endowed group, relying on engagement in off-farm activities to supplement household income.

## 3.2. Socio-economic characteristics of the UPA households

The differences in the socio-economic setting of the three cities have consequences for the social and economic structure of their UPA households (Table 3), which have varying access to agricultural resources.

### *3.2.1. Kano households*

Some socio-economic household characteristics such as the average age of the household head, varying between 48 and 55 years, are not significantly different ($P>0.05$) among the Kano clusters. The four clusters vary however in the length of the period with experience in UPA ($P<0.05$), but not in total number of members with

Table 3. Average values of socio-economic characteristics of households of the different farm types in the three West African cities studied.

| City | Farm type[1] | Age of household head (years) | Total household members (n) | Total educated members (n) | Total household members with off-farm employment (n) | | Farming experience (years) | Family labour [2] (n) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Regular | Temporary | | |
| Kano | cGCL | 48.2 | 12.4 | 4.9 | 0.5 | 1.7 | $32.9^{a}$ | 4.5 |
| | cLsC | 51.2 | 20.9 | 10.4 | 0.8 | 2.1 | $38.3^{ab}$ | 8.9 |
| | cGscC | 54.6 | 12.8 | 6.1 | 1.1 | 1.5 | $44.7^{b}$ | 5.9 |
| | cGscL | 49.2 | 9.9 | 5.4 | 0.8 | 1.4 | $38.4^{ab}$ | 4.4 |
| S.E.D [3] | | 1.5 | 1.3 | 0.7 | 0.1 | 0.3 | 1.5 | 0.5 |
| Sig [4] | | ns | ns | ns | ns | ns | ** | ns |
| Bobo Dioulasso | cGCL | $45.2^{a}$ | 7.1 | 2.8 | 0.1 | 0.7 | $34.7^{b}$ | 3.5 |
| | cLsC | $44.4^{a}$ | 7.5 | 2.5 | 0.4 | 0.5 | $20.6^{a}$ | 3.6 |
| | cGscC | $41.2^{b}$ | 9.0 | 2.3 | 0.13 | 0.6 | $16.3^{a}$ | 3.9 |
| | cC | $54.8^{b}$ | 9.2 | 2.4 | 0.21 | 1.3 | $16.4^{a}$ | 3.9 |
| S.E.D | | 1.4 | 0.5 | 2.6 | 0.1 | 0.1 | 1.5 | 0.2 |
| Sig | | ** | ns | ns | ns | ns | *** | ns |
| Sikasso | cGCL | $57.0^{b}$ | 21.4 | 9.6 | 1.8 | $5.6^{b}$ | $12.0^{abc}$ | 10.6 |
| | cLsC | $58.2^{b}$ | 20.6 | 7.6 | 2.4 | $1.3^{a}$ | $18.0^{cd}$ | 8.9 |
| | cGscC | $52.5^{b}$ | 13.8 | 7.6 | 1.6 | $2.3^{a}$ | $16.5^{c}$ | 6.6 |
| | cG | $40.5^{a}$ | 13.1 | 5.6 | 1.1 | $1.9^{a}$ | $7.8^{ab}$ | 5.8 |
| S.E.D | | 1.6 | 1.5 | 0.9 | 0.3 | 0.4 | 1.1 | 0.7 |
| Sig | | *** | ns | ns | ns | *** | ** | ns |

[1] cGCL = commercial gardening plus field crop-livestock, cLsC = commercial livestock plus subsistence field cropping, cGscC = commercial gardening plus semi-commercial field cropping, cGscL = commercial gardening plus semi-commercial livestock, cC = commercial field cropping, cG = commercial gardening.

[2] Family labour is calculated as manday equivalent (see text for explanation).

[3] S.E.D.: standard error of the differences per location.

[4] **, *** denote statistical significance at 0.05 and 0.01 probability, ns means not significant. $^{a,b,c,d}$ Within columns for each city, means with different letters are statistically different (Mann-Whitney U test).

formal education and total available family labour. Family size is smallest in the resource-limited households of cluster cGscL and largest in the rich livestock households of cluster cLsC, although the differences are not statistically significant (Table 3).

Engagement in off-farm activities is on average relatively low, and not statistically different among the clusters, but is lowest in the resource-limited households of cluster cGscL. The poor to well-off gardener households in cluster cGscC have longer experience ($P<0.05$) in UPA activities than the rich mixed farmers in cluster cGCL, but do not differ from the households in the other clusters. Partly due to their large family sizes, the availability of family labour is higher in the households of the rich livestock keepers (cluster cLsC) than in those of the other clusters. Formal education of the household heads varied significantly ($P<0.05$) within each cluster, but not across all clusters in the city (Table 4). Of the household heads in cluster cGCL, 14% had completed secondary education compared to 7% in cluster cLsC. For all households combined, 19% of the household heads completed primary or secondary formal education. The households surveyed in Kano belong to three ethnic groups, with 88% of the households belonging to the Hausa tribe, out of which 85% are involved in commercial gardening and field cropping activities (58% in cGCL; 13% cGcsL; 14% in cGscC). All the households in the cLsC cluster belong to the Fulani tribe (Fig. 4).

### *3.2.2. Bobo Dioulasso households*

Average age of the household heads varies between 41 and 55 years in the different clusters, with significantly ($P<0.05$) younger household heads in cluster cGscC than in cluster cLsC. Average household size, total number of educated members, average number of household members with off-farm income and total available family labour do not vary significantly among the clusters (Table 3). However, the rich mixed farmers of cluster cGCL have significantly ($P<0.05$) longer experience in UPA activities than those in the other clusters, which is different from the situation in Kano. The number of household members involved in off-farm activities is lowest in cluster cGscC.

Formal education levels of household heads are significantly different ($P<0.05$) among the clusters: for the commercial field crop farmers (cC), the highest education level of the household heads is primary education (Table 4), while 70% of the interviewed household heads have no formal education at all. The main

Table 4: Formal education of interviewed household heads of the different types of farm households in the three West African cities studied.

| City | Farm type[1] | n | Education (% of respondents) | | | |
|---|---|---|---|---|---|---|
| | | | None | Primary | Secondary | $X^2$ |
| Kano | cGCL | 58 | 72 | 14 | 14 | *** |
| | cLsC | 14 | 93 | 0 | 7 | *** |
| | cGscC | 14 | 93 | 0 | 7 | *** |
| | cGscL | 13 | 92 | 0 | 8 | *** |
| | Total | 99 | 81 | 8 | 11 | ns |
| Bobo Dioulasso | cGCL | 20 | 75 | 20 | 5 | *** |
| | cLsC | 46 | 65 | 26 | 9 | *** |
| | cGscC | 31 | 71 | 23 | 6 | *** |
| | cC | 14 | 71 | 29 | 0 | ns |
| | Total | 111 | 70 | 24 | 6 | ns |
| Sikasso | cGCL | 40 | 58 | 20 | 22 | *** |
| | cLsC | 8 | 25 | 38 | 38 | ns |
| | cGscC | 32 | 72 | 6 | 23 | *** |
| | cG | 28 | 68 | 14 | 18 | *** |
| | Total | 108 | 62 | 16 | 22 | ns |

*** Significant at $P \leq 0.01$, ns is not significant. Statistical difference is expressed within the farm types of each city. $Chi^2$ results are to be treated with care because of the low frequencies of some education levels.

[1] cGCL = commercial gardening plus field crop-livestock, cLsC = commercial livestock plus subsistence field cropping, cGscC = commercial gardening plus semi-commercial field cropping, cGscL = commercial gardening plus semi-commercial livestock, cC = commercial field cropping, cG = commercial gardening.

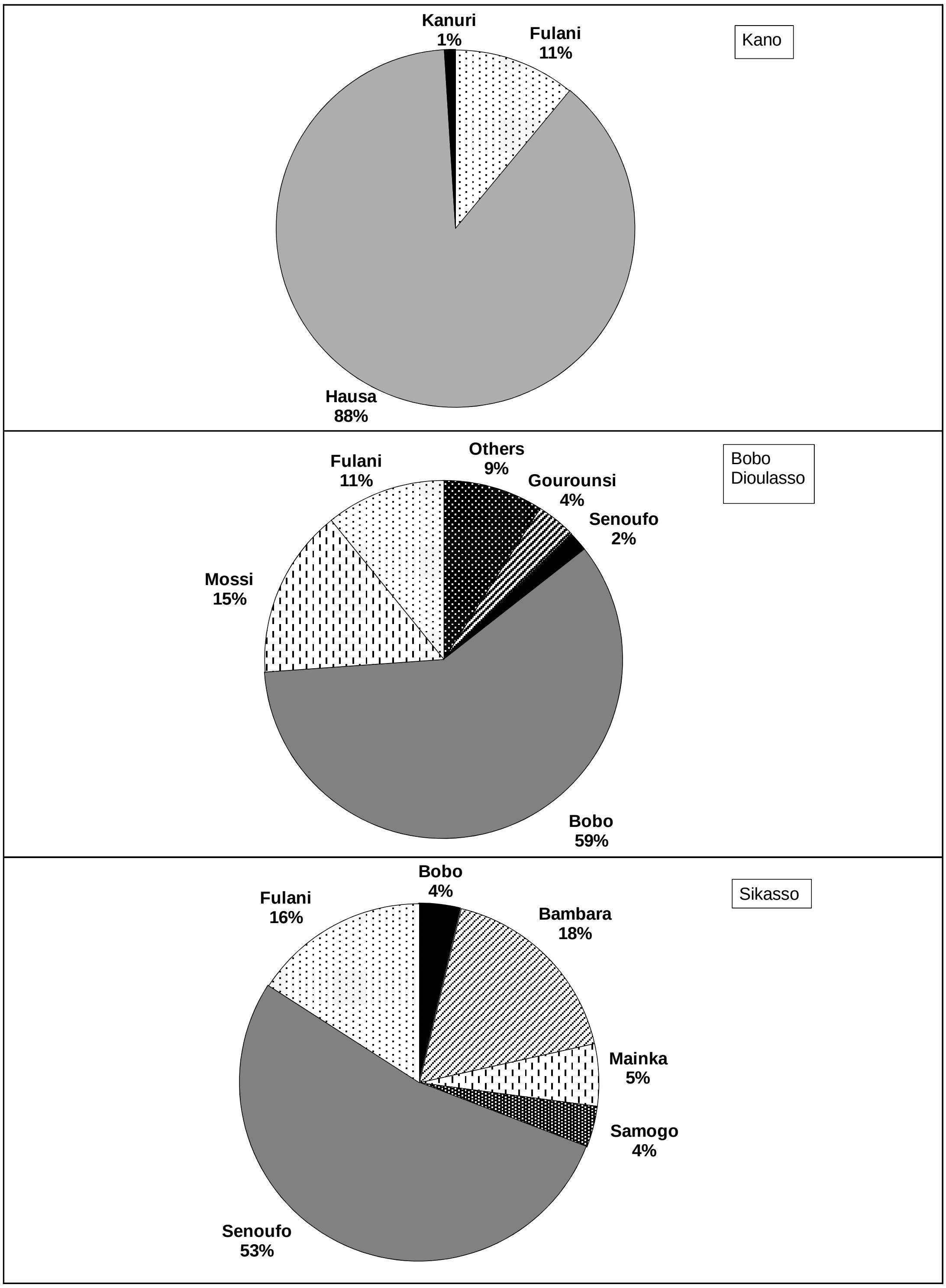

Fig. 4: Proportion of UPA farmers belonging to different ethnic groups in the three West African cities under study.

ethnic group is Bobo (59%). In this group about 51% of the activities constitute gardening and field cropping (18% in cGCL; 5% in cC; 28% in cGscC). The main ethnic group is then followed by Mossi and Fulani (Fig. 4), which have their activities predominant in the cLsC cluster.

### *3.2.3. Sikasso households*

Within Sikasso, the variability in socio-economic characteristics among the UPA households is larger than in the two other cities (Table 3). Average household sizes are the largest of the three cities, with the largest families in clusters cGCL and cLsC, although statistically not different from the cG cluster. Available family labour is highest in cluster cGCL, but the differences with the other clusters are not statistically significant. Within the clusters, statistically significant differences exist with respect to members with temporary or occasional off-farm income, age of the household heads and length of experience in UPA ($P<0.05$). Cluster cLsC is characterized by the highest proportion of members with regular off-farm earnings and household heads with the highest education.

However, 68% of the household heads in Sikasso have no formal education (Table 4). The dominant ethnic group of households is Senoufo (53%), out of which 50% (24%) in cGCL; 6% in cG; 20% in cGscC) are involved in commercial gardening and field cropping, followed by Bambara and Fulani (Fig. 4). The Fulani tribe is found in the cGCL cluster, which keeps large livestock herds, but diversifies into gardening and field cropping, unlike those in Kano. With the exception of the formal education level of the household heads, all socio-economic characteristics discussed above are significantly different ($P<0.05$) across the three cities.

## 3.3. Management practices in UPA gardens and fields

In the clusters that cultivate vegetables and field crops, households apply both organic and inorganic fertilizers in vegetable gardens and crop fields (Table 5). Inorganic fertilizers commonly used across all locations in crop cultivation are NPK compound fertilizers and urea at different application rates, either alone or in combination with organic fertilizers. Organic fertilizers commonly used are manure (Kano: 100% of the households, Bobo Dioulasso: 32%, Sikasso: 30%), compost and household waste (Sikasso: 49%, Bobo Dioulasso: 43%). Quantities applied are usually expressed in local units without reliable quantification during the baseline survey, thus only qualitative data were used for characterization. Use of mineral and organic inputs per

Table 5: Frequencies of application of specific farm management practices[1] by different farm types in the three studied West African cities.

| City | Farm type[2] | n | % that practice | | % that apply to garden | | % that apply to field | |
|---|---|---|---|---|---|---|---|---|
| | | | Field crop fallow | Garden crop rotation | Organic fertilizer | Mineral fertilizer | Organic fertilizer | Mineral fertilizer |
| Kano | | | | | | | | |
| | cGCL | 58 | 21 | 66 | 85 | 95 | 41 | 93 |
| | cLsC | 14 | 50 | - | - | - | 79 | 71 |
| | cGscC | 14 | 43 | 57 | 71 | 100 | 21 | 43 |
| | cGscL | 13 | - | 31 | 54 | 62 | - | - |
| Bobo Dioulasso | | | | | | | | |
| | cGCL | 20 | 5 | 100 | 85 | 90 | 55 | 95 |
| | cLsC | 46 | 15 | - | - | - | 85 | 52 |
| | cGscC | 31 | 7 | 97 | 90 | 93 | 36 | 45 |
| | cC | 14 | 36 | - | - | - | 79 | 50 |
| Sikasso | | | | | | | | |
| | cGCL | 40 | 10 | 70 | 98 | 75 | 30 | 70 |
| | cLsC | 8 | 13 | - | - | - | 88 | 88 |
| | cGscC | 32 | 9 | 72 | 97 | 41 | 13 | 53 |
| | cG | 28 | - | 61 | 93 | 71 | - | - |

unit area is higher in gardens than in fields, while more organic fertilizer is used on field crops by households owning more livestock (clusters cLsC in all three cities).

In vegetable gardens, land is predominantly prepared by hand (Kano and Sikasso: 100% of the respondents, Bobo Dioulasso: 73%) or by a combination of draught animals and hand-held implements (Bobo Dioulasso: 27%). Field preparation is done by hand (Kano: 98% of the respondents, Bobo Dioulasso: 20%, Sikasso: 48%), by draught animals (Kano: 2%, Sikasso: 43%), or their combination (Bobo Dioulasso: 74%, Sikasso: 9%) or by tractor-driven implements (Bobo Dioulasso: 4%). In all cities, field crops (Fig. 5) are cultivated mainly during the rainy season, predominantly maize (*Zea mays* L.), millet (*Pennisetum glaucum* (L.) R.Br.), sorghum (*Sorghum bicolor* L. Moench) and rice (*Oryza sativa* L.). Fallowing of crop fields is rare in all cities, but among households that use fallow in field cropping systems, 25–50% and even up to 100% of the total area under cultivation is left to fallow for one or two years. Crop rotation is intensive in the vegetable gardens due to the relatively short growing cycles of the vegetables. Gardens in all three cities are characterized by intensive year-round cultivation of vegetables in response to the economic opportunities they offer to farmers. Vegetables of temperate origin are mainly cultivated in the cool dry season between the months of October and February (Fig. 6). They include lettuce (*Lactuca sativa* L.), carrots (*Daucus carota* L.), cabbage (*Brassica oleracea* L.), onion (*Allium cepa* L.) and tomato (*Lycopersicum esculentum* Mill.). Cultivation may continue until the end of the dry season (May/June) and into the rainy season with vegetables better adapted to high temperatures, such as amaranthus (*Amaranthus* spp.) in Kano. The possibilities for year-round vegetable production depend on the availability of irrigation facilities in the dry months. Water is used from different sources, depending on the location of the gardens (Fig. 7). In Kano, all gardening households use a diesel or petrol pump to convey water to gardens from a variety of water sources. Wastewater irrigation is common in Kano, where most of the UPA gardens are situated close to waterways or rivers that flow through the city as discharge channels for municipal wastewater. Well water is more commonly used in Sikasso than in Bobo Dioulasso, but in both cities irrigation is predominantly done manually, using watering cans. Yet in Bobo Dioulasso, 22% of the respondents use irrigation pumps to fill up water basins near their gardens and later convey the water to the plots with cans.

## 3.4. Constraints to UPA in the three cities

Irrespective of cluster membership, major constraints identified in UPA across all three locations were similar. Prominent in garden and field cropping systems are the high costs of inputs, infestation of plants by pests and diseases and uncertainties in market conditions (Table 6). Moreover, the poor legal and institutional framework for land acquisition and UPA operations leads to uncertainty and risk. Land reforms oposed by the local planning authorities threaten the ownership of vegetable gardens of 6% of the gardening households in Kano and the ownership of crop fields of 6%, 19% and 2% of the farming households in Kano, Bobo Dioulasso and Sikasso, respectively. Shortages in irrigation water are a major problem in garden cultivation

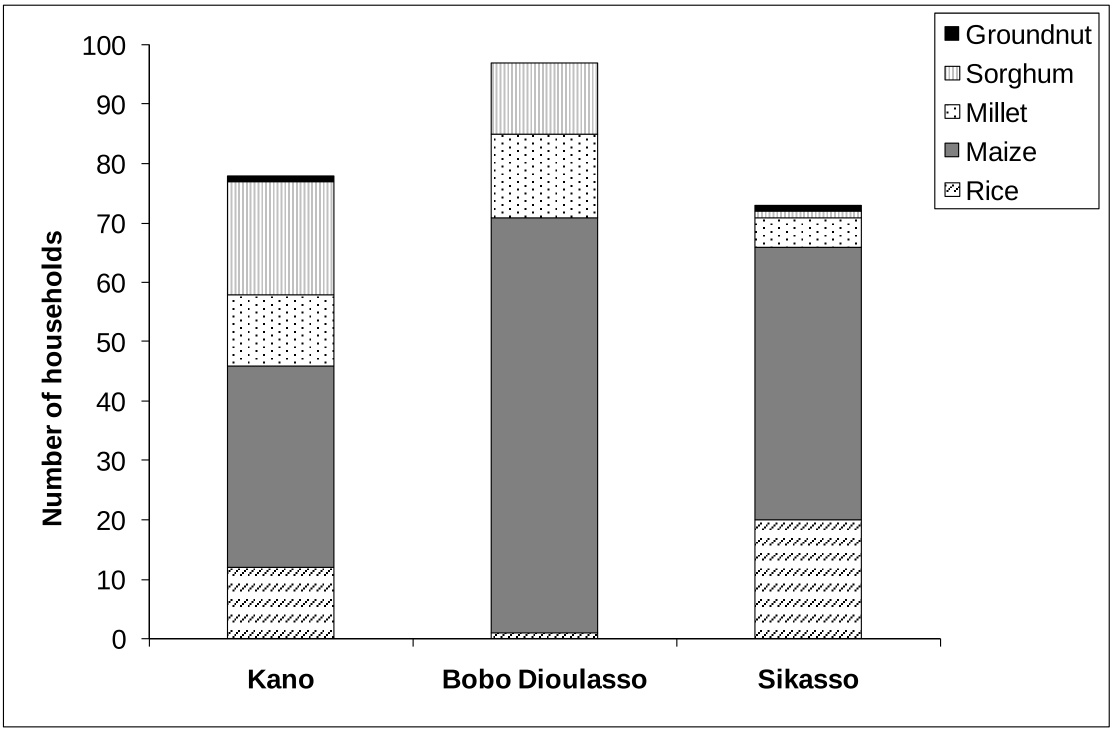

Fig. 5: Frequency of cultivating major field crops by surveyed households in the three West African cities.

in Sikasso and Bobo Dioulasso, especially at the peak of the hot dry season (March–May), when loss of crops appears to be frequent. Uncertainties in rainfall distribution, inadequate fertilizer supply and lack of financial sources constrain field crop production of many urban and peri-urban farm households.

Feed supply for animals is a major problem for livestock keepers, both in terms of purchasing costs and feed availability. Institutional support from the government for garden, field crop and livestock activities reaches 25%, 13% and 13%, respectively, of the interviewed households in Kano, 4%, 10% and 5% in Bobo Dioulasso and 10%, 7% and 67% in Sikasso. This support may take the form of subsidized fertilizer prices, livestock feed and veterinary medicines and services. Support from non-governmental bodies is poor in all cities, reaching only 1% and 2% of the households involved in livestock and garden activities in Kano and Bobo Dioulasso, respectively, and 9% and 1% of the households with gardens and crop fields in Sikasso. Support from cooperative groups is absent in Kano and Sikasso, but reaches 2%, 7% and 12% of the households having gardens, fields and livestock, respectively, in Bobo Dioulasso. This indicates the poor participation of these organizations in the support of UPA activities, although government support is relatively high for livestock activities in Sikasso.

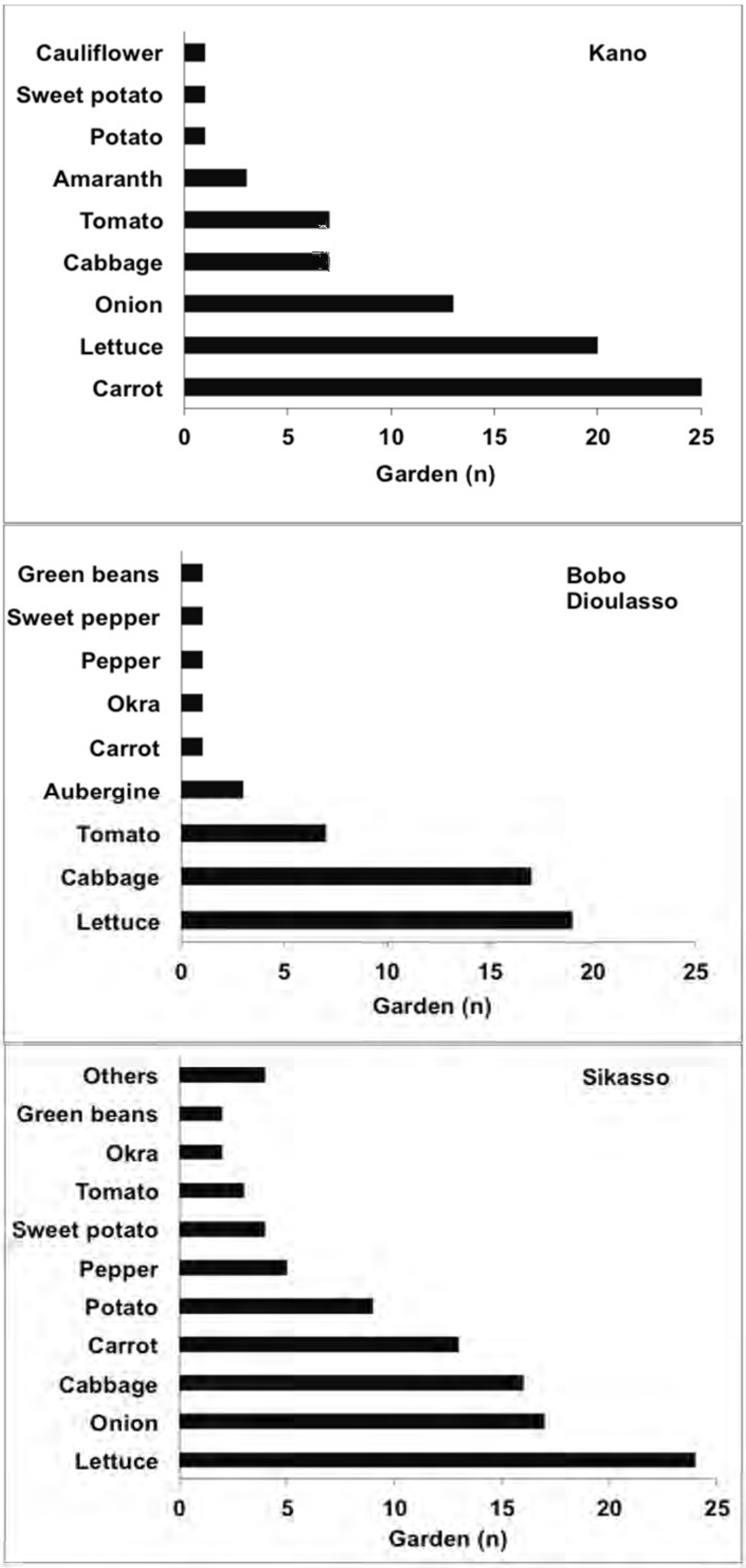

Fig. 6: Number of gardens in Kano, Bobo Dioulasso and Sikasso where different vegetables were grown in the cool dry season 2007/08 (October–February).

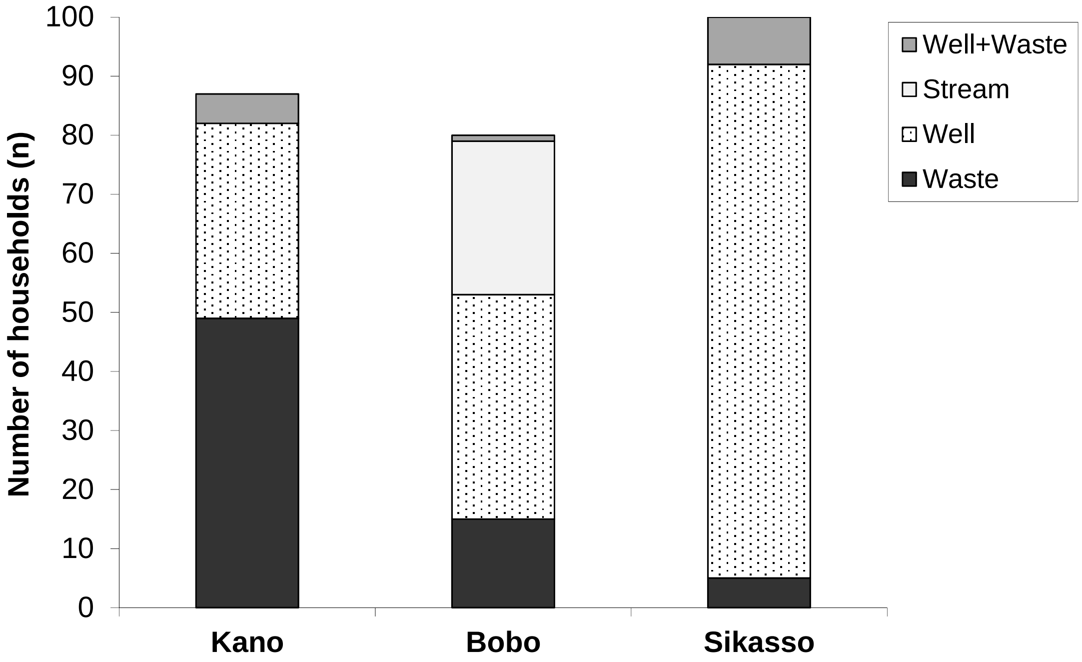

Fig. 7: Sources of irrigation water used for dry season cultivation of vegetables by households in the three West African cities.

Table 6: Major constraints to the three major urban and peri-urban agricultural activities in the three studied West African cities. Multiple answers were possible in some cases.

| Activity | Constraint | Proportion of respondents (%) | | | |
|---|---|---|---|---|---|
| | | Kano | Bobo Dioulasso | Sikasso | $X^2$ |
| Gardening | | (n=71) | (n=48) | (n=95) | |
| | High costs of inputs | 60 | 25 | 18 | *** |
| | Pest and disease incidence | 25 | 17 | 10 | *** |
| | Uncertain market conditions | 6 | 52 | 33 | *** |
| | Chemical pollution of irrigation water | 13 | - | - | *** |
| | Irrigation water shortage | 14 | 31 | 64 | *** |
| | Lack of finance | 4 | 13 | 1 | *** |
| | Lack of fertilizer | 1 | 21 | 10 | *** |
| | Land tenure system | 6 | - | 3 | *** |
| | Poor seed availability | - | - | 12 | *** |
| Field cropping | | (n=47) | (n=95) | (n=62) | |
| | Land tenure systems | 6 | 19 | 2 | *** |
| | High costs of inputs | 53 | 15 | 44 | *** |
| | Erratic rainfall | 11 | 23 | 5 | *** |
| | Lack of fertilizer | 2 | 30 | 2 | *** |
| | Lack of finance | 11 | 36 | 16 | *** |
| | Lack of mechanized equipment | 2 | 16 | 26 | *** |
| | Labor availability | 6 | - | 10 | *** |
| Livestock keeping | | (n=63) | (n=46) | (n=44) | |
| | Animal diseases | 22 | 22 | 48 | *** |
| | High cost of animal feed | 52 | 67 | 52 | *** |
| | Inadequate housing | 14 | 7 | 7 | *** |
| | Drinking water shortage | 10 | 22 | 11 | *** |
| | Limited access to grazing areas | 6 | 15 | 7 | *** |

***, Significant at P<0.01, $Chi^2$ results to be treated with care because of small number of observations (activity = 3) and low frequencies of some constraints.

# 4. Discussion

## 4.1. Socio-economic aspects of UPA systems

In general, urban and peri-urban agricultural systems in West Africa include livestock, gardening and field cropping activities, with the relative importance of each sector depending on ecological, social and household characteristics. Biophysical characteristics and socio-economic diversity of UPA activities are more contrasting in Kano than in Bobo Dioulasso and Sikasso. The latter two cities are agro-ecologically closer and share common ethnic and cultural features, but the Fulani tribe is present in all three cities and constitutes the large livestock keepers. UPA gardeners are more autochthonous and hail from the dominant ethnic groups in each city; Hausa in Kano, Bobo in Bobo Dioulasso and Senoufo in Sikasso. Autochthons are more inclined to commercial gardening and field cropping because they have relatively easier access to landholdings. Members from the Fulani tribe, who are mainly migrants/pastoralists, are traditionally involved in keeping cattle (Barry, 2005) and produce field crops on land leased from government in the peri-urban areas (Sodiya et al., 2009). They sell their livestock products, mainly dairy, to urban and peri-urban areas in response to the changing economic environment (Sodiya et al., 2009). Households may operate similar production systems and follow similar production orientations, but the interaction with variable and varying socio-economic factors results in variation in household livelihood strategies and farm management (Tittonell et al., 2010). Distribution of wealth in the different household clusters varies among cities and even within the different household types of one city. These differences further underline the need for site-specific description of UPA households. Livestock is generally managed in semi-intensive systems which involve grazing of cattle during the day, with the small ruminants roaming around the compounds and fed with cut fodder and purchased concentrates (Graefe et al., 2008). Land holdings for field crops are considerably smaller in Kano than in the other two cities. For garden plots, sizes vary from 100–500 $m^2$ (31%) and field sizes are <1 ha (58%) in the Kano UPA households, similar to the values reported by Binns and Fereday (1996) and Binns et al. (2003) for Kano. In densely populated Kano (Barau, 2006), these small garden sizes may be related to the traditional land tenure systems that are operating under a poorly defined legal structure where land fragmentation and transfer are commonly practiced (Lynch et al., 2001), while in Bobo Dioulasso and Sikasso more land is available in the less densely populated peri-urban areas. Land acquisition remains one of the major constraints to UPA activities because open-space cultivation occurs on public plots and threatens continuity and farmer’s investment in permanent farm structures. This could be addressed if it is incorporated into urban development plans that support UPA as advocated in several studies (Condon et al., 2010; De Bon et al., 2010).

While for the large-scale cattle owners the sale of milk constitutes a source of income (cluster cLsC), keeping small ruminants provides both tangible and non-tangible benefits (Berkhout, 2009). Livestock keeping may be more important though for the households in cluster cGCL in Sikasso who own considerably larger herds than those in Kano and Bobo Dioulasso. The combination of small livestock keeping and intensive gardening dominates in the urban centres, while extensive cattle rearing and field cropping are dominating in the peri-urban areas, creating a spatial gradient in the distribution of UPA production systems (Graefe et al., 2008). Livestock keeping provides an opportunity for soil fertility enhancement through the use of manure (Harris, 1998; Graefe et al., 2008). This holds particularly for cattle owners in all three cities who benefit from the manure in their field cropping activities, and which provides an avenue for nutrient cycling for this UPA farm type.

Diversification into off-farm income-generating activities, i.e. temporary or more permanent engagement in petty trading, driving commercial vehicles, or as night watch men, was low among the West African UPA households interviewed when compared to rural smallholder farmers in East Africa (Tittonell et al., 2005; Tittonell et al., 2010) and other UPA systems in developing countries (De Bon et al., 2010). For urban gardeners in Nairobi and Kumasi, UPA activities served as a supplementary income generation strategy to regular, but low income salary earners (Mwangi, 1995; Asomani-Boateng, 2002). Hence, these West African urban households, especially those in clusters cGscL and cGscC, are highly dependent on UPA which serves as their main source of cash income. Household head formal education level does not have a significant effect on the diversification into the different UPA activities, but it has, to some extent, on off-farm income generation. Household heads with a higher education tend to be more often employed in a more permanent position. This reflects that the UPA sector still remains largely an informal one.

Male farmers dominated the UPA activities in our survey. A few female-headed UPA household heads were encountered in Bobo Dioulasso and Sikasso, but female involvement in gardening and field cropping was completely absent in the Kano households. This reflects the traditional and religious role of the male gender in the household responsibilities in Kano, as in other parts of West Africa (Asomani-Boateng, 2002). This contrasts with the female participation in farming activities in other parts of sub-Saharan Africa, even though female participation in UPA is more pronounced in marketing than in gardening activities in many parts of Africa (Keraita et al., 2002; Asomani-Boateng, 2002). This also holds for the female household members in Kano who engage more in commercial poultry production and marketing of meat and eggs (Barau, 2006), as well as in other non-agricultural income generating activities such as tailoring, knitting and trading, but mostly in the homestead, which reflects the role of women in society (Rain, 1997).

## 4.2. Nutrient management in UPA sectors

In general, intensive use of organic and inorganic fertilizers in gardening and cropping is found in most UPA systems, with higher use of both types of fertilizers in the garden plots than in the crop fields (Table 5), probably because of the rapid returns from gardening, characterized by short-duration vegetables (Keraita et al., 2002). The more intensive use of organic and inorganic fertilizers in Bobo Dioulasso and Sikasso may be associated with the smaller proportion of households using waste water for irrigation compared to Kano. Sources of organic fertilizer vary, but the use of household waste and compost is similar in Bobo Dioulasso and Sikasso, and higher than in Kano. In the latter city, more manure is used, which is associated with higher access to animal dung (Harris, 1996; Binns et al., 2003) as well as with the deteriorating quality of the available urban waste, as shown in a recent study (Abdu et al., 2009). This is in contrast with the intense use of urban waste in Kano in the 1990s, and reflects that the declining waste availability and quality is also perceived by farmers (Lewcock, 1995). More intensive use of urban waste in Bobo Dioulasso and Sikasso may be related to the local governments' initiatives with respect to proper waste management, such as its sorting for better quality organic material for use in peri-urban agricultural systems (Eaton and Hilhorst, 2003). Promoting the concept of urban waste re-use in UPA will require more commitment of city officials to proper waste management in Kano as well as other African cities (Asomani-Boateng and Murray, 2010). Annual nutrient surpluses for urban and peri-urban gardens can be high, as reported for Vietnam (per hectare: 85–882 kg N, 109–196 kg P and 20–306 kg K; Khai et al., 2007), even if the systems rely solely on nutrient inputs through irrigation water, as reported for urban gardening systems in Niamey (2,427 kg N, 376 kg P and 1,439 kg K per hectare and year; Diogo et al., 2010a). Hence, heavy irrigation with waste water or municipal effluents, characteristic for many UPA systems, could fully meet the nutrient requirements of crop production (FAO, 2010b), although some urban gardeners only consider these effluents as a source of water and do not take into account the input of nutrients (Keraita et al., 2002). Another environmental and human health implication of waste water irrigation in UPA is the risk associated with heavy metal accumulation in soils (Mapanda et al., 2005; Abdu et al., 2011a) and contamination of food by microbial pathogens (Amoah et al., 2007; Diogo et al., 2010a). The heavy industrialisation of Kano has led to uncontrolled discharge of chemical effluents in the running streams used for irrigation (Binns et al., 2003). Respondents from Kano therefore reported chemical pollution of irrigation water as a constraint to crop and vegetable production.

Integration of one or more production systems is less common in the UPA setting than in rural agriculture, therefore the production of vegetables, field crops and livestock are taken as separate entities. Consequently, several attempts have been made to classify African UPA systems based on one or more criteria. Classifications were based on market orientation (Drechsel et al., 2006), location of activities (Asomani-Boateng, 2002), indigenous vegetables (Pasquini et al., 2010), main crops produced and cultivation practices (Kessler, 2003) or on multiple criteria, as described by Veenhuizen and Danso (2007). Vagneron et al. (2002; cited by Veenhuizen and Danso 2007) identified some production systems similar to those found in this study, but the systems were not characterized together with their production orientation and resource endowments as reported here. In their review, De Bon et al. (2010) highlighted some attempts towards farm typology related to socio-economic characteristics of UPA farmers. The present study provides a more detailed socio-economic profile of the UPA households, as well as UPA's diverse roles across the farm types.

Considering the diversity in management across the farm types and cities allows us to draw conclusions on the production strategies of these systems. Under livestock production, especially in cLsC, scavenging and grazing of livestock provides a cost-effective feeding strategy and ensures supply of manure for cultivating fields and the judicious cycling of nutrients, and a sustained productivity of pastures from animal excretions on pasture lands. This type of production system (scavenging), also found among the livestock keepers of cGCL and cGscL farm types, is often accompanied by improper manure handling and unrestricted dropping of faeces and urine on to urban surroundings which poses potential environment risks (Budisatria et al., 2007). Although much emphasis has been given on benefits associated to the use of organic and inorganic fertilizers in crop production, improper management may have an indirect effect on environmental quality as is the case with intensive market-oriented gardening households across all locations. High input of nutrients, characteristic of UPA systems, is often accompanied by nutrient leaching together with gaseous losses of nitrogen and carbon with detrimental environmental effects (Schröder et al., 2004). This aspect should be given more consideration in Kano where UPA farmers rely more on waste water irrigation in addition to other sources of nutrients, and where studies have shown a high concentration of cadmium and zinc in the waste water used for cultivation and its presence in vegetable crop parts (Abdu et al., 2011b). Similarly, wastewater use may lead to heavy metal build up in soils under contaminated waste water irrigation (Mapanda et al., 2005) although it has been shown that heavy metal build up in UPA soils is not always related to waste water irrigation (Witzling et al., 2010). Sustainability aspects of UPA have been highlighted in several studies (Veenhuizen and Danso 2007; De Bon et al., 2010). Depending on what aspect of sustainability we consider, the multifunctional role of UPA is crucial to the livelihood of the farming households in the different farm types and for the society at large. This renders the practices to be economically buoyant in their operational social settings but current management practices pose a trade-off with environmental quality and food safety (Vagneron, 2007). With the wealth of literature on UPA, efficient dissemination of research findings to stakeholders is a first step towards a more sustainable and economically viable UPA. This can only be achieved when government and other stakeholders formally recognise UPA activities in their constitutional domain (Dubbeling et al., 2010; Masson-Minock and Stockmann, 2010).

## 5. Conclusions

The study identified six different urban and peri-urban farm types across Kano, Bobo Dioulasso and Sikasso, three cities in West Africa with contrasting characteristics in terms of resource endowments, production orientation, farm management and socio-economic characteristics. Across the three cities, the households in Bobo Dioulasso and Sikasso are characterized by similar socio-economic conditions, farm management practices and production constraints, which differ from those for households in Kano, although for commercially-oriented gardening activities, production constraints were similar for all three cities. Irrespective of the clusters and cities, UPA activities remain an informal sector, owing to the limited formal education of the household heads and political disregard of the sector, but represent the major source of income generation for households involved. Few households diversify into non-farming activities to supplement household income. Where the urban and peri-urban agricultural sector is disadvantaged by lack of institutional and legal frameworks, high costs of inputs, limited access to credit, land and water, and at the same time bearing various environmental and health risks, policy measures at the municipal and/or national level should be taken to alleviate such constraints. Household characterization is a relevant tool to gain insight into the diversity of UPA systems, associated management decisions and livelihood contribution. This insight should serve as a starting point for formulation of an operational institutional framework that addresses site- and system-specific constraints and risks hampering the evolution of the UPA sector. This household characterisation also provides the basis for further studies of specific systems for in-depth analysis of UPA management-related issues on food safety and environmental challenges.

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# Chapter 4

# Nutrient flows and balances in urban and peri-urban agroecosystems of Kano, Nigeria

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## Abstract

Nutrient balances are useful indicators to assess the sustainability of farming systems. The approach investigates inflow and outflow of major nutrients in agricultural production systems. In this paper, 16 households representing three different urban and peri-urban (UPA) farming systems were studied using the MONQI toolbox (formerly known as NUTMON) to calculate nutrient flows and economic performances. The farm nitrogen (N) balance was positive at 56.6, 67.4 and 56.4 kg farm$^{-1}$ yr$^{-1}$ for commercial garden and crop-livestock (cGCL), commercial gardening and semi-commercial livestock (cGscL) and commercial livestock subsistence field cropping (cLsC) farm types, respectively. The same trend was observed for phosphorus (P) and potassium (K) in all farm types except an annual negative K balance of 16 kg farm$^{-1}$ in cGCL. Across the different activities within the farms, land uses had positive N (359, 387 and 563 kg N ha$^{-1}$ yr$^{-1}$) and P (74, 219 and 411 kg P ha$^{-1}$ yr$^{-1}$) balances for all farm types, but again a negative K balance in cGCL with an average loss of 533 kg K ha$^{-1}$ yr$^{-1}$. Partial nutrient balances in livestock production indicated a positive balance for all nutrients across the farms types but were slightly negative for P in cLsC. Commercial livestock keeping (cLsC) was economically more profitable than the other farm types with an average annual gross margin (GM) and net cash flow (NCF) of \$9033 and \$935. Cropping activities within cGCL and cGscL had GMs (\$1059 and \$194) and NCFs (\$757 and \$206), respectively, but livestock activities in both farm types incurred financial losses. Potassium inputs were limited under vegetable and crop production of cGCL, threatening long-term K nutrient availability in this system. Overall, the results indicated large annual surpluses of N and P in urban and peri-urban vegetable and crop production systems which pose a potential threat when lost to the environment. Appropriate policies should aim at promoting sustainable production through efficient nutrient management in the Kano UPA sector.

**Keywords**: MONQI, NUTMON, sustainability, farm management, production systems, farm types.

# 1. Introduction

Urban and peri-urban agricultural (UPA) activities have been expanding for the past decade in response to the growing city population in sub-Saharan Africa (Cofie et al., 2003). This has led to land use changes of undeveloped city land and grounds in the peri-urban areas for vegetable and food crop production in addition to keeping livestock within inhabited areas. It provides additional employment opportunities to the urban farmers (Asomani-Boateng, 2002) and these UPA production systems ensure fresh supply of vegetables (10-90%), meat (up to 70%), eggs (90-100%) and others such as fruits, milk and fish to local markets of some cities (Madelano, 2000; Smith, 2001; Cofie et al., 2003; Drechsel et al., 2005b). Commercial-oriented open-space vegetable cultivation is very common in many urban cities in West Africa (Keraita et al., 2002). Because of the intensive nature of these UPA systems, they imply extensive use of urban resources for vegetable and crop production and may involve large inputs such as urban solid wastes, animal manures and municipal water loaded with domestic and industrial wastes (Binns et al., 2003; Drechsel et al., 2005b). Continuous use of inputs such as wastewater with high concentrations of heavy metals as a consequence of industrial discharge increases the risks of recycling toxic elements back into the system or human food chain (Binns et al., 2003). Mobility of heavy metals and subsequent contamination of vegetables was assessed in irrigated vegetable systems in Kano (Abdu et al., 2010) and the risk of potential heavy metal build up in soils occurred under wastewater vegetable production (Mapanda et al., 2005). High levels of faecal pathogens in wastewaters increase risks of translocation into vegetables meant for consumption. Contamination of vegetables with faecal pathogens has been reported from the use of urban wastewater for irrigation in Kumasi and Niger (Drechsel et al., 2008; Diogo et al., 2010a). Incidence of pathogens is also associated with shallow ground water as a result of wastewater irrigation (Foppen et al., 2008), and with other health-related issues such as anaemia, worm infestation and skin-related problems (Hunshal et al., 1997). Nutrient balance studies have been used widely as indicator to assess the sustainability of an agricultural production system. There are several definitions of sustainability and a wide array of sustainability indicators exists but the most commonly used indicator in land use studies is the nutrient balance (Jansen et al., 1995; Eckert et al., 2000). According to Pearce and Turner (1990, cited by Jansen et al., 1995) “sustainability involves maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time”. To ‘maintain’ the quality of the natural resource, short term studies on quantifiable indicators (nutrient balances) are used to project long term consequences. This projection may be scale-dependent, and assessing nutrient balances at farm-level provides good information and understanding of on-farm nutrient management. Calculation of nutrient balances involves assessing the difference between total nutrient inflow and outflow of farm production systems. Such flows could be management-related, e.g. inflows through organic and inorganic fertilizers/feed and outflows as harvested products and residues as well as animal products and manures. Some nutrient flows are losses to the environment, such as leaching, volatilization and erosion which are estimated based on empirical relations otherwise known as transfer functions (Stoorvogel and Smaling, 1990; Lesschen et al., 2007). A farm nutrient balance is calculated when the management and environment-related flows are considered simultaneously. The NUTMON toolbox (now called MONQI), a static model that calculates nutrient flows and economic performance of tropical farming systems, has been widely applied in several nutrient balance studies (De Jager et al., 1998; Van Den Bosch et al., 1998b; Van Beek et al., 2009). In contrast to a major crop-based full nutrient balance study that indicated alarming rates of soil fertility decline in sub-Saharan Africa (Stoorvogel and Smaling, 1990), nutrient balance studies under intense UPA systems indicate large positive balances (Hedlund et al., 2003; Huang et al., 2007; Diogo et al., 2010a). In Niger for example, annual partial balances were as high as 1133 kg N ha$^{-1}$, 233 kg P ha$^{-1}$ and 312 kg K ha$^{-1}$ for vegetable production and 126 kg N ha$^{-1}$, 20 kg P ha$^{-1}$ and 0.4 kg K ha$^{-1}$ for millet fields (Diogo et al., 2010a). Similar positive partial balances were observed for peri-urban vegetable production systems in Vietnam (Khai et al., 2007) and in China (Wang et al., 2008).

It has been suggested that the application of the NUTMON/MONQI toolbox could be limited to the management-related flows in urban and peri-urban vegetable-based systems where nutrient limitation is not a prevailing situation. This would provide a quick diagnosis of farmers’ nutrient management strategies to support decisions related to nutrient use (Van den Bosch et al., 2001). Nevertheless, intensive nutrient input in UPA vegetable, crop and livestock production poses both short and long-term environmental risks (Wolf et al., 2003). The diversification of UPA in production systems and orientation (Dossa et al., 2011) warrants that nutrient balance studies cannot be limited to the plot-level nutrient flows due to the existing interactions between system compartments (crop-livestock-environment) within the farm. In this study, we adapted the NUTMON/MONQI framework to evaluate the effect of the use of resources on both biophysically-related and economic flows. The specific objective is to quantify the nutrient flows in the urban and peri-urban agroecosystems in Kano, Nigeria, to evaluate the systems’ sustainability and associated environmental impacts.

# 2. Materials and methods

## 2.1. The study site

Kano municipality is located in the northern part of Nigeria (Fig. 1), covers a total land area of 550 km$^2$ (Tiffen, 2001) and centres around latitude 12$^o$00’N and longitude 8$^o$31’E. It harbours a population of 3.14 million according to the last country census (NPC, 2006; UNUP, 2007). The climate is semi-arid and dry most of the year (from October to May) with a marked rainy season distributed over a five months period from May to September with average annual rainfall of 750 mm (2007–2009) as measured at the weather station of the Institute for Agricultural Research sub-station in Kano. Maximum day temperature is about 38 °C in the hot dry months of March to May and can be as low as 22 °C during the cool dry season between November to February. The soils are predominantly sandy loam in texture with poor fertility (Jones, 1973) and are ferruginous tropical soils formed from basement complex rocks (Jones and Wild, 1975) classified as Nitosols/Ultisols (FAO/UNESCO, 1974).

Kano UPA is characterized by intensive urban vegetable cultivation and livestock keeping, especially of sheep and goats, within the city’s residential areas. Cattle keeping is found more in the peri-urban areas. Sometimes vegetable cultivation occurs in low-lying ‘fadama’ soils which are hydromorphic in nature. The main river that flows through the city is the Jakara river. It lies on the northern part of the city and has main tributaries from different parts of the city. During the dry season, the water is almost entirely made up of municipal sewage and industrial effluents (Bichi and Anyata, 1999). Substantial vegetable production takes place on upland soils along the river side (Dawaki et al., 2010) which serves as a source of water for dry season cultivation while well water or stagnant city waste water serves farms that are located further away. Irrigation water is usually conveyed with irrigation pumps.

## 2.2. UPA farm types and farm selection

A total of 16 households involved in UPA activities with different production orientation, resources and farm management were selected for this study (Table 1), based on a classification of the households (Abdulkadir et al., 2012; Dossa et al., 2011). Households were selected to represent the farm types and within each farm type the selected households represent the average and minimum resource endowment in the different production systems that represent the diversity of the UPA in Kano. The classification revealed that households pursue a mixture of activities including

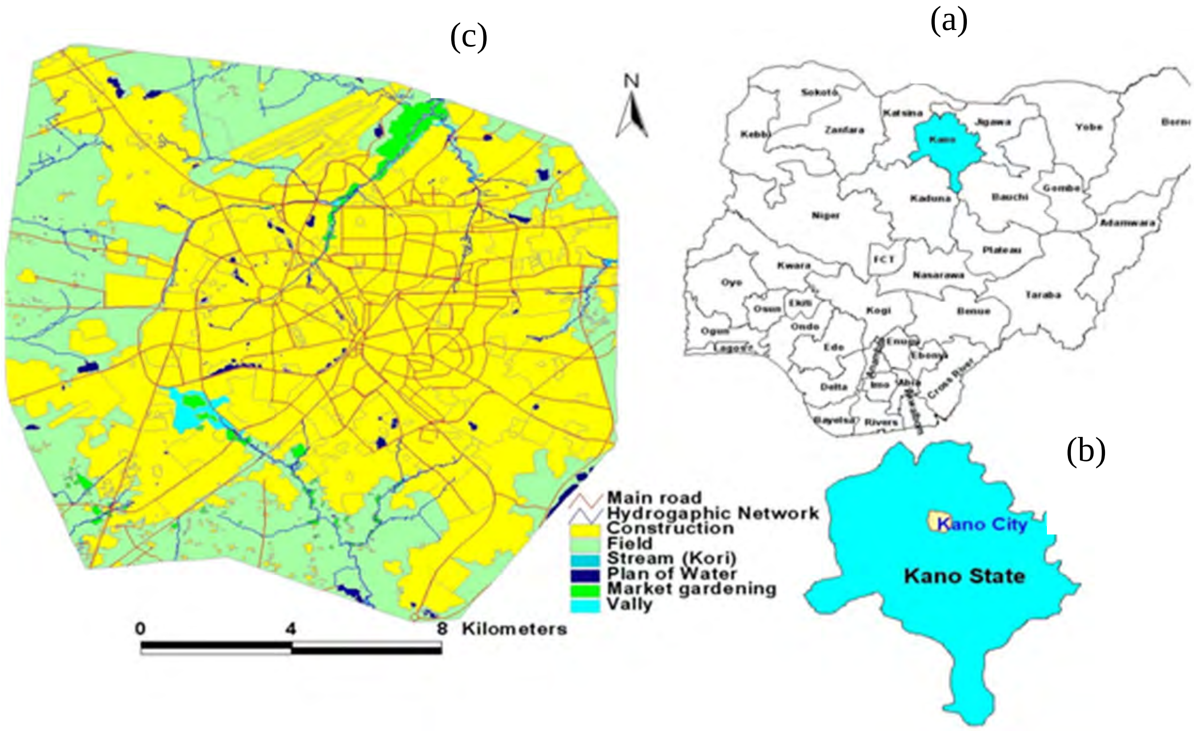


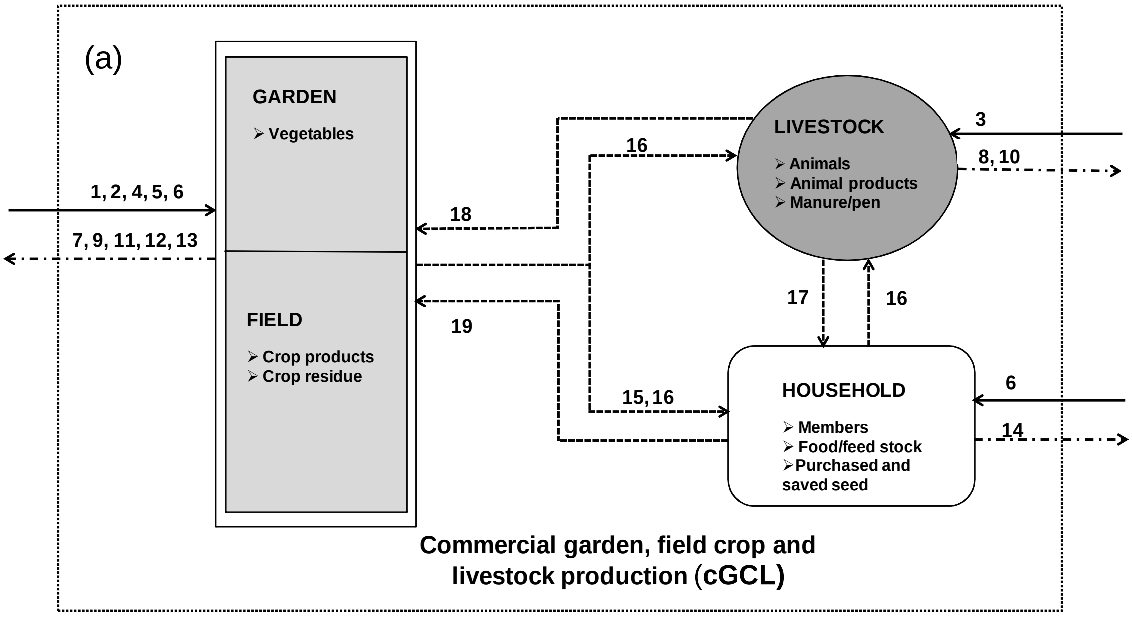
Fig. 1: Map indicating the location of the study site in Nigeria (a), within Kano State (b), and detailed map of Kano city (c).
Source: Ibrahima Kadaouré, Catographie -GPS-GIS-Télédétection institute, Niamey, Niger.

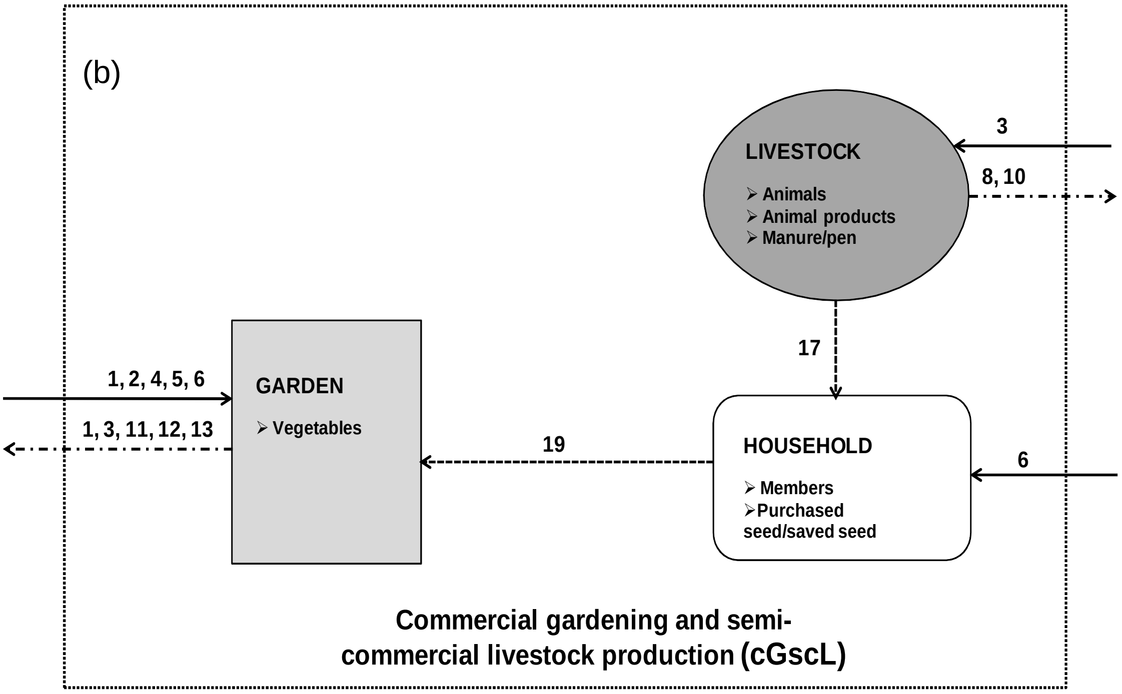
gardening, field cropping and livestock keeping in farm type cGCL, gardening and livestock keeping in cGscL, and livestock keeping together with or without field cropping in cLsC (Fig. 2a-c). Livestock and garden activities were not integrated in cGscL farms, but were separate activities (Fig. 2b) i.e., households within this farm type either kept livestock or were engaged in gardening. This was because households engaged in mixed gardening-livestock keeping within the farm type had no livestock during monitoring due to death, slaughter and sale; as a result, only the garden component was monitored. In cLsC, only two households cultivated field crops.

Table 1: Description of the selected farm types studied.

| Name of farm type | Acronym | n[1] | Description |
|---|---|---|---|
| Commercial garden, field crop-and livestock production | cGCL | 6 | Market-oriented year-round vegetable production and seasonal field crop cultivation usually on small plots and fields; mainly small ruminants are kept. |
| Commercial gardening and semi-commercial livestock production | cGscL | 6 | Market-oriented year-round intensive vegetable production, usually on small plots. Some of the households either keep small ruminants or cultivate garden crops. |
| Commercial livestock and subsistence field crop production | cLsC | 4 | Market-oriented cattle production usually on a large scale together with small ruminants; seasonal cultivation of field crops for subsistence. |

[1] number of studied households in each farm type.


(a)
GARDEN
➢ Vegetables
FIELD
➢ Crop products
➢ Crop residue
LIVESTOCK
➢ Animals
➢ Animal products
➢ Manure/pen
HOUSEHOLD
➢ Members
➢ Food/feed stock
➢ Purchased and saved seed
1, 2, 4, 5, 6
7, 9, 11, 12, 13
18
19
16
15, 16
17
16
3
8, 10
6
14
Commercial garden, field crop and livestock production (cGCL)


(b)
LIVESTOCK
➢ Animals
➢ Animal products
➢ Manure/pen
3
8, 10
17
GARDEN
➢ Vegetables
HOUSEHOLD
➢ Members
➢ Purchased seed/saved seed
1, 2, 4, 5, 6
1, 3, 11, 12, 13
19
6
Commercial gardening and semi-commercial livestock production (cGscL)

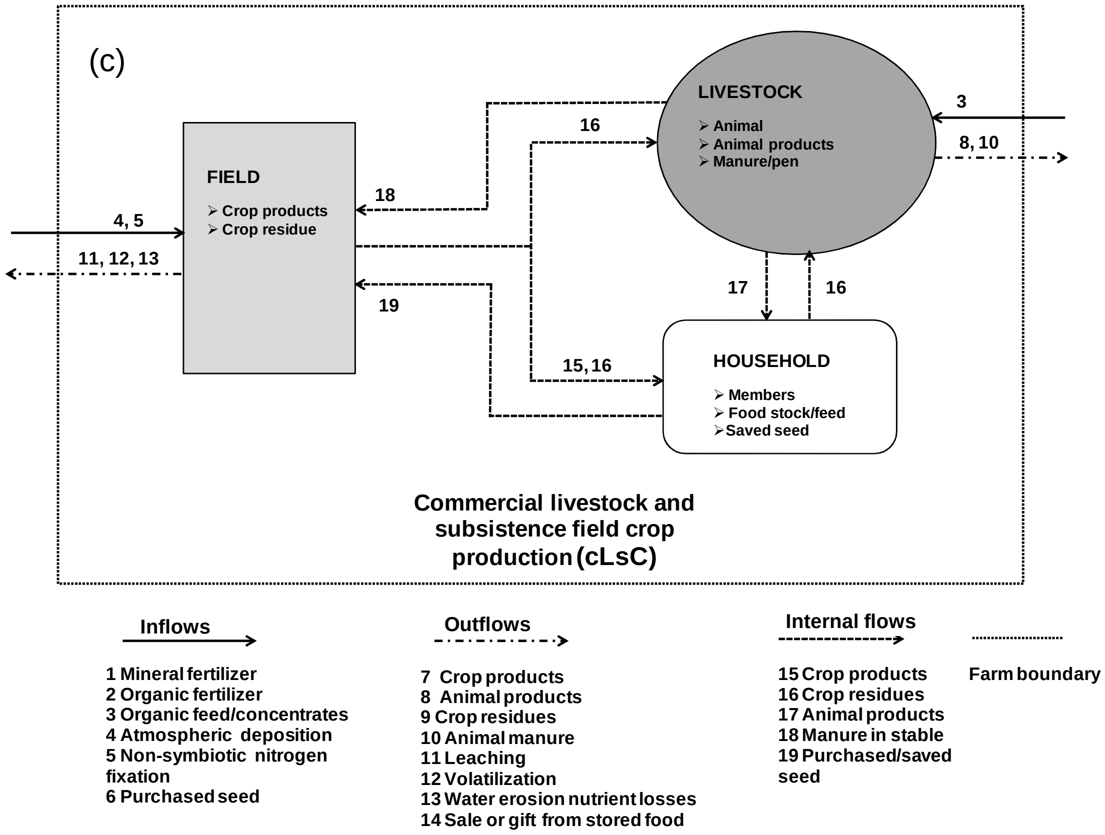


Fig. 2 (a-c): Schematic representation of nutrient flows in the three farm types (a: cGCL; b: cGscL; c: cLsC) studied. In cGscL, purchased seed is stored for future use.

## 2.3. Description and application of MONQI

The NUTMON toolbox has been widely and successfully applied to nutrient balance studies across different farming systems and was thus applied in the current study. The Monitoring for Quality Improvement (MONQI) currently represents a follow up of the NUTMON methodology and aims to improve the quality of farm management, crop production, environmental conditions and livelihood standard of small scale farming enterprises in its monitoring approach (www.monqi.org). Output generated from the MONQI software ranges from nutrient balances to economic performance for individual farms and farm compartments, i.e. individual activities in the farm enterprise, separated into land (LA, formerly referred to as primary production unit; PPU), animal activity (AA, formally secondary production unit; SPU), redistribution activity (RA, formerly RU), stock activity (SA, formerly Stock) and household/human activity (HA, formerly HH). It also provides an integrated monitoring of the financial performance of an agricultural enterprise as a starting point to evaluate the socio-economic status and general biophysical conditions operating in a farming system. Just as with the NUTMON methodology, it makes use of a set of questionnaires, manuals and the software in the overall approach and has related sets of flow variables that were adapted for this study (Table 2). Inputs through mineral fertilizer (IN1), organic fertilizer (IN2), animal feed (IN3) and purchased seed (IN6) into the farm, as well as outputs of harvested crop (OUT7 and 9) and animal products (OUT8) represent flows that are easy to identify and manipulate by the farmer. For the calculation of the full balance, the default settings of the software (MONQI version 7.7) makes use of spatially explicit empirical relationships or transfer functions (Lesschen et al., 2007) for estimating the environmental flows (see section 2.3.1). These include nutrient inflows via atmospheric deposition (IN4) and biological nitrogen fixation (IN5) and outflows through leaching (OUT11), gaseous losses (OUT12) and erosion (OUT13). These equations were revised after those in the NUTMON software were criticized for overestimation of these outflows (Faerge and Magid, 2004). Sedimentation was not considered in our study because the studied plots are on flat land, but nutrient inputs through wastewater irrigation were registered. Inflows through deep capture or sub-soil exploitation of nutrients obtained from beyond 1 m depth by deep-rooted crops, as well as outflows of human excreta formerly present in NUTMON do not exist in MONQI. Internal flows are considered to remain within the farm boundary but occur between farm compartments or sub-systems. Partial balances result from processes and flows that are managed by the farmer and are calculated as the difference between mineral and organic inputs (fertilizers and feed) as well as outputs via farm products. Full balances include both the manageable flows and those that the farmer cannot directly manipulate (also referred to as environmental or hard-to-quantify flows, and usually obtained from literature). As opposed to NUTMON, MONQI output does not take account of the internal flows. This has to be considered manually, taking into account nutrient flow destination within and outside of the farm to report the farm balances. Changes in soils' nutrient stocks were calculated from the resulting nutrient balances similar to methods used by Van den Bosch et al. (1998b) and Kante et al. (2007). The model has a user-friendly interface that allows easy data entry, and organizes data on farm management in a structured way to facilitate analysis and data interpretation of individual farm reports or a group of farms (MONQI, 2007). Explanation of the MONQI financial calculation rules for the economic indicators is given in the MONQI manual (MONQI, 2007).

Table 2. Nutrient input, output and internal flow acronyms for data required and quantification methods adapted in this study.

| Acronyms | Flows (kg) | Quantification method | Estimated accuracy |
|---|---|---|---|
| *Inflows* | | | |
| IN1 | Mineral fertilizers | Asking the farmer on amount and type applied | ++ |
| IN2 | Organic fertilizer including waste water nutrient input | Asking the farmer and on-farm measurements | ++ |
| IN3 | Organic feed/concentrate | Asking the farmer on quantity offered and type | ++ |
| IN4 | Atmospheric deposition | Transfer functions in model, on-farm measurements | + |
| IN5 | Non-symbiotic nitrogen fixation | Transfer functions in model | −+ |
| IN6[1] | Purchased seed | Asking the farmer | ++ |
| *Outflows* | | | |
| OUT7 | Crop products leaving the field | Asking the farmer and on-farm measurements | ++ |
| OUT8 | Animal products leaving farm | Asking the farmer | ++ |
| OUT9 | Crop residue leaving the field | Asking the farmer and on-farm measurements | ++ |
| OUT10 | Produced animal manure | Asking the farmer, on-farm measurements and literature | −+ |
| OUT11 | Leaching from land use activity | Transfer functions in model | −+ |
| OUT12 | Gaseous losses from soils, fertilizers and manures in land uses | Transfer functions in model | −+ |
| OUT13 | Water erosion losses | Transfer functions in model | −+ |
| OUT14 | Outflow from food stock | Asking the farmer | ++ |
| *Internal flows* | | | |
| INT15 | Produced crop products | Asking the farmer | ++ |
| INT16 | Crop residue | Asking the farmer | ++ |
| INT17 | Animal products | Asking the farmer | ++ |
| INT18 | Animal manure for redistribution | Asking the farmer | ++ |
| INT19[1] | Saved seed | Asking the farmer | ++ |

See section 2.3.1 for transfer function used based on fertilizer, soil and rainfall data. ++, +, −+ denotes high, medium and low accuracy levels, respectively, based on expert knowledge.

[1] Nutrients from purchased and saved seed are registered as organic input in the model.

### 2.3.1. Quantification of nutrients in UPA systems

The methods used to quantify nutrient flows of a farm enterprise are given in Table 2. Information collected from interviews included quantities and types of mineral fertilizer (IN1) applied and of manure (IN2) usually expressed locally in ‘mangala’ (donkey loads)[1] or bags. These quantities were transformed into S.I. units based on repeated measurements of the three different sized pouches or bags and an average representative value was thus obtained. Additionally, quantities of irrigation water used with known nutrient concentrations were recorded as organic input (IN2), and quantities of offered fodder and concentrates are registered as IN3. Import of nutrients through seed was also registered as organic input. They were then converted to nutrient quantities and used for further calculations of nutrients flows and balances based on dry matter contents and nutrient concentrations (Van Den Bosch et al., 1998).

Harvested products (OUT7) and residues (OUT9) as well as animal products (OUT8) and produced manure (OUT10) were registered as exports when they left the farm or as internal flows if they were taken to a manure heap or household food/feed stock. Nutrient off-take through grazing was assumed to balance export of urine and faeces in the livestock production systems (Schlecht et al., 2004) as well as in the scavenging habits of small ruminants that freely roam around in living quarters. Manure production by each livestock species was estimated based on daily dry matter production per tropical livestock unit of each species assuming that only 43% of total daily manure produced is recovered in the animal stable and 57% is lost due to grazing (Schlecht et al., 1995).

Leaching and gaseous losses from manure storage (in kraal/animal pen) were not considered because for cGCL and cGscL, manure storage was minimal due to the constraint of keeping manure in dwelling places. Manure in this case was disposed together with domestic waste or frequently applied to garden plots. Such losses were only important in case of the peri-urban cattle keepers with manure often piled up in open heaps near the homestead. This way of working is a result of a more sparse population and thus larger living spaces in the peri-urban areas. However, an attempt was made to estimate these losses from literature (Predotova et al., 2010b). Calculations of inputs and outputs from the hard-to-quantify flows were based on extensive literature research on spatial data from a continental-scale African study that resulted in a nutrient balance assessment with a low level of uncertainty (Lesschen et

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[1] A mangala is a pannier or jute- woven pouch transported on a donkey’s back.

al., 2007). Full farm balances were calculated based on the equations used to estimate the environmental flows as given below by Lesschen et al. (2007):

*Nitrogen fixation (IN5)*

Non-symbiotic N fixation, Nfixed, was estimated from annual precipitation developed by Stoorvogel and Smaling (1990) and given as:

$$Nfixed = 0.5 + 0.1 \times P^{1/2} \qquad (1)$$

where $P$ = precipitation (mm $\text{yr}^{-1}$)

Symbiotic fixation for non-leguminous plants was assumed to be zero and all crops were assumed to benefit from non-symbiotic N fixation.

*Leaching (OUT11)*

It was assumed that 1.6% of organic soil N is annually mineralized to a soil depth of 30 cm and variables in the equation were similar to the 'De Willigen, 2000' model in NUTMON but with revised parameters given as:

$$OUT11_N = \left(0.0463 + 0.0037 \times \left(\frac{P}{C \times L}\right)\right) \times \left(F_N + D \times NOM - U\right) \qquad (2)$$

$$OUT11_K = -6.87 + 0.0117 \times P + 0.173 \times F_K - 0.265 \times CEC \qquad (3)$$

where

$OUT11_N$ means nitrogen leaching (kg N $\text{ha}^{-1}$ $\text{yr}^{-1}$); $OUT11_K$ means potassium leaching (kg K $\text{ha}^{-1}$ $\text{yr}^{-1}$)

$P$ = precipitation (mm $\text{yr}^{-1}$)

$C$ = clay (%)

$L$ = layer thickness (m) = rooting depth (0.3 m was used)

$F_N$ = mineral and organic fertilizer nitrogen (kg N ha$^{-1}$ yr$^{-1}$)

$D$ = decomposition rate of organic matter (1.6% yr$^{-1}$)

$NOM$ = amount of nitrogen in soil organic matter (kg N ha$^{-1}$)

$U$ = uptake by crop (kg N ha$^{-1}$ yr$^{-1}$)

$F_K$ = mineral and organic fertilizer potassium (kg K ha$^{-1}$ yr$^{-1}$)

$CEC$ = cation exchange capacity (cmol kg$^{-1}$)

*Gaseous losses (OUT12)*

$$OUT12 = 0.025 + 0.000855 \times P + 0.13 \times F + O \qquad (4)$$

where

$OUT12$ = gaseous N loss (kg N ha$^{-1}$ yr$^{-1}$)

$F$ = mineral and organic fertilizer nitrogen (kg N ha$^{-1}$ yr$^{-1}$)

$O$ = soil organic carbon content (%)

*Atmospheric deposition (IN4) and Erosion losses (OUT13)*

Atmospheric deposition and soil water erosion were estimated based on transfer functions for all nutrients given in the NUTMON manual and annex (Vlaming et al., 2001). Nutrient input through atmospheric deposition is linked to rainfall by relations developed by Stoorvogel and Smaling (1990) given as:

a. $IN4(N) = 0.14 \times P^{1/2}$

b. $IN4(P) = 0.023 \times P^{1/2}$

c. $IN4(K) = 0.092 \times P^{1/2}$ (5a-c)

Soil erosion was calculated from the universal soil loss equation (USLE) for all nutrients and all variables adopted from the NUTMON manual as given by Smaling and Fresco, 1993.

### *2.3.2. Sampling and laboratory analysis*

*Soils and plant sampling*

Total garden and field sizes were determined by a hand-held Global Positioning System (GPS: Trimble Pro XR, Sunny-Vale, CA, USA). For selected vegetable gardens, three subplots (1–2 $m^2$) were sampled for soils and crop products while for crop fields, samples were taken at the four corners of the field and at the central point. Soils were sampled at depths of 0–20 cm at each vegetable or crop harvest which marks the beginning of the next crop cycle. Soils were sampled from 15 auger points per garden i.e. five sub-samples each from three subplots together making three composite samples for each garden, which were later bulked to represent one sample for each sampling period and garden. This was done because the samples were representative for each garden as well as to reduce the number of samples and costs of analysis. For the field crops, two replicate samples were collected from five points of the field and pooled to obtain one representative sample. Plant samples were collected at harvest or at the same physiological stage from the same sampling plots and comprised of two replicates per plot to obtain a composite of 500 g of fresh sample. Samples were weighed immediately to determine the fresh weights and, after drying, the dry weights. Soil and plant samples were collected from 3 gardens each in cGCL and cGscL and two fields from cLsC farm type, and the average data used for the other un-sampled plots/fields. The vegetable, crop product and residue samples were washed and oven-dried at 60 °C and stored in paper bags at ambient temperature and humidity prior to chemical analysis. Air-dried soil samples were stored in polythene bags. Chemical analysis was conducted on all the samples after a period of three to four months.

### *Water and dust sampling*

Samples of the irrigation water were collected fortnightly (from January 2008 to March 2009) from 5 irrigated sites in the mornings and evenings to obtain representative concentrations of the nutrients contained. Two replicate samples of 100 ml irrigation water were collected with 250 ml plastic containers. Well water was sampled from one well-water-irrigated site only twice during the dry months and bulked. The samples were labelled and refrigerated at 4 °C to avoid contamination until they were taken to the laboratory for analysis. To quantify nutrient input through waste or well water irrigation, the discharge rate of farm-specific irrigation pumps, duration of irrigation per day and total number of irrigation days per vegetable or crop cycle were monitored. Rainfall data was collected from the weather station of the Institute for Agricultural Research (IAR) and rain water samples were collected for every rainfall event in the rainy season of 2008 and pooled to obtain representative samples. Preparation, handling and storage of rain water samples were the same for the irrigation water. Additionally, dust was collected weekly (or every two weeks depending on the severity of the Harmattan period) using a dust trap (Abdu et al., 2011a) during the two dry seasons of 2007–2008 and 2008–2009; samples were pooled to obtain representative dust samples for each dry season to estimate the dry deposition of nutrients. All the sampled materials were analysed for the major nutrients after digestion with $H_2SO_4$-salicylic acid-$H_2O_2$ with selenium as catalyst. Total N content was measured colorimetrically in the digest using the Bertholet reaction method (Chaney and Marbach, 1962); total P was determined colorimetrically with the ascorbic acid reduction of phosphomolybdate complex described by Lowry and Lopez (1946); Total K ion in the digest was determined with an atomic absorption spectrophotometer (AAS; Perkin-Elmer Analyst A400). Other measured soil properties such as organic carbon, soil pH, bulk density, particle sizes, exchangeable K and cation exchange capacity (CEC) were determined using routine laboratory analytical methods.

Information on type, origin and destination and average quantities of inputs applied to both crop and livestock production systems were entered in MONQI version 7.7 for individual farm records. Farm-specific nutrient contents of soil, fertilizers, irrigation water, feed and manure with pre-determined dry matter contents were also entered into the database.

*Calculation of nutrient use efficiencies*

Nutrient use efficiency (NUE) was calculated for each nutrient element from farm-level flows using the partial nutrient balance approach for assessing farm-based nutrient management practices (Dobermann, 2007). Nutrient input to different farm components and output as farm products were considered. NUE is calculated for each element from:

$$NUE = \frac{\sum_{i=1}^{n} Output_{Xi}}{\sum_{i=1}^{n} Input_{Xi}} \times 100 \qquad (6)$$

where

$Output_X$ = output of nutrient $X$

$Input_X$ = input of nutrient $X$

$n$ is the total number of $i$ nutrient input or output events.

*Balance calculations with measured environmental flows*

Model output was compared with data of leaching and gaseous nutrient loss measurements for urban gardens in Niamey, Niger. These measurements were based on experiments with anion exchange resins and a photo-acoustic multi-gas infrared monitor, respectively (Predotova et al., 2010a; Predotova et al., 2011) and represent nitrate, ammonium and phosphate leaching (OUT11), and nitrous oxide and ammonia gas losses (OUT12). This data was used to compare the model outcomes with, because the Niamey gardens have similar characteristics as our systems. Actual measurements of rain and dust nutrient inputs in Kano were also used as data for IN4.

## 2.4. Statistical analysis

Model output for all the nutrient flows and balances and economic performance indicators were aggregated per farm for each of the farm components (vegetables/crops and livestock) before being subjected to descriptive statistics on farm type basis. The farm balance was calculated based on the farm components or activities within and outside the farm boundary, irrespective of the location of an activity (distant fields or gardens). Annual nitrogen, phosphorus and potassium flows and balances and economic performance indicators are expressed as averages for farms in the three different farm types. Farm-level balances are expressed in kg per farm to compare the farm types. However, results on yields and flows for land uses are standardized on a kg per hectare basis. Aggregated economic performance indicators at both farm and activity levels were subjected to one-way analysis of variance (ANOVA) with Tukey's HSD test ($P \leq 0.05$) to compare the different farm types. Off-farm income and socio-economic household characteristics across the farm types were subjected to Mann Whitney U non-parametric test ($P \leq 0.05$) for differences between the farm types (Green and Salkind, 2008). Spearman's two-tailed correlations (0.01 and 0.05 probability) between nutrient flows and balances and socio-economic farm characteristics were performed to evaluate relationships with nutrient management. All statistical analysis was conducted in SPSS/PASW version 18.0 (SPSS Inc. 2010).

## 2.5. Model sensitivity

Questions on how realistic are the assumptions on aggregation of spatial data by Lesschen et al. (2007) are not addressed in this study, because of the small scale of production of the UPA systems under study. To test the sensitivity of the model output to changes in input variables in the transfer functions (section 2.3.1) for the hard-to-quantify flows, we adopted an elasticity measure. The elasticity measure was used to detect the relative effect of small changes in the input variables on the output of these flows (Pannell, 1997; Leffelaar, 2008):

$$E_{s,p} = \left(\frac{\partial \ln S}{\partial \ln P}\right) = \left(\frac{\partial S}{\partial P} . \frac{P_{default}}{S_{p=default}}\right) \qquad (7)$$

where

$E_{s,p}$ = elasticity of the output $S$ (from model transfer function) to input parameter $P$

$\partial S/\partial P$ = relative change in the output $S$ for changes in input parameter $P$

$P_{default}$ = default value of parameter $P$

$S_{p=default}$ = value of the output with $P$ value at default

We used this equation to calculate the output sensitivity for all individual parameters, but it is similar to the term elasticity (Leffelaar, 2008). To approximate the elasticity of the output $S$ to small changes in the input variables $P$, say by 2%, Equation (7) can be written in terms of a central difference equation:

$$E_{s,p} \approx \left( \frac{(S_{p=\max} - S_{p=\min}) / S_{p=default}}{(P_{\max} - P_{\min}) / P_{default}} \right) \tag{8}$$

where

$P_{max}$ = maximum value of parameter $P$ over the range of its change

$P_{min}$ = minimum value of parameter $P$ over the range of its change

$P_{default}$ = default value of parameter $P$

$S_{p=max}$, $S_{p=min}$, $S_{p=\mathrm{default}}$ are the resulting output values of (state variable) $S$, calculated at maximum, minimum and default values of $P$, respectively.

Sensitivities of the different output variables were calculated for each input parameter or input variable using the central difference method expressed by Equation (8). These values are taken with respect to ±2% deviations (from the default values) to better approximate these sensitivities. The degree of sensitivity is described in Table 3 (Leffelaar, 2008).

Table 3: Sensitivity classes used to describe the degree of model sensitivity to changes in input variables or model parameters.

| Sensitivity class | Degree of sensitivity |
|---|---|
| 0.0−0.1 | Hardly |
| 0.1−0.5 | Rather |
| 0.5−1.0 | Quite |
| 1.0−2.0 | Very |
| >2.0 | Extremely |

Source: (Leffelaar, 2008).

# 3. Results and discussion

## 3.1. Farm characteristics and management

Soils in our study farms are poor in total nitrogen but high in total phosphorus and exchangeable potassium. They are sandy loam with moderate to high alkaline soil reaction in water. Bulk density is moderate for soils in all the farm types but lower in cLsC, probably due to a higher use of manure. Cation exchange capacity is low across all the farm types with low levels in cGscL which indicates that these soils are poor in retaining important plant nutrients (Table 4). Total nitrogen (TN) and organic matter (a proxy with organic carbon; Corg) are low which is in line with published findings of savanna soils in Nigeria (Jones and Wild, 1975). Low amounts of TN and Corg observed for cGscL may be due to the small input of manure which was complemented by more input of mineral fertilizer and wastewater use. Family sizes (Table 5) were not significantly different ($P<0.05$) across the farm types and represented average family sizes reported for Kano (Tiffen, 2001), while plot sizes are small especially in cGscL. Average field size is approximately 0.2 ha in cGCL and slightly larger for the cLsC farms. Households across the farm types engage in off-farm income activities with statistically similar earnings ($P>0.05$).

Table 4: Average soil properties from 0-30 cm depth of the studied UPA farm types in Kano.

| Properties | Farm types[1] | | |
|---|---|---|---|
| | cGCL (n=3) | cGscL (n=3) | cLsC (n=2) |
| pH ($H_2O$) | 8.9 | 7.6 | 7.7 |
| BD (Mg $m^{-3}$) | 1.6 | 1.6 | 1.5 |
| Sand (%) | 61.5 | 66.0 | 64.0 |
| Silt (%) | 20.5 | 20.0 | 22.0 |
| Clay (%) | 18.0 | 14.0 | 14.0 |
| Exch K (cmol $kg^{-1}$) | 0.8 | 0.8 | 0.9 |
| CEC (cmol $kg^{-1}$) | 10.6 | 5.8 | 8.5 |
| Organic C (g $kg^{-1}$) | 6.2 | 1.6 | 5.5 |
| N total (g $kg^{-1}$) | 0.9 | 0.5 | 1.0 |
| P total (g $kg^{-1}$) | 0.3 | 0.5 | 0.6 |
| K total (g $kg^{-1}$) | 3.7 | 2.7 | 3.3 |
| Total N stock (Mg $ha^{-1}$)[2] | 4.3 | 2.5 | 4.4 |
| Total P stock (Mg $ha^{-1}$)[2] | 1.4 | 2.3 | 2.4 |
| Total K stock (Mg $ha^{-1}$)[2] | 17.8 | 12.4 | 14.7 |

[1] cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.
[2] Total nutrient stock in the upper 30 cm (rooting depth) of soil calculated from average bulk density values (Mg $m^{-3}$) per farm type.
Standard deviations are not given due to the small sample size.

Table 5: Average (± standard deviation) farm characteristics of the studied UPA farm types in Kano.

| Characteristics | Farm types | | |
|---|---|---|---|
| | cGCL<br>n=6 | cGscL<br>n=6 | cLsC<br>n=4 |
| Age of household head (years) | 44<br>(11) | 49<br>(10) | 47<br>(15) |
| Total family size (#) | 8.30<br>(1.8) | 7.50<br>(2.3) | 8.25<br>(1.5) |
| Total garden size ($m^2$) | 1499 [a]<br>(1719) | 460 [b]<br>(274) | – |
| Total field size (ha) | 0.18<br>(0.16) | – | 0.24<br>(0.04) |
| Total livestock (TLU)[1] | 0.62 [a]<br>(0.5) | 2.67 [a]<br>(0.5) | 47.7 [b]<br>(14) |
| Off farm income (US$ $farm^{-1}$ $yr^{-1}$)[2] | 1143<br>(1530) | 1033<br>(1254) | 1200<br>(1697) |
| Total family labour (#)[3] | 4.5<br>(2.6) | 4.1<br>(1.6) | 4.7<br>(0.9) |
| Mineral fertilizer (kg $ha^{-1}$ $yr^{-1}$) | 282<br>(184) | 225<br>(86) | 0 |
| Organic manure use (t $ha^{-1}$ $yr^{-1}$)[4] | 9.8 [a]<br>(9.6) | 0 | 99.8 [b]<br>(18.6) |
| Irrigation water use ($m^3$ $ha^{-1}$ $yr^{-1}$)[5] | 14277<br>(11719) | 21617<br>(6464) | – |

[a,b] represent means that are statistically different. Means with the same letter are the same (Mann-Whitney U test, P<0.05).

[1] TLU: Tropical Livestock Unit with a standard weight of 250 kg; TLU conversion factors used: cattle = 0.80, sheep and goats = 0.10, poultry = 0.01.

[2] 1 US$ was equivalent to 150 Nigerian Naira during the monitoring period.

[3] Family labour given as man equivalent (See Hardiman et al., 1990).

[4] Expressed on a wet-weight basis.

[5] Quantity applied to all crops within the monitoring year.

Statistical values do not always represent the number of households (n) in a farm type, especially when certain activities are absent.

The selected farm types are unique with respect to the farm management practices and characteristics. Land uses are divided into vegetable garden and field crop production for the different farm types. Vegetable production is market-oriented, intensive and a year round activity that is under irrigation during the dry season. Water is mainly conveyed from open water to plots with diesel pumps that have varying discharge rates between 5.8 and 16 l $s^{-1}$ similar to reported ranges of pump discharge of small-scale irrigated farms in northern Nigeria of 4 to 23 l $s^{-1}$ (Kimmage and Adams, 1990). Gardens are subdivided into small sub-plots of approximately 1–2 $m^2$ and up to 4 $m^2$ each and commonly cultivated with amaranthus (*Amaranthus caudatus* L.), lettuce (*Lactuca sativa* L.), carrot (*Daucus carota* L.) or parsley (*Petroselinum crispum* L.). At most, 7 vegetable cycles are attainable in a year, although cultivation depends on the climatic condition and market demand which leads to a high degree of vegetable rotation within the same garden plots (Drechsel and Dongus, 2010).

Livestock keeping in farms cGCL and cGscL are mainly small ruminants (sheep) while the cLsC farms keep more than 45 heads of cattle and sheep, all under a semi-intensive system. Large herds are grazed from 9 a.m. until 6 p.m. (approximately 9 hours daily) on natural pastures 3–5 km and up to 25 km from homesteads in the dry season and supplemented with crop residues and stored hays. Sheep roam in the streets and around the homestead from morning to evening but are usually supplemented with concentrates, hay and freshly cut grass depending on the seasonal availability of feed and purchasing power of the farmer.

### 3.1.1. Nutrient inputs to gardens and field crops

Nutrient inputs to vegetables and crops were mainly through mineral fertilizers (urea and NPK), manure and waste water sources (Table 5). In cGCL, manure contributes 6% N, 18% P and 5% K of the total input through both the application of organic and inorganic fertilizer (IN1 + IN2); mineral fertilizer accounts for 12% N, 14% P and 7% K while 82% N, 68% P and 88% K are contributed from waste water irrigation. During dry season irrigation, waste water contains on average per litre, 75 mg N, 12 mg P and 60 mg K while nutrient concentrations in well water were 1.2 mg $l^{-1}$ N, 1.0 mg $l^{-1}$ P and 2.4 mg $l^{-1}$ K. Households in cGscL do not use manure with only 11% of N input coming from mineral fertilizer (urea), contributing an annual input of 104 kg N $ha^{-1}$. All other nutrient supply comes from waste water irrigation with inputs of 856 kg N $ha^{-1}$, 285 kg P $ha^{-1}$ and 1,927 kg K $ha^{-1}$, making up 88% of N supply and 100% supply for both P and K. Manure was the main source of nutrients in cLsC (Table 6)

Table 6: Means of flows of nitrogen (N), phosphorus (P) and potassium (K) (kg $ha^{-1}yr^{-1}$) at plot level in the three farm types.

| | Nutrients | N | | | P | | | K | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Flows | Farm[1] types | cGCL | cGscL | cLsC | cGCL | cGscL | cLsC | cGCL | cGscL | cLsC |
| *Inflows* | | | | | | | | | | |
| Mineral fertilizer | IN1 | 152 | 104 | 0 | 20 | 0 | 0 | 20 | 0 | 0 |
| Organic input | IN2 | 650 | 856 | 844 | 120 | 285 | 472 | 288 | 1927 | 1035 |
| Atmospheric deposition | IN3 | 4 | 7 | 3 | 1 | 1 | 1 | 3 | 5 | 2 |
| Non-symbiotic N-fixation | IN4 | 3 | 6 | 3 | NA | NA | NA | NA | NA | NA |
| ***Total inflow*** (Σ IN) | | ***809*** | ***973*** | ***850*** | ***141*** | ***286*** | ***473*** | ***311*** | ***1932*** | ***1037*** |
| *Outflows* | | | | | | | | | | |
| Crop products | OUT7 | 352 | 422 | 93 | 58 | 58 | 30 | 759 | 870 | 28 |
| Crop residue | OUT9 | 51 | 46 | 101 | 9 | 9 | 32 | 130 | 155 | 303 |
| Leaching losses | OUT11 | 29 | 73 | 56 | n.a. | n.a. | n.a. | 10 | 81 | 60 |
| Gaseous losses | OUT12 | 18 | 45 | 37 | NA | NA | NA | NA | NA | NA |
| Erosion losses | OUT13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ***Total outflow* (Σ OUT)** | | ***450*** | ***586*** | ***287*** | ***67*** | ***67*** | ***62*** | ***844*** | ***1106*** | ***391*** |
| **Full balance[2]** | | **359** | **387** | **563** | **74** | **219** | **411** | **−533** | **826** | **646** |

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[1] cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

[2] Full balance = (Σ IN – Σ OUT). NA= not applicable; n.a. = not assessed. Flows were aggregated before averaging across farm types (2009 monitoring year).

and supplies an average input of 844 kg N $ha^{-1}$ $yr^{-1}$, 472 kg P $ha^{-1}$ $yr^{-1}$ and 1,035 kg K $ha^{-1}$ $yr^{-1}$ across all crops.

### *3.1.2. Yields*

Average fresh yield of major vegetable crops per crop cycle was 14.5, 6.6 and 14.8 t $ha^{-1}$ for lettuce, amaranthus and carrots, respectively, in cGCL farms, whereas yields were 19.0, 15.6 and 25.9 t $ha^{-1}$, respectively, in cGscL (Table 7). Yields were higher in cGscL for all crops, which can be explained by higher nutrient inputs in this farm type. Lettuce yields were in the range of 12–32 t $ha^{-1}$ obtained in south-eastern Nigeria (Ogbodo et al., 2010). Fresh yields of amaranthus were below the world average of 14.2 t $ha^{-1}$ but yields of cGCL were similar to 6.3 t $ha^{-1}$ reported for the low input gardens of Niamey, Niger (Diogo et al., 2010a). However, amaranthus yields in cGscL were close to values reported in Nigeria (15.7 t $ha^{-1}$) with poultry manure application rates of 12 t $ha^{-1}$ (Law-Ogbomo and Ajayi, 2009). Carrot yields of 25.9 t $ha^{-1}$ in cGscL were higher than in cGCL and close to potential yield levels of 30 t $ha^{-1}$ (PPIC, 2003). Lettuce yields for the two studied farm types were less than yields reported under similar production systems in Niger where more nutrient inputs were used. In Niger, average additions of 474 kg N $ha^{-1}$, 73 kg P $ha^{-1}$ and 355 kg K $ha^{-1}$ to lettuce and 531 kg N $ha^{-1}$, 73 kg P $ha^{-1}$ and 300 kg K $ha^{-1}$ to amaranthus per crop cycle were reported for high input systems (Diogo et al., 2010a). Nitrogen inputs were 3-fold higher to carrot production compared with inputs to amaranthus in cGscL, and P and K input were 5-fold higher in carrots compared with that applied to amaranthus in cGscL.

Field crop production commonly found at the city outskirt is for staple crops e.g. sorghum (*Sorghum bicolor* L. Moench) and millet (*Pennnisetum glaucum* L.) for household consumption, but farmers sometimes convert their garden plots temporarily to field cropping at the onset of rains (Ruma and Sheikh, 2010) which is usually due to high market prices of crops like fresh maize (*Zea mays* L.) and the low labour demand for production. Sorghum and millet grain yields were 1.4 and 3.8 t $ha^{-1}$, respectively, in cLsC (Table 7). Sorghum yields were higher than yields obtained in the Nigerian savannah (Mohammed et al., 2008; Rahman, 2006) and close to yields of 1.5–2.5 and up to 3.5 t $ha^{-1}$ when improved varieties are used in northern Nigeria (Ogbonna, 2008). The average millet yield of 3.8 t $ha^{-1}$ was close to the 2–4 t $ha^{-1}$ reported for the Nigerian savannah (Kassam and Kowal, 1975). Millet yields may be modest despite high nutrient inputs because farmers cultivate local varieties with poor responses to added nutrients (Nwasike et al., 1982). For 2008 cropping season, annual

Table 7: Yields (t $ha^{-1}$; mean ± one standard deviation) and input (kg $ha^{-1}$; mean ± one standard deviation) of nitrogen (N), phosphorus (P) and potassium (K) applied to selected crops in one cropping cycle or season, as determined for the three farm types in Kano.

| Farm type[1] | Vegetable | n | Yield[2] | N | P | K |
|---|---|---|---|---|---|---|
| cGCL | Lettuce | 10 | 14.5 (10.8) | 194.4 (467) | 30.1 (75) | 51.4 (96) |
| | Amaranth | 18 | 6.6 (3.3) | 106.4 (83) | 17.4 (15) | 46.3 (43) |
| | Carrot | 4 | 14.8 (7.5) | 103.5 (152) | 16.4 (23) | 60.1 (103) |
| | Maize grain[3] | 3 | 4.8 | 162 | 47 | 83 |
| cGscL | Lettuce | 6 | 19.0 (12) | 178.4 (167) | 29.4 (25) | 108.2 (102) |
| | Amaranth | 12 | 15.6 (7) | 126.6 (52) | 14.4 (12) | 109.4 (62) |
| | Carrot[3] | 2 | 25.9 | 673.4 | 100.5 | 642.3 |
| cLsC | Sorghum grain[3] | 2 | 1.4 | 388 | 225 | 480 |
| | Millet grain[3] | 2 | 3.8 | 282 | 157 | 345 |

[1] cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

[2] Yields are on a fresh weight basis (Average dry matter of economic crop parts: lettuce = 11%; amaranthus = 12%; carrot = 12%; maize = 87%; sorghum = 85%; millet = 88%).

[3] Standard deviations are not given due to small sample size (n).

n=number of crops present in each farm type in 2009. Grain crops are cultivated under rain-fed conditions.

average grain yields of maize and rice were 6.5 and 5.8 t $ha^{-1}$, respectively, in cGCL (data not shown). For the same farm type, maize yield was 4.8 t $ha^{-1}$ in 2009. Other studies report rice grain yields of 4.6 to 5.6 t $ha^{-1}$ in Kano; yields of 10 t $ha^{-1}$ were achieved on research plots (Kebbeh et al. 2003).

## 3.2. Nutrient flows and balances

### 3.2.1. Land use-level

Plot and field-based full nutrient balances across the farm types reveal annual average net positive balances for nitrogen (359 and 387 kg N ha$^{-1}$) and phosphorus (74 and 219 kg P ha$^{-1}$) in cGCL and cGscL, respectively (Table 6). Potassium balance was negative in cGCL with a net annual loss of 533 kg K ha$^{-1}$. Balances in cLsC farm type were positive for all three nutrients at annual averages of 563, 411 and 646 kg ha$^{-1}$ for N, P and K, respectively. Inflow of nutrients was highest through organic sources (IN2) with no statistical difference between the farm types except for K, which was statistically similar ($P>0.05$) in cGscL and cLsC, and both differ with cGCL. Input from mineral fertilizer (IN1) was higher in cGscL than cGCL although not statistically different ($P>0.05$), there was no addition of mineral or inorganic fertilizer into fields of cLsC, only organic input from manure, produced within the farm. Outflows of N, P, and K through crop products, i.e. those that leave the farm, are statistically similar ($P>0.05$) for farm types cGCL and cGscL. This may be due to the similarity in production systems and orientation of the cGCL and cGscL farms compared to the cLsC farm. Leaching loss accounted for 4%, 7% and 8% of applied (mineral and organic fertilizer) N and 3%, 4% and 6% of applied K in cGCL, cGscL and cLsC, respectively. Nutrient balances with respect to the soil stock resulted in annual accumulation of 13–18% and 5–17% of the total soil N and P stock, respectively, across the farm types. K was mined (3%) in cGCL, whereas 4% and 7% K was accumulated in cGscL and cLsC, respectively.

P is more likely to accumulate than N and K. Total organically-bound nitrogen may increase but nitrate build-up is unlikely especially in sandy soils because of poor retention properties (Gaines and Gaines, 1994) and implies eventual leaching and volatilization losses of ammonia and nitrous oxide. Increased concentrations of nitrate in ground water may constitute a health problem especially for urban households that rely almost entirely on well water for cooking and drinking purposes. Volatilization of nitrous oxide contributes to the quantity of greenhouse gases in the atmosphere while that of ammonia causes atmospheric pollution. A positive P balance indicates that soil P is increasing, but soil P sorption properties determine the availability of P for plant uptake. Long-term P surpluses have been shown to hasten the degree of soil P saturation (Hooda et al., 2001). If saturation would be reached, soils can no longer retain extra P. Soluble P as a result of these surpluses is likely to cause an environmental threat because it could be lost to the ground water and cause eutrophication in surface water. Studies have shown that $K^+$ is easily displaced by calcium ions ($Ca^{2+}$) from soil into soil solution, a form which can be readily leached especially if the soils are sandy and of low buffering capacity and if leaching water has high amounts of $Ca^{2+}$ (Kolahchi and Jalali, 2007). The reverse is the case for savanna soils of northern Nigeria which, despite having a dominance of kaolinite, have a higher preference of $K^+$ than $Mg^{2+}$ and $Ca^{2+}$ (Agbenin and Yakubu, 2006; Yakubu and Agbenin, 2010). Similarly, Udo (1978) and Pleysier et al. (1979) reported greater affinity of $K^+$ than $Ca^{2+}$ in kaolinitic Ultisols of western Nigerian savanna soils. Kaolinitic soils that have greater selectivity for $K^+$ than $Ca^{2+}$ may be explained by the presence of illite in the clay suite (Goulding and Talibudeen, 1980) possibly causing K-fixation, and by the lower adsorption energy of $K^+$ by water (Levy et al., 1988). In another study, Alves and Lavorenti (2003) also reported $K^+$ preference over $Ca^{2+}$ by Oxisols of Sao Paulo, Brazil. Therefore, for the cGscL and cLsC farm types with $K^+$ surpluses, $Mg^{2+}$ and $Ca^{2+}$ deficiencies are likely to occur in these soils due to preferential adsorption of $K^+$ (Yakubu and Agbenin, 2010).

### *3.2.2. Livestock level*

The livestock sub-system comprises the stable and the inputs through feed and the output as milk. Here, we assume that manure that is not used by the household constitutes an outflow from the farm. This may be a crude assumption as manure constitutes part of the animal flooring that may never leave the farm. This also holds for the stored manure which leaves the farm only on demand by crop cultivators. Across the farm types, livestock N and P partial balances were positive: 15.9 and 49.8 kg N $farm^{-1}$ $yr^{-1}$ and 4.4 and 20 kg P $farm^{-1}$ $yr^{-1}$ in cGCL and cGscL, respectively. Similarly, partial balances were positive for N and K nutrients in cLsC, and slightly negative for P, because P outflow as manure exceeded input via feed, although eventual outflow is higher in households with no fields within this farm type. Higher nitrogen input was observed per tropical livestock unit: 34.5 kg N $TLU^{-1}yr^{-1}$ in cGCL compared to 3.1 kg N $TLU^{-1}$ $yr^{-1}$ in cLsC. A similar trend was observed for the other nutrients with higher annual positive partial balances in cGCL and cGscL than cLsC (Fig. 3). This is due to the higher number of livestock in the latter farm type. Nutrient requirements of the livestock are probably met via grazing since it constitutes the major feeding system in cLsC farm type.

Nutrients in manure represent total amounts present at the time it was analysed, irrespective of losses that might have occurred before sampling. However, up to 40–60% of urine and manure N could be lost from the animal stable through leaching and

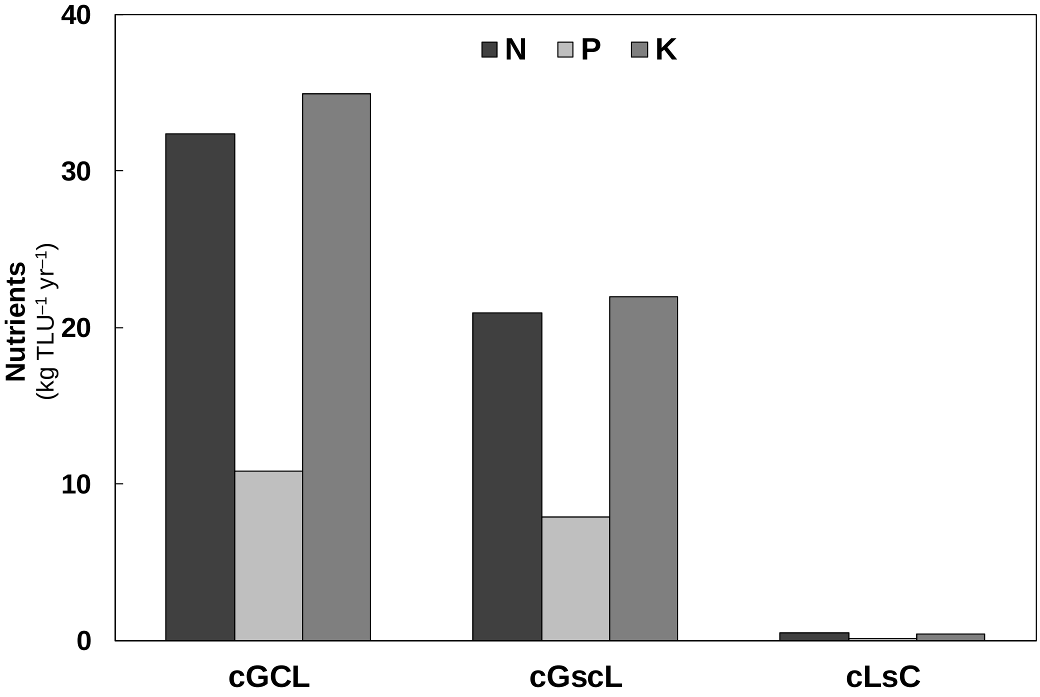

Fig. 3: Partial nutrient balances in the livestock unit of the three UPA farm types, calculated as the difference between nutrient inflows and outflows at the unit level and reported on an animal (TLU) basis. cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

volatilization (Mohamed Saleem, 1998; Schlecht et al., 2004).

These losses could have occurred before manure samples were taken, such that the easily mineralizable N had already been lost from the manure heap. Nitrous oxide ($N_2O$) losses from fresh manures are low. Measurements have shown that 2% of annual manure produced is converted to nitrous oxide (Davidson, 2009), but more of this N could be lost as a result of poor management practices where up to 17% of total N could be lost through volatilization of $NH_3$ (Mahimaraja et al., 1995). Gaseous N losses could be reduced by 50% when the manure heap is covered by plastic sheets (Predotova et al., 2010b; Tittonell et al., 2010). In case of the cattle keepers who corral the animals in open spaces near the homestead, a manure heap is completely exposed to environmental influences of fluctuating temperature, wind and rainfall. This could enhance the processes that drive gaseous N and carbon losses to the atmosphere and N leaching. Stored manure in cLsC farms could thus be subject to annual losses of 4.7 kg N, 1 kg P and 51 kg K farm$^{-1}$, before it is redistributed to other farm units or leaving the farm. These numbers were calculated based on loss percentages from experiments on gaseous emissions and leaching losses from dung stores in UPA farms in Niger (Predotova et al., 2011). Assuming manure is stored in cGCL and cGscL, total N losses were calculated as 0.06 and 0.2 kg N farm$^{-1}$yr$^{-1}$, while P and K leaching were 0.02 and 0.1 kg P farm$^{-1}$ yr$^{-1}$, and 0.8 and 1.5 kg K farm$^{-1}$ yr$^{-1}$, respectively. These losses were negligible for N and P but more severe for potassium in cLsC, namely 51 kg K farm$^{-1}$ yr$^{-1}$. This was due to a higher percentage of manure K lost by leaching in the rainy season (Predotova et al., 2011).

### *3.2.3. Overall farm level*

Average annual farm balances were positive for N (56.6, 67.4 and 56.4 kg farm$^{-1}$) and P (15.3, 26.2 and 39.1 kg farm$^{-1}$) for cGCL, cGscL and cLsC, respectively (Fig. 4 a, b). Potassium balances were positive in cGscL and cLsC, but it was negative in cGCL with an average value of 16 kg farm$^{-1}$ (Fig. 4c).

Partial balances were positive for all the nutrients across the farm types except for K which was still negative in cGCL (Fig. 5). Even with nutrient outflows through leaching and gaseous losses, nutrient input was so high that the farm balances remain positive (Table 8). Harvested products taken to the food stock of the farm constituted 11 kg N farm$^{-1}$yr$^{-1}$, 2.3 kg P farm$^{-1}$ yr$^{-1}$ and 9.1 kg K farm$^{-1}$ yr$^{-1}$ in cGCL, while all vegetable products left the farm in cGscL. Sale of stored food occurred in cGCL with annual outflows of 2.7 kg N farm$^{-1}$, 0.7 kg P farm$^{-1}$ and 0.7 kg K farm$^{-1}$. All crop products and residues were used for home consumption and feed in cLsC, respectively, with leaching and gaseous losses as the main outflows from the farm. Average annual inflow to household stock in the form of milk was 0.5 kg N, 0.1 kg P and 0.2 kg K in cLsC. Part of the manure produced in the animal pen was redistributed to the fields of the large livestock keepers that cultivate crops.

## 3.3. Socio-economic characteristics and nutrient balances

Economic performance indicators at farm level show profitable returns of UPA to the farm households with high net farm incomes in cGCL and cLsC farm types while the indicators for cGscL show an average annual net loss of $428 (Table 9). At activity level, garden enterprise was a profitable venture for the farmers in cGscL with annual positive gross margin (GM) and net cash flows (NCF) of $194 and $206 respectively, while in the animal activity, an average yearly negative gross margin of $1025 was recorded. Aggregating cash flows from garden and livestock activities masked the net gain of market gardening within the farm type. A similar trend was observed in cGCL farm types and, probably, one year of monitoring of small ruminants is insufficient to

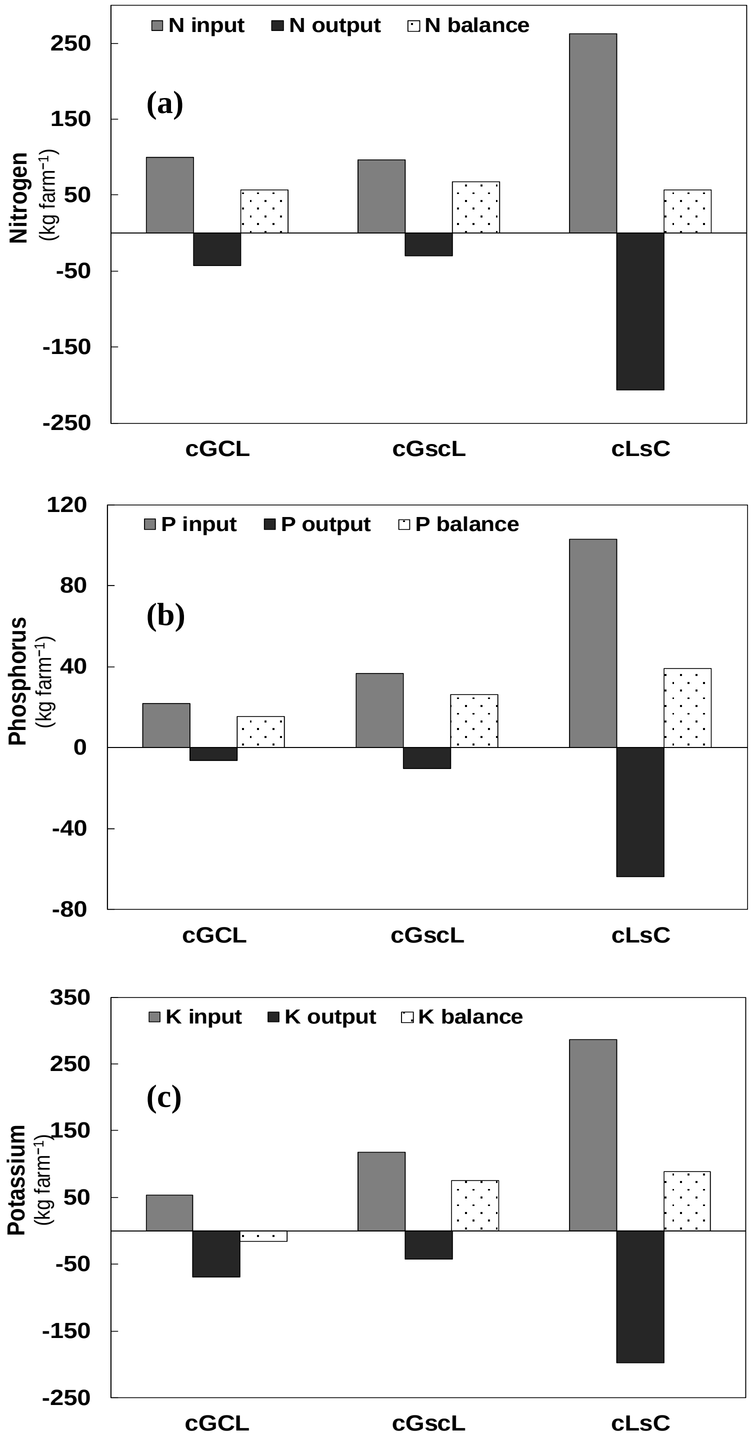

Fig. 4: Yearly farm-level nitrogen (a), phosphorus (b) and potassium (c) balances in three UPA farm types of Kano. cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

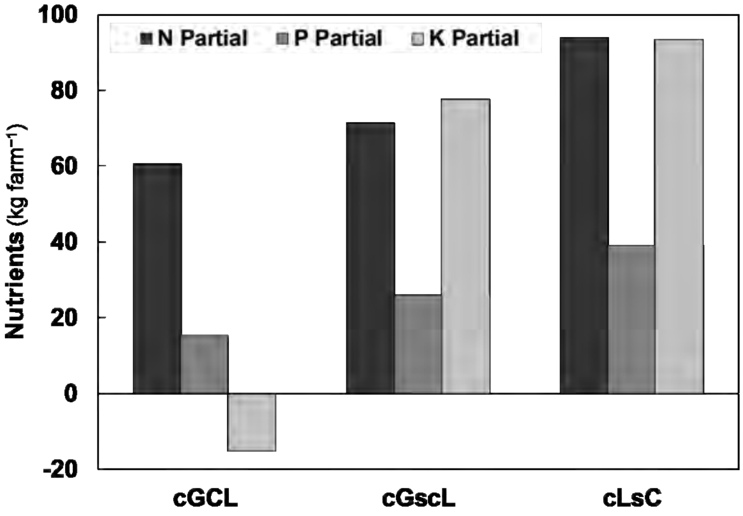

Fig. 5: Yearly partial farm balances of nitrogen (N), phosphorus (P) and potassium (K) in the three UPA farm types. cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

indicate the net gains from livestock keeping through the sale of live animals, because small livestock are kept mainly for security and serve as an immediate cash source for the household in times of need (Rischkowsky et al., 2006b; Berkhout, 2009). In contrast, the large cattle keepers (cLsC) sell milk and manure and procure net average annual positive gross margins and net cash flow in livestock activity of $9033 and $935, respectively. This system (cLsC) relies on grazing livestock and spends less cash on livestock feed as compared to the other farm types. Findings from this study underline some profitable aspects of certain UPA activities and such practices will continue as long as they play an integral role in household livelihood. Similar financial benefits from UPA were reported with annual income levels of US$ 400−800 and monthly gains of US$ 35–160 by urban gardening in Kumasi, Ghana (Obuobie et al., 2006) and US$ 137 monthly gross margin in Akwa Ibom, Nigeria (Okon and Enete, 2009). Drechsel et al. (2006) indicated a range of profitability from urban cultivation in different African cities and reported a monthly income of US$ 53–120 for Lagos, Nigeria. In another study in Enugu metropolis in Nigeria, urban cultivation contributes most to the livelihood of the farmers with US$ 44 per month (Chah et al., 2010). In our study, the farm gross margin is composed from the integrated activities of gardening, crop cultivation and livestock keeping, but for cGCL and cGscL, the largest part of the gross margin mainly comes from cultivating crops and vegetables, making up 56% and 200% for the respective farm types. The

Table 8: Nitrogen (N), phosphorus (P) and potassium (K) flows (kg farm$^{-1}$ yr$^{-1}$) of the three UPA farm types in Kano.

| Flows | Nutrients | N | | | P | | | K | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Farm types[1] | cGCL | cGscL | cLsC | cGCL | cGscL | cLsC | cGCL | cGscL | cLsC |
| *Inflows* | | | | | | | | | | |
| Mineral fertilizer | IN1 | 17.9 | 2.8 | 0.0 | 4.1 | 0.0 | 0.0 | 4.1 | 0.0 | 0.0 |
| Organic fertilizers | IN2 | 63.2 | 33.4 | 75.5 | 12.7 | 8.4 | 42.3 | 28.4 | 56.6 | 92.6 |
| Organic animal feed | IN3 | 17.0 | 60.0 | 186.6 | 5.0 | 28.1 | 60.6 | 20.8 | 61.1 | 193.9 |
| Atmospheric deposition | IN4 | 0.5 | 0.4 | 0.3 | 0.1 | 0.1 | 0.1 | 0.4 | 0.2 | 0.2 |
| Non-symbiotic N-fixation | IN5 | 0.5 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ***Total inflows (Σ IN)*** | | ***99.1*** | ***96.9*** | ***262.7*** | ***21.9*** | ***36.6*** | ***103*** | ***53.7*** | ***117.9*** | ***286.7*** |
| *Outflows* | | | | | | | | | | |
| Crop products | OUT7 | 29 | 13 | 0.0 | 4.4 | 2.0 | 0.0 | 57.3 | 25.7 | 0.0 |
| Animal products | OUT8 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 |
| Crop residue | OUT9 | 4.7 | 1.6 | 0.0 | 0.8 | 0.3 | 0.0 | 8.4 | 5.0 | 0.0 |
| Animal manure | OUT10 | 1.1 | 10.3 | 0.0 | 0.6 | 8.1 | 0.0 | 2.2 | 9.3 | 0.0 |
| Leaching losses | OUT11 | 3.0 | 2.8 | 34.8 | n.a. | n.a. | n.a. | 1.1 | 2.6 | 5.3 |
| Gaseous losses | OUT12 | 2.0 | 1.8 | 3.3 | NA | NA | NA | NA | NA | NA |
| Erosion losses | OUT13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Outflow from farm | OUT14 | 2.7 | 0.0 | 166.9 | 0.7 | 0.0 | 63.7 | 0.7 | 0.0 | 192.7 |
| ***Total outflow (Σ OUT)*** | | ***42.5*** | ***29.5*** | ***206.3*** | ***6.56*** | ***10.4*** | ***63.9*** | ***69.7*** | ***42.6*** | ***198.3*** |
| **Full balance** | | **56.6** | **67.4** | **56.4** | **15.3** | **26.2** | **39.1** | **−16.0** | **75.3** | **88.4** |

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[1] cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

NA= not applicable; n.a. = not assessed.

Table 9: Economic performance indicators (US\$ farm$^{-1}$ yr$^{-1}$) of Kano UPA farms.

| | Farm types | | |
|---|---|---|---|
| | cGCL | cGscL | cLsC |
| Net cash flow crop | 757$^{a}$ | 206$^{b}$ | −8$^{c}$ |
| Net cash flow livestock | −205$^{c}$ | −683$^{b}$ | 935$^{a}$ |
| Gross margin crop | 1059$^{a}$ | 194$^{c}$ | 296$^{b}$ |
| Gross margin livestock | −37$^{c}$ | −1025$^{b}$ | 9033$^{a}$ |
| Net farm income (NFI) | 1011$^{b}$ | −428$^{c}$ | 9115$^{a}$ |
| Family earning (FAMEARN) | 2155$^{b}$ | 606$^{c}$ | 9715$^{a}$ |
| Household net cash flow (HHNCF) | 1725$^{a}$ | 663$^{c}$ | 1529$^{b}$ |
| Farm net cash flow (FARMNCF) | 590$^{b}$ | -357$^{c}$ | 929$^{a}$ |

$^{a,b,c,}$ represent means that are statistically different (Tukey’s HSD test, P<0.05)
1 US\$ is equivalent to 150 Naira.
Net farm income (NFI) = sum of all the Gross margins in the farm; Family earning = NFI + total Off-farm income.

latter percentage was obtained in cGscL because of the negative gross margin realized from livestock activities, while gardening contributes positively to the farm income (Appendix i). From net farm income and average number of household members per farm type, a per capita household income of 2.7 US\$ per day was achieved in cLsC, which is above the international poverty line of 2 US\$ per day, while those in cGCL and cGscL fall below the poverty line with 0.37 and 0.21 US\$, respectively.

Among all the economic indicators of the farms, only off farm incomes were not significantly different (P<0.05) between the farm types. Correlations between socio-economic farm characteristics such as resources and household demographics and nutrient flows and balances reveal a positive relationship between field size and P input and balance (r = 0.94). Highly positive correlations exist between family labour and N and P inputs, respectively, in the cLsC farm type. A strong and positive relationship was observed in the cGscL between N, P and K inputs and their respective balances with household off-farm income. This may be related to the purchased inputs (feed and fertilizers) by the farm households from income generated from off-farm activities. For the gardeners in the same farm type (cGscL), a negative relationship exists (r = –0.50) between garden sizes and their respective N input and balances. This indicates that smaller garden plots receive a higher input. Livestock numbers related positively (r = 0.50) to N, P and K inputs and balances in cGscL. The positive relation with livestock numbers may be related to inflows through supplement feed observed in the farm type.

## 3.4. Sensitivity of the transfer functions

Calculated sensitivities of the model transfer functions for a number of variables that make up these functions are provided as supplementary materials (Appendix ii-v). Based on sensitivity classes of Table 3, nitrogen leaching ($OUT11_N$) was quite sensitive to ±2% variations in soil clay content and organic fertilizer input with respect to the default, and rather sensitive to precipitation in all the farm types (Fig. 6). The sensitivity of nitrogen leaching was more pronounced in cLsC for organic fertilizer input than in the other farm types probably because of a higher use of manure. Model N leaching output was hardly sensitive to total nitrogen (TN) and mineralization rates in all the farm types. It was rather sensitive to mineral fertilizer in cGCL, but it was hardly sensitive to mineral fertilizer in the other farm types (Appendix ii). Potassium leaching ($OUT11_K$) was quite sensitive to ±2% changes in organic fertilizer input for all farm types, while it remains hardly sensitive to changes in precipitation in the other farm types except cGCL (Fig. 7). Potassium leaching was also not sensitive to changes in CEC and mineral fertilizer input in all three farm types (Appendix iii)

Gaseous losses of N (OUT12) were only quite sensitive to changes in organic fertilizer input, while they were hardly sensitive to changes in precipitation, organic carbon and mineral fertilizer in all the farm types (Appendix iv). Sensitivity was thus more pronounced with changes in variables for nitrogen-related flows than for the other nutrients. Nitrogen-related flows were also found to be more sensitive in the former NUTMON model when the same set of variables were subjected to sensitivity analysis (Vlaming, 2001). Among all the variables in the transfer functions, organic fertilizer input had most influence on the sensitivities of the model functions. This could be expected because of the high application of organic nutrient inputs in UPA systems (Drechsel et al., 2005b). In addition, the model functions were not parameterized for the high nutrient inputs on UPA farms. The model outcome shows differences in responses to changes in input variables such as organic fertilizer input and precipitation of $OUT11_N$, $OUT11_K$ and OUT12 for the farms types. This has resulted from differences in nutrient management and biophysical conditions of individual farming households in the model. This indicates some uncertainty with

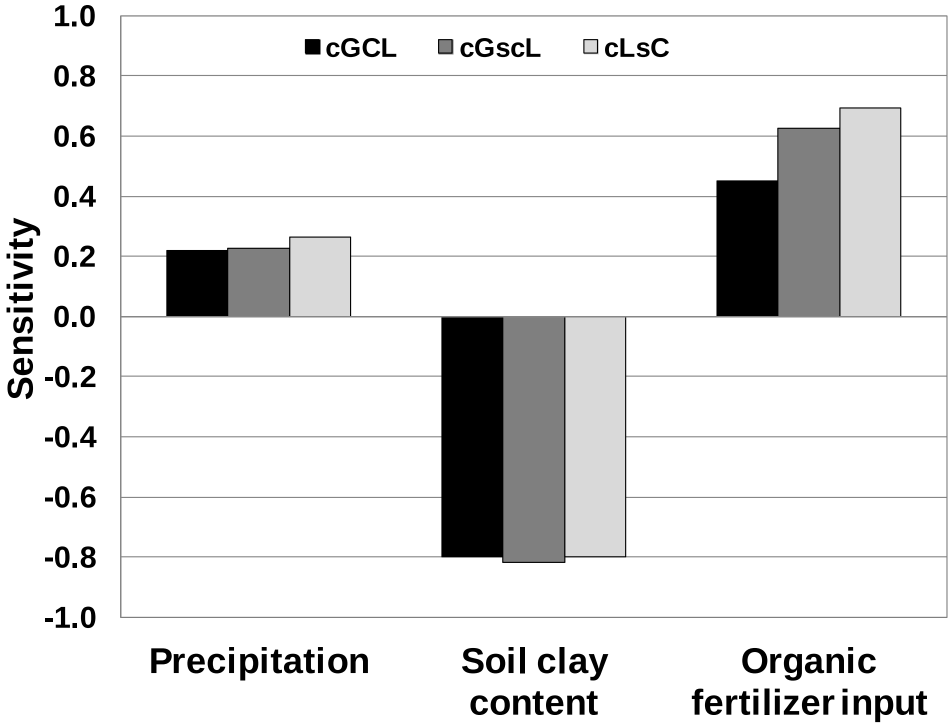

Fig. 6: Calculated sensitivities of nitrogen leaching ($OUT11_N$) in the MONQI model with respect to precipitation, soil clay content and organic fertilizer input. Reported calculations refer to the central (default) values at ±2% deviation for the different farm types. cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

respect to the estimation of leaching and gaseous N losses and their generalization across different farming systems (Thorsen et al., 2001) as shown in this study.

### 3.5. Farm balances calculated from measured environmental flows

Approximate total annual dust deposition was 936 kg $ha^{-1}$. Dust deposition occurred mainly in the dry season and values were highly variable (average of 1.8 ±5 g $m^{-2}$ per week). The average value was scaled up for a year as occasional storms occur before rainfall events with substantial dust deposition. Earlier studies reported annual dust deposition of 922 kg $ha^{-1}$ (McTainsh, 1980) and 990 kg $ha^{-1}$ (Wilke et al., 1984) for northern Nigeria. Average nutrient contents of sampled dust at six urban gardens were8.7 ±5.5 g N $kg^{-1}$, 2.0 ±0.9 g P $kg^{-1}$ and 13.0 ±4.0 g K $kg^{-1}$ dust, resulting in estimated annual inputs of 8.13 ±5.2 kg N $ha^{-1}$, 1.83 ±0.8 kg P $ha^{-1}$ and 12.2 ±3.8 kg K $ha^{-1}$. Phosphorus and K deposition were comparable, whereas N deposition was higher than values reported by Wilke et al. (1984) for northern Nigeria. Input from rain was measured as a function of total annual precipitation and nutrient contents in

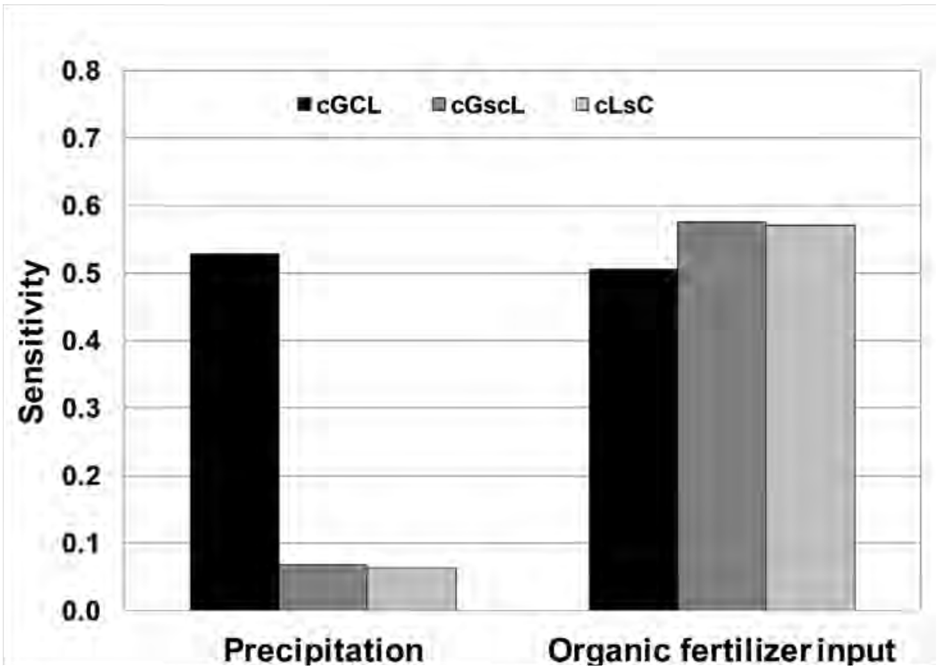

Fig. 7: Calculated sensitivities of potassium leaching ($OUT11_K$) from the MONQI model with respect to precipitation and organic fertilizer input. Reported calculations refer to the central (default) value at ±2% deviation for the different farm types. cGCL = commercial gardening plus field crop-livestock, cGscL = commercial gardening plus semi-commercial livestock, cLsC = commercial livestock plus subsistence field cropping.

rain water. Average nutrient influx by rainfall was estimated at 4.2 g N $mm^{-1}$ $ha^{-1}$, 5.2g P $mm^{-1}$ $ha^{-1}$ and 13.4 g K $mm^{-1}$ $ha^{-1}$ in Kano (average rainfall of 750 mm $yr^{-1}$) and contributed average annual inputs of 3.1 kg N $ha^{-1}$, 3.9 kg P $ha^{-1}$ and 10.1 kg K $ha^{-1}$. While for N the values were in the range of estimated nutrient inputs reported by Herrmann (1996) cited by Schlecht et al. (2004) for the Sahelian region of 2–4 kg N $ha^{-1}$, this was not the case for P input. However, values were close to estimated rain N input in the Nigerian savanna (Adeniyi, 2006), and slightly lower than rain inputs of 4.5 kg N $ha^{-1}$ found in the northern Guinea savanna of Nigeria (Jones and Bromfield, 1970).

In a study from Niamey, Niger, with high input of nutrients under similar garden and field production systems, experimentally measured nutrient leaching via cation/anion exchange resin were 3.6 kg N $ha^{-1}$ $yr^{-1}$ and 2.7 kg P $ha^{-1}$ $yr^{-1}$ for millet fields and 17 kg N $ha^{-1}$ $yr^{-1}$, 1.2 kg P $ha^{-1}$ $yr^{-1}$ and 24.9 kg K $ha^{-1}$ $yr^{-1}$ for gardens, while gaseous N loss was 17 kg N $ha^{-1}$ $yr^{-1}$and 92 kg N $ha^{-1}yr^{-1}$ for millet fields and gardens, respectively (Predotova et al., 2010a; Predotova et al., 2011). These measured values were used together with measured IN4, to calculate the overall farm balances after standardizing these values to the area of cultivated plots/fields for each crop. For all the farm types, measured leaching decreased, while IN4 and OUT12 were higher. In calculating the new balance, the higher and lower values of flows cancelled out and gave similar measured and modelled full farm balances for P ($r^2$=0.995) and K ($r^2$=0.982) across all the farms types, but different balance values for N ($r^2$=0.015). The nitrogen balance was similar for cGCL and cGscL ($r^2$=1.000) but a poor relationship was observed when N balance from cLsC was included. This is because the measured leaching for millet fields in Niger was used, which underestimates the situation in cLsC farm type. Apparently, lower annual leaching (0.35 kg N farm$^{-1}$) resulted when the measured value was used compared to that from the model (34.8 kg N farm$^{-1}$) for the farm type. Compared with the nutrient input of 844 kg N ha$^{-1}$ in cLsC, using the value of 3.6 kg ha$^{-1}$ of N leached in Niger grossly underestimates situations explained in different studies. Almost 10-folds of nutrients were applied in cLsC farm type compared with the high input millet systems in Niger. Also, only aspects of mineral nitrogen leaching were captured in these measurements. Several studies (Siemens and Kaupenjohann, 2002; Van Kessel et al., 2009) reported annual N leaching of 6–10 kg of the dissolved organic components from cultivated sites in Europe which accounts for up to 26% of total soluble N. If the organic N component is considered, it could have resulted in more N leaching than what was obtained in the measurement. Nitrogen loss is often related to application rates and management, where up to 40% of applied N is lost from the system (Janssen and Willigen, 2006).

### 3.6. Farm-level: full versus partial balances

Full farm-level nutrient balances from MONQI for the studied UPA farm types were positive for N and P. Full farm balances were positive for K in cGscL and cLsC but not in cGCL. Partial balances (considering only IN1, IN2 and IN3, OUT7, OUT8, OUT9 and OUT10) were positive for all nutrients with the exception of K in cGCL. This shows that the outflow of K exceeds its inflow in that farm type. Because K plays an important role in improving the quality of most vegetables, crop removal constituted the major outflow of K. Negative partial and full balances for potassium indicate a potential for K deficiencies in these systems in the long run except with continuous K fertilization. Similar values of negative K balances were obtained in peri-urban vegetable cultivation in China (Wang et al., 2008). In cGCL, nitrogen outflows were mainly through crop uptake (OUT7 and OUT9) but overall balances remained positive because of the flows within the system where produced crops are taken to the household stock for food and feed. Livestock feed inflow is only from external sources in cGscL, which contributed to the negative net cash flow and gross margin. Positive balances for P across all farm types may be attributed to the poor mobility and little plant uptake of nutrient P from the soil (Janssen and Willigen, 2006).

For the land uses, though no P leaching was recorded in this study, 1.2 and 2.7 kg P ha$^{-1}$ yr$^{-1}$ were leached under intensive gardening and millet cultivation, respectively, in Niamey UPA (Predotova et al., 2010a), and up to 25% of P from fresh manures (Tittonell et al., 2010) in Kenya. These values are negligible to the P balance of the studied systems. Despite high nutrient inputs, modelled nitrogen leaching from land uses were 29, 73 and 56 kg ha$^{-1}$ yr$^{-1}$ for cGCL, cGscL and cLsC, respectively, while modelled gaseous N losses ranged from 18 to 45 kg ha$^{-1}$ yr$^{-1}$ across the farm types. In the cGscL and cLsC farm types, estimated leaching values exceeded the annual critical limit that is detrimental for groundwater quality (50 mg N l$^{-1}$) of 35–42 kg N ha$^{-1}$ set for The Netherlands (Verhagen and Bouma, 1998). The World Health Organization (WHO) also set this standard limit for N concentration in groundwater, which was adapted by the EU (Schröder et al., 2004). Annual gaseous N losses in this study were lower than experimentally measured values of 92 kg N ha$^{-1}$ yr$^{-1}$ under a similar UPA production system in Niger (Predotova et al., 2010a). It still remains difficult to impose a critical limit to gaseous losses of nutrients but ways have been suggested to reduce these through proper management (Tittonell et al., 2010).

## 3.7. Nutrient use efficiencies and sustainability of the UPA system

Farm-level NUE of 49, 26 and 94% for N; 44, 29, 89% for P and 150, 34 and 125% for K were calculated for cGCL, cGscL and cLsC, respectively. The ability to efficiently use a nutrient when nutrient output and input ratio equals 1 (100%), is a commonly used index to asses NUE as it represents the ideal situation within an agroecosystem, and often is impossible to attain (Olsson, 1988). Based on this index, NUE was generally poor in cGCL and cGscL farm types. This occurred because the amounts of nutrients applied were much more than the amounts needed and actually really used. Efficiencies above one hundred percent obtained for potassium (150 and 125%) in cGCL and cLsC, respectively, show outflows exceed inflows. Unlike in cGCL, where K outflow is mainly from crop products and residues, it is mainly from manure in cLsC, where it is re-used in crop production. In general, efficiency is higher in cLsC because NUE is close to 100% compared to the other farm types. Differences in nutrient flows observed for the farm types as influenced by management played an important role in these systems. This is related to the study that found nutrient management to be a crucial factor in nutrient budgets (Oenema and Pietrzak, 2002).

Efficiencies in nutrient uses could be discussed from the point of view of the two major aspects of production in the UPA farms. Under small livestock production systems, nutrients are supplemented as offered feed but animals are often left to scavenge around the living areas and exposed to public waste dumps. These systems are characterized by poor feeding strategies and low feed conversion efficiencies as shown for a similar UPA livestock production system in Niger (Diogo et al., 2010b). Livestock keeping in the cLsC farm type involves mainly grazing and supplementation with concentrate especially during the dry periods when access to grass is limited (Schlecht et al., 1995; Moritze, 2010). The productivity of this system will depend on the herbage quality of the grazing pastures and the supplemented feed for continued productivity (Schlecht et al., 1995). Also, current practice in cattle keeping involves animals being corralled on bare land close to the homestead after daily grazing on natural pastures. Corralling of livestock on crop fields has been shown to increase nutrient use efficiencies because of direct soil capture of nutrients and reduced labour associated with transporting manures (Schlecht et al., 2004). Such practice is often driven by decisions taken at household level (Ramisch, 2005) as the farmers indicated a preference for keeping livestock close to the homestead. Under the same farm type (cLsC), manure from the homestead is taken to the fields 2 to 3 times during the dry season (October–April) and left in open heaps which are subject to further nutrient losses. In a study of small holder farming systems in Kano closed-settled zone, manure was found to be inferior in macro nutrients as a result of poor management in storage and handling (Beavington et al., 2000). As a result, large quantities of manure taken to the field may not well represent nutrient supply for crop production because of the losses incurred. In view of these practices, efficiencies in the use of manure could be much improved with proper management such as covering manure heaps and reducing the storage time (Tittonell et al., 2010). Manure outflow from farms with large herds through sale and gift also ensures a distribution to other farm holdings that do not keep animals and require manure to fertilize fields or plots.

Nutrient use in UPA cultivation is mainly supported by the use of waste water to irrigate farmland and gardens, such that 5000 $m^3$ of water applied to a hectare with nitrogen concentrations of 50 mg $l^{-1}$, 10 mg $l^{-1}$ P and 30 mg $l^{-1}$ K can supply all the nutrients needed in the production of vegetable or field crop (FAO, 2010b). Nutrient contents in the studied UPA farms exceed this concentration and farmers perceive wastewater as a source of nutrients and water for irrigation (Keraita et al., 2002). Depending on what aspect of sustainability we look at, it is often questioned according to excesses in nutrient application as observed in this study. This poses a greater environmental challenge in the eventual fate of these nutrients. Sustainability of these systems are further hampered by poor management in livestock keeping with consequences and inconveniences such as those attributed to humans living in close proximity to animal stables (Budisatria et al., 2007).

### 3.8. Challenges and implication of research

We expressed flows on a farm basis to understand the processes of nutrient flows between farm components and the environment. The results indicated poor nutrient use efficiencies of the UPA systems and a large effect on the environment from excess nutrient applications to fields and vegetable gardens. The high positive balances in cropping activities point to a high build-up of nutrients in soils. With the different and dynamic processes that occur with nitrogen in soils, a substantial amount of N will be lost to the environment. In the long-term, P leaching or run-off could occur when the soils become saturated and release P into the soil solution (Behrendt and Boekhold, 1993). The same applies to the livestock sub-systems where considerable losses of nutrients are likely to occur from open/unprotected manure heaps and stables. With these consequences, UPA systems should be considered and incorporated into environmental policies by local authorities up to the central administrative bodies of government.

## 4. Concluding remarks

In contrast to nutrient balance studies of smallholder farms in East and West Africa that often show negative balances, positive balances are observed for the urban and peri-urban agricultural (UPA) production systems in Kano. This study provides insights into the complexity within these UPA systems. We conclude that:

1. MONQI allowed us to depict flows/balances and economic performance indicators but still has certain weaknesses to evaluate the N-related hard to quantify flows with the transfer functions used (leaching and gaseous flows).

2. Therefore the results presented for the farm types (cGCL, cGscL and cLsC) have to be viewed with care but point to excess nutrient application in all the farm types with the exception of K in the cGCL farm type.

3. From critical limits set for safe groundwater quality (50 mg N $l^{-1}$) by WHO and

EU, nitrogen leaching in the UPA systems most probably exceeds this limit in cGscL and cLsC farm types, but remains within safety limits in cGCL.

4. Economic indicators suggest that UPA activities in Kano are a profitable venture for all the farm types, especially cLsC farm type.

The limitations accompanying the application of MONQI in this study could be overcome with system-specific expressions/equations that better approximate field or plot-level processes such as leaching and volatilization. It is recommended to rationally use nutrients for a more sustainable production and to prevent long-term K deficiencies in the cGCL farm type. In view of ecological and economic considerations ensuing from this study, improvement in resource use and management could be achieved with a better recognition of the sector by means of institutionalizing UPA into government structure. The Kano municipality as well as city officials of other Nigerian/West African cities should ensure implementation of effective policy measures with more strict regulations on waste management and waste quality in crop and vegetable production. This could also create awareness and appreciation of UPA activities in agricultural extension agencies and other stakeholders for an efficient dissemination of methods that would reduce the negative environmental impacts from UPA practices.

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# Appendix

Table i: Gross margin (US$ $\text{farm}^{-1}$ $\text{yr}^{-1}$) realized from different activities in the three farm types of the Kano UPA households.

| | Farm types[1] | | |
|---|---|---|---|
| | cGCL | cGscL | cLsC |
| Gross margin LA | 1059 | 194 | 296 |
| Gross margin AA | −37 | −1025 | 9033 |
| Gross margin RA | −1 | 0 | −65 |
| Gross margin SA | −278 | −116 | −1144 |
| Gross margin HA | 1166 | 1044 | 916 |
| Total gross margin | 1909 | 97 | 9036 |
| Gross margin portion from crops/vegetables (%)[2] | 56 | 200 | 3 |
| Gross margin portion from livestock (%)[2] | −2 | −1057 | 100 |

[1] cGCL = commercial gardening plus field crop-livestock; cGscL = commercial gardening plus semi-commercial livestock; cLsC = commercial livestock plus subsistence field cropping.

[2] Percentages for land and animal activities were calculated from total gross margin.

LA= land activity; AA= animal activity; RA= redistribution activity; SA= stock activity; HA= human activity.

Table ii: Calculated sensitivities of MONQI model variables on N leaching ($OUT11_N$) with respect to ±2% deviations around the default value for the different farm types.

| Variables | Farm types | | |
|---|---|---|---|
| | cGCL | cGscL | cLsC |
| Precipitation | 0.219 | 0.227 | 0.263 |
| Soil clay content | –0.800 | –0.817 | –0.801 |
| Mineral fertilizer | 0.000 | 0.000 | 0.000 |
| Organic fertilizer input | 0.450 | 0.625 | 0.692 |
| Mineralization rate | 0.002 | 0.001 | 0.001 |
| Total nitrogen (TN) | 0.010 | 0.000 | 0.000 |

Table iii: Calculated sensitivities of MONQI model variables on K leaching ($OUT11_K$) with respect to ±2% deviations around the default value for the different farm types.

| Variables | Farm types | | |
|---|---|---|---|
| | cGCL | cGscL | cLsC |
| Precipitation | 0.530 | 0.068 | 0.063 |
| Mineral fertilizer | 0.000 | 0.000 | 0.000 |
| Organic fertilizer input | 0.506 | 0.575 | 0.571 |
| Cation exchange capacity (CEC) | −0.001 | 0.000 | 0.000 |

Table iv: Calculated sensitivities of MONQI model variables on N gaseous losses (OUT12) with respect to ±2% deviations around the default value for the different farm types.

| | Farm types | | |
|---|---|---|---|
| Variables | cGCL | cGscL | cLsC |
| Precipitation | 0.035 | 0.022 | 0.008 |
| Organic carbon | 0.003 | 0.002 | 0.001 |
| Mineral fertilizer | 0.000 | 0.000 | 0.000 |
| Organic fertilizer input | 0.722 | 0.890 | 0.982 |

Table v: Calculated sensitivities for atmospheric depositions (IN4) of nitrogen (N), phosphorus and potassium (K) and for nitrogen fixation (IN5) at ±2% changes in precipitation with respect to the deviations around the default value for the different farm types.

| | Farm types | N | P | K |
|---|---|---|---|---|
| IN3 | | | | |
| | cGCL | 0.298 | 0.289 | 0.294 |
| | cGscL | 0.300 | 0.289 | 0.294 |
| | cLsC | 0.300 | 0.289 | 0.294 |
| IN4 | | | | |
| | cGCL | 0.223 | - | - |
| | cGscL | 0.223 | - | - |
| | cLsC | 0.223 | - | - |

## Chapter 5

# Nutrient balances in urban and peri-urban gardens of three West African cities

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Abdulkadir, A. Nutrient balances in urban and peri-urban gardens of three West African cities.

## Abstract

Urban and peri-urban (UPA) cultivation supplies fresh vegetables and employment for the increasing number of urban inhabitants. It is characterized by the use of large nutrient inputs to increase productivity and often associated with negative environmental risks. For these reasons, this study quantified nutrient (nitrogen, N; phosphorus, P; and potassium, K) flows and economic performance in UPA gardening of the three West African cities of Kano, Nigeria; Bobo Dioulasso, Burkina Faso; Sikasso, Mali, during a two year period using the MONQI toolbox. The study considered inflow of nutrients from mineral and organic sources, from depositions through rain and dust and from non-symbiotic N-fixation. Outflows included harvested products, crop residues, leaching losses, volatilization and erosion losses. Average annual N, P and K balances were positive for all gardens in the three cities with N balances of 279, 1127 and 74 kg N ha$^{-1}$ in Kano, Bobo Dioulasso and Sikasso, respectively, except two annual K deficits of 222 and 187 kg K ha$^{-1}$ in Kano and Sikasso, respectively. Efficiencies were 63%, 51% and 87% for N use in Kano, Bobo Dioulasso and Sikasso, respectively, with poor P use efficiencies due to excess application in all three cities. However, a high K efficiency was observed in Bobo Dioulasso (87%) while K applications were lower than required in Kano and Sikasso with efficiencies of 121% and 110%, indicating possible K mining. The average annual gross margins from gardening indicates a higher return of US$3.83 m$^{-2}$ in Bobo Dioulasso and differs statistically ($P<0.05$) from returns obtained in Kano (US$0.92 m$^{-2}$) and Sikasso (US$1.37 m$^{-2}$). Across the different cultivation seasons, gross margins obtained were different in all three cities and differ ($P<0.05$) between Bobo Dioulasso and Sikasso in the hot dry and in the rainy season. Lowest returns from gardening were obtained in the hot dry season between February and May. Results indicate an oversupply of nutrients in excess of crop demand and suggest significant losses to the environment. Although an economically vibrant activity, intensive UPA vegetable production needs to be reviewed for strategic planning towards improving N and P use efficiencies in order to maintain its productivity as well as safeguard the environment. Appropriate K fertilization is necessary to avoid long term K depletion in Kano and Sikasso UPA gardening.

**Keywords**: nutrient budgets, urban and peri-urban agriculture, gross margin, nutrient use efficiencies, MONQI toolbox.

# 1. Introduction

Rapid urbanization and population surge, especially in the developing world, has led to increasing food demand and subsequent cultivation of arable lands in and around cities. Urban and peri-urban vegetable production is a common practice that has received a lot of attention in the past decade with regard to food production under critical water-scarce semi-arid conditions of sub-Saharan West Africa. In many developing regions of West Africa, urban cultivation is found on fallow land in cities either under a legal contract or on free land, situated along the course of city drainage canals or waterways. These sites and plots serve to intensively cultivate vegetables thus providing employment opportunities to the urban dwellers (De Bon et al., 2010; Drechsel and Dongus, 2010). Reports show that urban and peri-urban agriculture (UPA) meet the urban demand for fresh vegetables by 10–90% and up to 70% of meat and 100% of poultry products (Cofie et al., 2003; Smith, 2001), and highlighted its contribution to sustainable urban supply. In view of the continuous growth of urban population and the economic benefits it offers, UPA will remain an important activity to support the livelihood of the urban poor farmer (Gyiele, 2002; Danso et al., 2002).

Most of the UPA vegetable systems make use of urban resources such as labor, waste and wastewater, and operate in areas where access to proper waste disposal is minimal. Many cities are characterized by unchecked disposal of municipal and industrial wastes into urban rivers or streams, which raises concerns of food safety when this water is used for cultivation. In many West African cities, wastewater serves as the main source of water for irrigating the crops (Keraita et al., 2002).

Despite the externalities associated with the UPA practice of wastewater irrigation (Abdu et al., 2010; Binns et al., 2003; Drechsel et al., 2008), a significant amount of nutrients is applied to crops and serves a cost-efficient method for the urban cultivators in crop production. For Kumasi, Ghana, Keraita et al. (2002) reported yearly nutrient inputs from water amounting to 10–200 kg nitrogen (N), 130–300 kg phosphorus (P) and 240–470 kg potassium (K) per hectare of irrigated land. Similarly, in Pakistan yearly nutrient inputs of 864 kg N $ha^{-1}$, 86 kg P $ha^{-1}$ and 363 kg K $ha^{-1}$ were reported by Van der Hoek et al. (2002) through wastewater irrigation. In a recent study, waste water irrigation accounted for inputs of 2427 kg N $ha^{-1}$, 376 kg P $ha^{-1}$ and 1439 kg K $ha^{-1}$ in the urban vegetable gardens of Niamey (Diogo et al., 2010a). Ensink et al. (2002) stressed the win-win situation of wastewater use by urban farmers and city officials of Pakistan with respective benefits from nutrient supply for vegetable cultivation and a levy of US$3.50 per hectare per year charged to use such water. Intensification in UPA gardening will continue in order to increase production per unit area of scarce land (Lynch et al., 2001). This is also driven by the increased demand for food and vegetables from the pressure of urbanization. High nutrient inputs to UPA gardening activities may create an imbalance in the soil-crop system (Wang et al., 2008; Diogo et al., 2010a; Douxchamps et al., 2010; Mishima et al., 2010; Pathak et al., 2010) and thus, pose a potential threat to the environment through leaching and volatilization.

Nutrient balances, especially at the farm level, have been used to assess on-farm nutrient management from the knowledge of nutrient flows (Öborn et al., 2003). Nutrient balances have also been successfully used in evaluating the sustainability of farming systems (He et al., 2007). The approach accounts for element balances through differences between inputs and outputs while taking changes in the soil pool into consideration (Færge et al., 2001; Öborn et al., 2003; Oenema et al., 2003). This procedure to set up balances necessitates gathering quantitative information on the nutrient flows and serves as a basis to develop policies that could be adapted for sustainable production from agronomic, economic and environmental perspectives (Mishima et al., 2010). Several models have been used to quantify nutrient budgets in agricultural lands. Færge et al. (2001) developed a simple static inflow/outflow model to monitor the flow of N and P in Bangkok. The present study used the MONQI toolbox (MONQI, 2007) to quantify flows and balances of major nutrients as well as the economic performance of small-scale urban and peri-urban vegetable gardens in three West African cities, namely Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali). The objectives of the study are to (i) quantify the fluxes of the major nutrients in UPA gardens of the three cities, (ii) gain insight into nutrient use efficiencies in UPA vegetable production systems, (iii) assess the economic benefits of UPA gardening, and (iv) infer the rate of nutrient accumulation in the soil from the nutrient budgets.

## 2. Materials and methods

### 2.1. Study sites and farm selection

A total of fourteen gardens were selected for this study across the three cities, 6 from Kano (Nigeria), 2 from Bobo Dioulasso (Burkina Faso) and 6 from Sikasso (Mali). They represent the secondary cities in each country with 3.6 million, 200,000, and 400,000 inhabitants in Kano, Bobo Dioulasso (further called Bobo) and Sikasso, respectively. Gardens were selected following an initial baseline survey of UPA farmers across the three cities (Abdulkadir et al., 2012; Dossa et al., 2011) and represent vegetable production sections of identified farm types. These systems are similar in production orientation (market) across the three cities. The two gardens selected in Bobo represent the two main UPA garden irrigation management systems that exist within the city. A brief description of their biophysical characteristics and farm management is given in Table 1. Rainfall is seasonal and shows an uni-modal distribution across all cities, and Bobo has an average long-term (44 years) annual rainfall of 1143 mm (Abdel-Rahman et al., 2008) although 728 mm were recorded in the year 2008.

Two irrigation management systems exist within the UPA gardening systems. In Kano, vegetable cultivation takes place along the banks of the major river that runs through the city. The river serves as a main discharge point of domestic, municipal as well as industrial wastes (Mashi and Alhassan, 2007). Most of the gardeners in Kano reported long-term (>30 years) cultivation with the same water source. A similar wastewater irrigation practice is found in Bobo and Sikasso, where cultivation also takes place along the rivers banks, although most farmers have dug-up wells in their gardens and rely on well water irrigation, especially in Sikasso. Therefore, nutrient supply for cultivation in the latter two cities is mainly from organic and inorganic fertilizers. Garden areas are usually between <0.1 ha to 0.4 ha (Abdu et al., 2011) and cultivated with crops like lettuce (*Lactuca sativa* L.), amaranthus (*Amarathus caudatus* L.), carrots (*Daucus carota* L.), and cabbage (*Brassica oleracea* L.). Other crops include parsley (*Petroselinum crispum* Mill.), tomato (*Lycopersicum esculentum* L.), coriander (*Coriandrum sativum* L.), beet (*Beta vulgaris* L.), kenaf (*Hibiscus cannabinus* L.), and onion (*Allium cepa* L.). In Kano, five of the six selected gardens use wastewater in dry season irrigation and one garden used well water (Table 2). In Bobo, one garden irrigates with waste water and the other with well water, whereas only two gardens irrigate with waste water in Sikasso. Except for one farmer in Sikasso, garden households involved in UPA for less than 25 years were classified as either immigrants or recently engaged in UPA gardening. All the farmers in Kano were considered as indigenous or autochthons (Table 2).

Table 1: Characteristics of the three West African study locations.

| | | Kano | Bobo Dioulasso | Sikasso |
|---|---|---|---|---|
| City coordinates | | 12$^{o}$ 00’ N, 8$^{o}$ 31’ E | 11$^{o}$10’ N, 4$^{o}$19’ W | 11$^{o}$19’N, 5$^{o}$40’W |
| Altitude (a.s.l)[1] m | | 487 | 432 | 410 |
| Annual rainfall (mm) [2] | (2007–2009) | 750 (Unimodal) | 728 (Unimodal) | 1271 (Unimodal) |
| Rainy season | | May to September | May to October | May to October |
| Agro-ecological zone | | Sudano- Sahel Savanna | Sudanian Savanna | Sudanian Savanna |
| Mean annual temperature ($^{o}$C) | | 29–38 | 23–33 | 28 |
| Soils | | Nitosols,Ultisols | Lithosols, Alfisols | Luvisols |
| Main vegetables | | Amaranth, Lettuce, Carrots | Lettuce, Carrots, Tomato,Cabbage | Lettuce, Carrots, Cabbage |
| Others crops | | Parsley, Coriander, Kenaf | | Beet, Onion |
| Fertilizers (t $ha^{-1}$ $yr^{-1}$) [3] | Urea | 0.29 | 2.09 | 0.34 |
| | NPK[4] | 0.11 | 2.44 | 0.57 |
| | Urea+NPK | - | 1.54 | - |
| | Manure | 7.42 | 54.85 | - |
| | Waste | - | 59.98 | 235 |
| Water applied ($m^3$ $m^{-2}$ $yr^{-1}$) [5] | | 1.89 | 1.75 | 2.20 |
| Cultivation seasons [6] | | CD, HD, RS | CD, HD, RS | CD, HD, RS |

[1] Above sea level.

[2] Rainfall record in the study years; (Sources Bobo-Dioulasso[c]: Abdel-Rahman et al., 2008).

[3] Average of aggregated input of different fertilizers across all crops grown within a year; [4] NPK = 15-15-15.

[5] Average aggregated irrigated water applied across all crops grown within a year.

[6] CD = cold dry, HD = hot dry, RS = rainy.

Table 2: Some basic information on selected garden households in the three West African cities.

| City | Site in city | Location[1] | Total plot area ($m^2$) | Status in UPA[2] | Off-farm income | Farm type[3] | Irrigation water source |
|---|---|---|---|---|---|---|---|
| Kano (n=6) | Gada | U | 231 | A | no | cGscL | Waste |
| | Katsina road | U | 941 | A | yes | cGCL | Waste |
| | Zungeru | U | 880 | A | no | cGCL | Waste |
| | Kwakwace | U | 384 | A | yes | cGscL | Waste |
| | Koki | U | 764 | A | no | cGscL | Waste |
| | Legal | P | 836 | A | yes | cGCL | Well |
| Bobo (n=2) | Dogona | P | 250 | M | yes | cGCL | Waste |
| | Kodeni | P | 200 | A | yes | cGCL | Well |
| Sikasso (n=6) | Sanoubougou 2 | U | 3000 | M | no | cGscC | Well |
| | Sanoubougou 1 | U | 100 | M | yes | cGCL | Waste |
| | Kabohila | U | 2500 | M | no | cGCL | Waste |
| | Sanoubougou 2 | U | 1070 | A | no | cGscC | Well |
| | Mancourani | U | 5000 | M | yes | cG | Well |
| | Sanoubougou 2 | U | 1000 | M | no | cG | Well |

[1] U= urban; P = periurban.

[2] A = autochthonous; M = Migrant.

[3] cGscL=commercial gardening plus semi-commercial livestock keeping; cGCL= commercial gardening plus field crop-livestock; cGscC = commercial gardening plus semi-commercial field cropping; cG = commercial gardening.

## 2.2. Sampling

In MONQI, imported materials include all the nutrient inputs applied to the garden plots (inflows; IN) and exported materials include all harvested products (outflows; OUT). These quantities are recorded as mineral fertilizer (IN1) and organic inputs (IN2) while harvested products are recorded as (OUT1) and residues (OUT2).

### *2.2.1. Soils and crop*

At the beginning of the study, soil samples were taken from five gardens in Kano, and one garden each in Bobo and Sikasso, for later chemical analysis (section 2.3). Each time, three replicates from three sub-plots (1–2 $m^2$) in each garden at 0–20 cm depth were taken. Also, soil profiles were dug and sampled in five gardens in Kano to a depth of 1.5 m, and one profile each in Bobo and Sikasso, respectively. More soil profiles were sampled in Kano because this study was related to an investigation of heavy metal distribution in soil profiles (Abdu et al., 2011). The latter research was started because of reports on the release of industrial waste into streams in Kano (Binns et al., 2003). Because of a low probability of soil contamination with heavy metals in Bobo Dioulasso and Sikasso, and to reduce the costs of analysis, soil profiles were there sampled in one waste water irrigated garden each. In Kano, subsequent soil samples were collected at the beginning of each crop cycle or at harvest from the surface soil of the three sub-plots in each garden. These soil samples were pooled to form one composite sample per garden. Undisturbed soil cores were collected to determine bulk density from surface soil (0–20 cm) (Blake and Hartge, 1986). However, soil samples were collected in the cold dry season of only 2007 and 2008 in Bobo and Sikasso. In all three cities, crops were sampled from the same garden plots at each vegetable harvest. Crop sampling involved collection of 20–25 vegetable samples from the three sub-plots, and these were pooled into one sample per crop cycle to represent each harvest per garden. However, crop samples were analyzed for all three replicates per harvest in Bobo gardens because of the few number of gardens involved in the study. Crop samples were separated into edible parts (leafy/root part) and non-edible parts (residues), to make up the total harvested biomass. Subsequently, fresh and dry weights were determined to calculate crop-specific dry matter.

### 2.2.2. Nutrient input sources

Organic and inorganic fertilizers constitute the major nutrient input sources to garden plots in UPA (Table 1). Information on amounts of nutrients applied with mineral fertilizers used by the farmer was derived from the applied type of fertilizer and its nutrient composition. Information on the type, frequency and quantity of crop-specific organic inputs such as manure and waste, was collected. The manure and waste were subsequently analyzed for N, P, K and organic carbon (OC). Samples were collected over the entire study period from the gardens studied and pooled for the different cultivation seasons. However, organic carbon content of waste was obtained from literature (Bernal et al., 1998).

### 2.2.3. Irrigation water sampling

In Kano, irrigation water samples were collected fortnightly (from January 2008 to March 2009) from irrigated vegetable sites in the mornings and evenings to obtain representative nutrient concentrations.

Two replicates of 100 ml irrigation water were collected in plastic bottles, labelled and stored in the refrigerator at freezing temperature prior to laboratory analysis. These water samples were analysed on seasonal basis. Similarly in Bobo, well and waste water samples were collected once every week and pooled on a monthly basis. Average nutrient contents of waste and well water from Bobo and Kano were used for Sikasso because of the absence of sampling in Sikasso due to logistical constraints. Nutrient input through waste and well water irrigation was quantified from measured concentrations of nutrients multiplied by the discharge rate of farm-specific irrigation pumps or the capacity of the watering can, duration of irrigation per application and frequency of irrigation in each vegetable crop cycle. In case of use of a watering can, information on the number of cans applied per plot and crop was recorded. The amounts of water applied with irrigation pumps are approximations and thus there is some uncertainty in the quantification of the nutrient inputs.

### 2.2.4. Rain and dust collection

Rainfall data were collected from the weather station of the Institute for Agricultural Research (IAR) in Kano. Rain water samples were collected from every rainfall event of 2008 and 2009. For Bobo and Sikasso, rainfall data from Farakoba Agricultural Research Station in Bobo (Abdel-Rahman et al., 2008) and the Institute for Economic

Research (IER) in Sikasso were used. Dust was collected during cold dry (harmattan) periods of 2007–2008 and 2008–2009 with the aid of a dust trap. To this purpose 0.1 $m^2$ containers mounted on 2 m high sticks were installed in five of the studied gardens in Kano. Approximately 0.18 g of dust was collected per week from each container. Dust collection is based on methods described by Drees et al. (1993) and similarly adopted by Abdu et al. (2011). Extrapolated dust depositions from Harmattan distribution map of West Africa and nutrient concentrations in dust were obtained from FAO (2005b), and were used to quantify nutrient inputs through dry deposition for Sikasso and Bobo. Similarly, nutrient concentrations in rain water from FAO (2005b) were used to quantify N, P and K inputs to gardens in Bobo and Sikasso.

## 2.3. Sample preparation and chemical analysis

Soil samples were air-dried for 2–3 days, crushed and sieved through a 2-mm sieve. Crop samples were washed with tap water to get rid of adhered soil and small debris, drained of water and the fresh weights were assessed. Subsequently, they were placed in opened paper envelopes and oven-dried at 65 °C for 2–3 days and dry matter contents were calculated. Soil particle sizes were determined by the method described by Gee and Bauder (1986) and bulk density was determined by the Blake and Hartge (1986) method. Soil pH was measured in 1:2.5 soil to water solution with a glass electrode pH meter and cation exchange capacity (CEC) was determined by the silver-thiourea extraction method (Van Reeuwijk, 1993). Soil organic carbon (OC) was determined by the Walkley-Black wet oxidation method (Nelson and Sommers, 1986). For determination of total nitrogen (N), phosphorus (P) and potassium (K) in soil, water, plant and manure, samples were digested with $H_2SO_4$-salicylic acid-$H_2O_2$ with selenium as catalyst. N content was measured colorimetrically in the digest using the Bertholet reaction method (Chaney and Marbach, 1962) with an N-auto-analyser (TECHNICON AAII, CA, USA) at 660 nm.

Colorimetric determination of total phosphorus was based on ascorbic acid reduction of phosphomolybdate complex described by Lowry and Lopez (1946) at 882 nm on a visible spectrometer (Van Reeuwijk, 1993). Total K ion in the digest was determined with an atomic absorption spectrophotometer (AAS; Perkin-Elmer Analyst A400).

## 2.4. Data entry and quantification of nutrient flows in MONQI

Quantitative data was collected from regular monitoring of gardens households through interviews on quantities of applied inputs and output as harvested products and residues. These interviews were complemented with measurements and calibrations of local units of given quantities such as bags or donkey loads. Monitoring took place from October 2007 to October 2009 in Kano and Sikasso, whereas it took place from March 2008 to March 2010 in Bobo Dioulasso, although soil sampling started in all three cities in 2007. This represents two study years in each city. Vegetables were cultivated in the cold dry season (CDS) between October/November and February, in the hot dry season (HDS) between March and May, and in the rainy season (RS) between May and September. Quantities of inputs (IN1 and IN2) as well as harvested products (OUT1) and residues (OUT2) further referred to as manageable flows, are registered in farm-specific databases in the model. Atmospheric deposition from rain and dust (IN3) was calculated directly from measured nutrient content in rain and dust for Kano. Annual dust deposition was obtained by extrapolation from the map of dust distribution as 100 kg ha$^{-1}$ for Sikasso and 400 kg ha$^{-1}$ for Bobo, and nutrient contents were 3.8 g N, 0.79 g P and 18.7g K per kg of dust (FAO, 2005b). Using nutrient concentrations of 4.88 mg N, 0.63 mg P and 2.63 mg K mm$^{-1}$ of rain for the latter two cities (FAO, 2005b), site-specific amounts of precipitation was used to calculate nutrient inputs.

Other (environmental) flows include non-symbiotic nitrogen fixation (IN4), leaching (OUT3), and volatilization (OUT4) all of which were calculated based on transfer functions given by Lesschen et al. (2007), whereas soil erosion (OUT5) was calculated from the Universal Soil Loss Equation (Vlaming et al., 2001). Information was also collected on the costs of garden operations such as costs for seed, fertilizer, hired labour, and costs incurred for irrigation and pesticide application. Cash received from sale of vegetables was also included to assess economic flows following the approach of De Jager (2009). The market situation of the produced vegetables was monitored across the different seasons. Quantitative data and the economic value of each flow variable were entered into the data entry module of the MONQI toolbox for each garden and city. Garden-specific soil data and nutrient contents of vegetable crops and nutrient inputs were stored in the database. In principle, nutrient contents from analysed materials were converted to quantities by multiplying these by the amount of dry matter of the materials imported to or exported from the garden in the calculation module of the software. Similarly, the unit price of each farming operation such as weeding was multiplied with total time used for that operation, while the unit price of a vegetable was multiplied by the total amounts of harvested product to obtain total amounts per operation or harvest.

## 2.5. Nutrient balance calculation and nutrient use efficiencies (NUE)

Soil nutrient balances concern the soil-plant systems and relate to the changes between applied and extracted nutrients. Partial balances ($\mathrm{Partbal}_X$) were calculated for each nutrient element (X) as the difference between nutrient input as fertilizers and output as harvested products:

$$\mathrm{Partbal}_X = (\mathrm{IN1}+\mathrm{IN2}) - (\mathrm{OUT1}+\mathrm{OUT2}) \tag{1}$$

Full balances were calculated to include environmental flows such as IN3, IN4 and OUT3–5 together with those in the partial balance, given as:

$$\mathrm{Fullbal}_X = \sum \mathrm{IN} - \sum \mathrm{OUT} \tag{2}$$

Equations (1) and (2) are an application of the law of mass conservation where the left hand side of the equation represents the change in soil pool with respect to the applied nutrients. A positive balance indicates that inputs exceed outputs and the reverse is the case if the balance is negative.

Nutrient use efficiency (NUE) was calculated for the major elements N, P, K for the management-related flows using the partial balance method (Dobermann, 2007) with components of equation (1) using:

$$NUE = \frac{\sum_{i=1}^{n} Output_{Xi}}{\sum_{i=1}^{n} Input_{Xi}} \times 100 \tag{3}$$

where,

$Output_{Xi}$ = output of nutrient $X$

$Input_{Xi}$ = input of nutrient $X$

$n$ = the total number of $i$ nutrient input/output events.

In equation (3), the output accounts for nutrient (N, P, K) outflow from harvested products and their inflow as fertilizers (organic and inorganic).

### 2.6. Statistical analysis

Data was aggregated over a year for all flows and balances. For this purpose, the pivot function of Microsoft Excel program was used to take a yearly sum of all the flows in each of the studied households. The analysis was done using simple descriptive statistics across all the gardens in the three cities. Aggregated flow variables were subjected to Kruskal-Wallis non-parametric procedure for significant differences with city as independent variable, and means were later separated by the step-down Bonferroni multtest procedure (SAS Institute, 1999). Spearman’s rank correlation was performed between all flow variables for each city. All statistical analysis were conducted with SAS version 9.1 (SAS, 2003).

## 3. Results

### 3.1. Overview of UPA management

Gardening is a market-oriented UPA activity as described in an earlier study and it represents a major income generating activity (Abdulkadir et al., 2012). Across all three cities, 50% of the farmers generate income from non-farming activities to complement gardening. Amongst the cultivated vegetables, only lettuce and carrots were found to be common across the three cities during the period of monitoring, although a diverse range of other vegetables were cultivated. Gardens were mostly located in the urban areas and garden sizes were smaller in Kano than Bobo and Sikasso. Nutrient application was either through the use of mineral fertilizers or different organic sources or both. However, no statistical difference was observed between organic and inorganic nutrient inputs to UPA gardens under well or waste water irrigated systems in all cities.

### 3.2. Soil profile and surface properties

In all three cities, selected soil profile properties reveal decreasing nutrient concentrations from the upper soil layer to the deeper layers (Fig. 1) particularly for N, P, K and OC, thus showing the accumulation of nutrients in the upper soil layer. This is mainly caused by the application of nutrients in crop production. There was a trend of decreasing soil pH with depth in Kano and Sikasso, but a slight increase was observed in Bobo (data not shown). Vertical distribution of CEC was similar to the

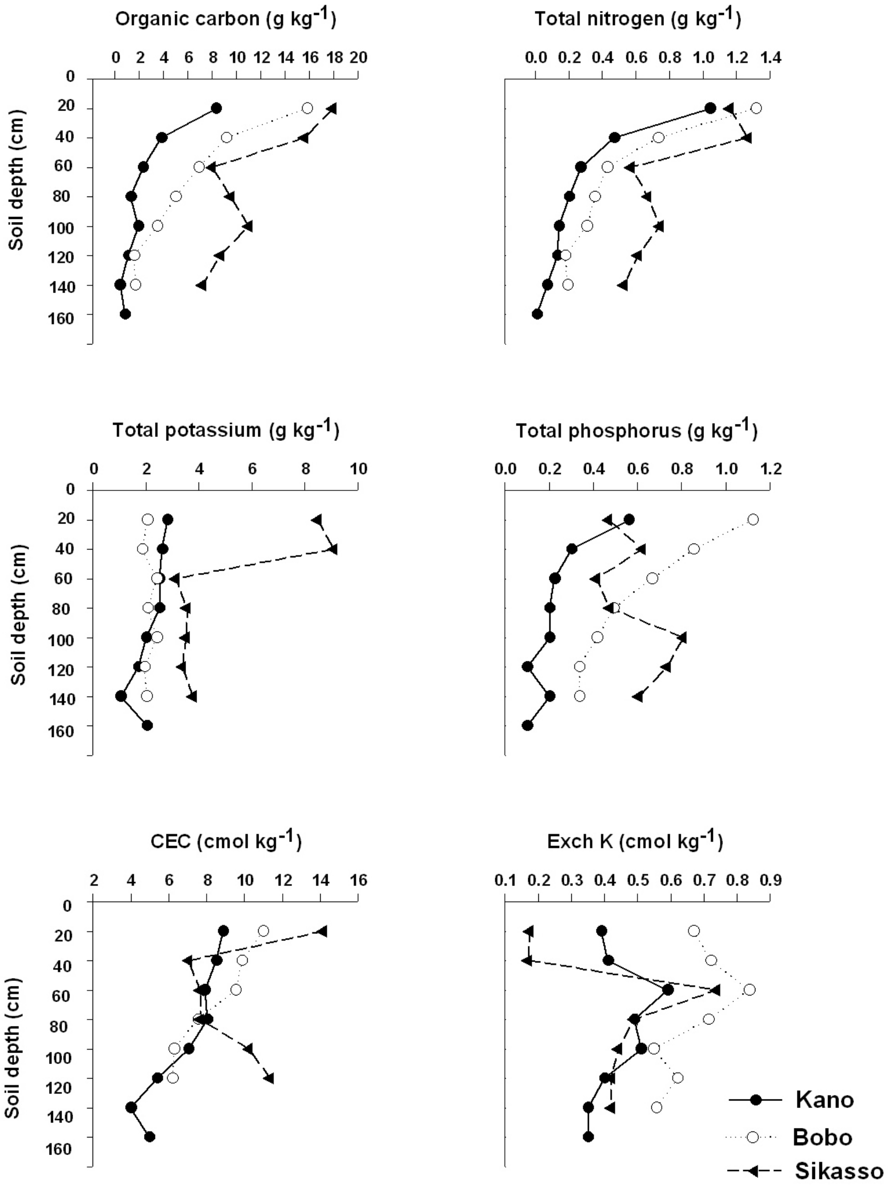

Fig. 1: Soil profile properties in UPA gardens of Kano, Bobo Dioulasso and Sikasso. Data for Kano represents mean of five gardens, and for one garden each in the other cities.

other properties in Kano and Bobo but was different in Sikasso. For all cities, there was a sharp increase in exchangeable potassium between 40–80 cm soil depths and decreased thereafter with depth. Table 3 gives average soil properties for the 0–20 cm depth in the three cities. Total nitrogen was 1.1 g kg$^{-1}$ in for gardens in both Kano and Sikasso, and 0.9 g kg$^{-1}$ in Bobo. Total phosphorus ranged from 0.5–1.1 g kg$^{-1}$ across the three cities, while organic carbon in Kano was 9.7 g kg$^{-1}$. Soil pH and bulk densities were within the range for ideal soil fertility across all three cities (USDA, 2008).

Table 3: Soil properties and soil nutrient stocks (Mg $ha^{-1}$) in the 0–20 cm depth of the studied UPA gardens.

| Soil properties | Total N (g $kg^{-1}$) | Total P (g $kg^{-1}$) | Total K (g $kg^{-1}$) | OC (g $kg^{-1}$) | pH water (1:2.5) | CEC (cmol $kg^{-1}$) | BD (Mg $m^{-3}$) | Clay (g $kg^{-1}$) | Sand (g $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Kano (n=6) | 1.1 | 0.7 | 3.2 | 9.7 | 6.9 | 8.7 | 1.5 | 150 | 648 |
| Bobo (n=1) | 0.9 | 1.1 | 1.6 | 13.1 | 6.4 | 10.4 | 1.5 | 200 | 620 |
| Sikasso (n=1) | 1.1 | 0.5 | 5.9 | 15.0 | 6.5 | 10.6 | 1.5 | 180 | 650 |

| Soil stock | N | P | K | OC |
|---|---|---|---|---|
| Kano (n=6) | 3.3 | 2.1 | 9.6 | 29.1 |
| Bobo (n=1) | 2.7 | 3.3 | 4.8 | 39.3 |
| Sikasso (n=1) | 3.3 | 1.5 | 17.7 | 45.0 |

N =nitrogen; P = phosphorus; K = potassium; OC = organic carbon; CEC = cation exchange capacity; BD = bulk density. Data for Kano represents average soil surface properties in the first year of study for all gardens. Properties for Bobo and Sikasso represent the average of 2007 and 2008 data collected from one garden each.

## 3.3. Nutrient inputs

Mineral fertilizer (IN1) and organic fertilizer (IN2) constitute major nutrient inputs to UPA gardens with organic inputs making up 89%, 51% and 84% of applied fertilizer N in Kano, Bobo and Sikasso, respectively, and over 90% of P and K inputs in Kano and Sikasso. There was no statistical difference ($P>0.05$) between organic N, P and K inputs in the three cities (Fig. 2). However, P and K mineral fertilizer inputs differed between all three cities ($P<0.05$). Mineral fertilizers contributed 49%, 43% and 19% of the applied N, P and K in Bobo and differed statistically ($P<0.05$) with Kano and Sikasso, showing higher use of mineral fertilizers in Bobo than the other cities. Nitrogen, P and K input through atmospheric deposition (IN3) was statistically different between Kano and the other two cities ($P<0.001$), and also differed between Bobo and Sikasso for all three nutrients ($P<0.05$). Nitrogen input through biological fixation (IN4) was similar ($P<0.05$) in all three cities.

In Table 4, the mean nutrient concentration of different input sources used in cultivating vegetables is indicated. Organic inputs to UPA gardens differed across the three cities. Wastewater was the main source of organic input in Kano and constituted 89%, 71% and 92% of applied N, P and K to UPA gardens, respectively. Manure and waste were the main sources of organic nutrient input in Bobo, while waste was the major organic input in Sikasso. Nutrient content in wastewater in Kano was higher than in the other cities and correlated significantly ($P<0.001$) with N, P, and K inputs ($r^2= 0.608$, 0.677 and 0.561 respectively).

Aggregated average annual N inputs were 937, 2478 and 958 kg ha$^{-1}$ in Kano, Bobo and Sikasso, respectively (Fig. 2). The high value in Bobo may be due to higher inputs of mineral fertilizers as well as large quantities of manure and waste used as compared to Kano. In Kano, farmers applied an average of 7.4 t DM ha$^{-1}$ yr$^{-1}$ manure, whereas 55 t DM ha$^{-1}$ yr$^{-1}$ were used in Bobo. No application of waste was observed in the studied gardens of Kano, but 60 t DM ha$^{-1}$ yr$^{-1}$ of waste was applied to gardens in Bobo and 4-times more was applied in Sikasso. Average N, P and K inputs to lettuce per crop cycle was significantly different ($P<0.05$) across the three cities, but no difference was observed for all nutrients applied to carrots (Table 5). Nutrients applied to cabbage were different between Bobo and Sikasso ($P<0.05$), while the amount of water applied to lettuce was higher in Sikasso, water applied to lettuce in Kano and Bobo was similar ($P>0.05$). Dry matter produced from water applied per crop cycle indicated poor to good water productivity (range 0.7 to 4.5 kg DM m$^{-3}$) and did not differ across the three cities (Table 5). Water applied to carrots per crop

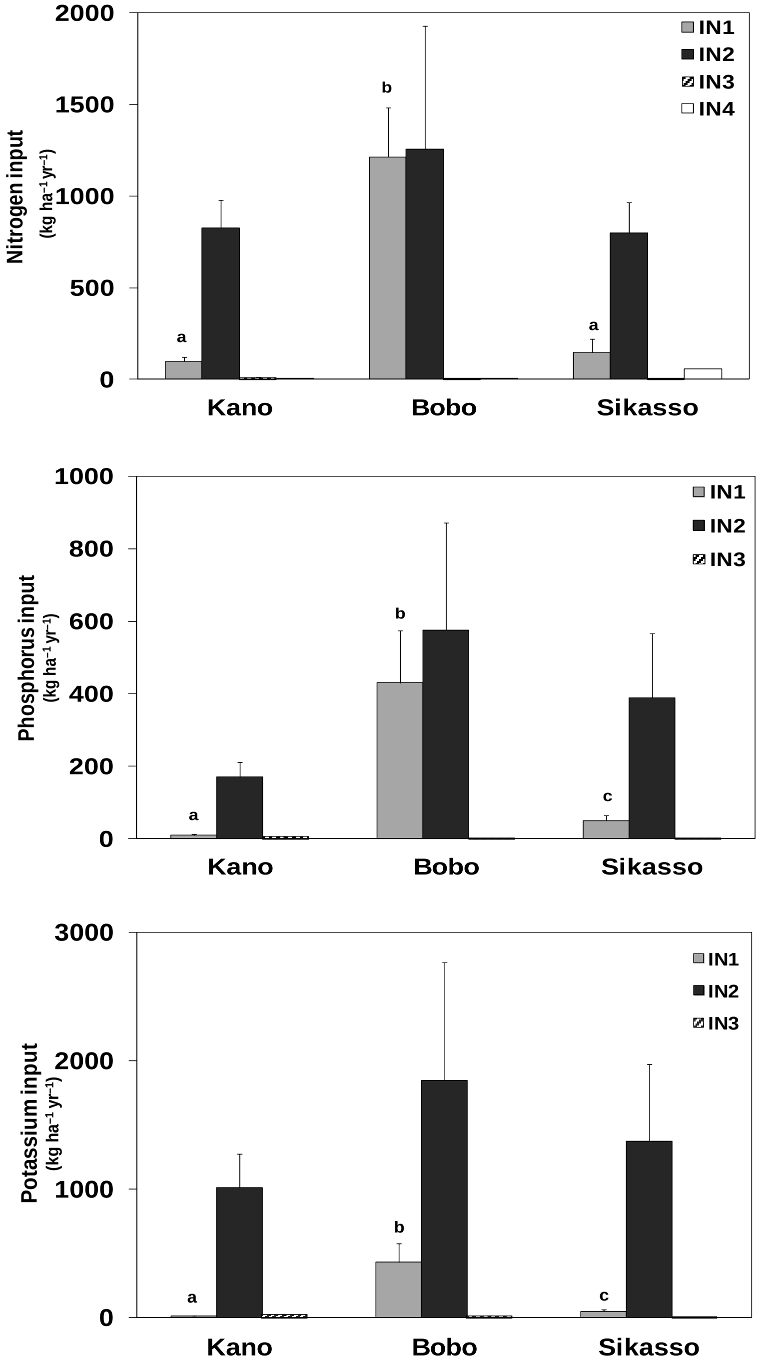

Fig. 2: Aggregated annual nutrient input to gardens in Kano (n=6), Bobo (n=2) and Sikasso (n=6) during a 24 month monitoring period. Data represent means plus one standard error. Bars with different letters are statistically different (Kruskal-Wallis test and Bonferroni multtest, $P<0.05$) across the three cities, and those without letters have no statistical difference between them. IN1 = mineral fertilizer; IN2 = organic fertilizer; IN3 = atmospheric deposition; IN4 = non-symbiotic N-fixation. IN3 and IN4 are hardly visible because of the large scale of the y-axis.

Table 4: Mean of nitrogen (N), phosphorus (P), potassium (K) concentrations and organic carbon (OC) contents of different input sources applied to UPA gardens in Kano, Bobo and Sikasso during a 24 months monitoring period.

| | | N (mg l$^{-1}$) | P (mg l$^{-1}$) | K (mg l$^{-1}$) |
|---|---|---|---|---|
| Wastewater | | | | |
| | Kano (n=15) | 39.7 (34.63) | 10.4 (5.67) | 76.4 (42.97) |
| | Bobo (n=8) | 6.8 (1.48) | 0.4 (0.23) | 10.3 (0.14) |
| | Sikasso (n=1) | 28.2 | 0.6 | 52.0 |
| Well water | | | | |
| | Kano (n=3)[1] | 0.6 (0.0–1.19) | 0.8 (0.67–0.99) | 3.6 (0.17–8.30) |
| | Bobo (n=10) | 10.3 (8.95) | 0.3 (0.15) | 4.1 (3.66) |
| | Sikasso (n=1) | 8.5 | 0.3 | 2.8 |
| Rain | | | | |
| | Kano (n=13) | 0.5 (0.66) | 0.7 (0.42) | 1.4 (1.10) |

(% in dry matter)

| | | N | P | K | OC |
|---|---|---|---|---|---|
| Manure | | | | | |
| | Kano (n=9) | 1.4 (0.57) | 0.8 (0.18) | 1.7 (0.81) | 34.7 (9.58) |
| | Bobo (n=10) | 1.2 (0.38) | 0.6 (0.32) | 1.7 (0.36) | 40.0 (0.00) |
| | Sikasso (n=0) | - | - | - | - |
| Waste | | | | | |
| | Bobo (n=2) | 0.9 | 0.6 | 1.7 | 20.0 |
| | Sikasso (n=1) | 0.9 | 0.5 | 1.7 | 20.0 |

[1] Minimum and maximum values in parenthesis for n<5, otherwise standard deviation.

Table 5: Nitrogen (N), phosphorus (P), potassium (K) and organic carbon (OC) input (kg ha$^{-1}$), total DM yields, gross margin (US \$ m$^{-2}$), water applied and water productivity per crop cycle of selected vegetables cultivated in the UPA gardens of the three cities.

| Crop | City | Crop cycle (#)$^{1}$ | DM yields (t ha$^{-1}$) | N | P | K | OC | Gross margin (US \$ m$^{-2}$) | Water applied per crop cycle (m$^{3}$ ha$^{-1}$) | Water productivity (kg DM m$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Lettuce | Kano | 18 | 3.8$^{a}$ | 135$^{a}$ | 29$^{a}$ | 96$^{a}$ | 80$^{a}$ | 0.2$^{a}$ | 2670$^{ab}$ | 1.4 |
| | Bobo | 10 | 3.9$^{ab}$ | 530$^{b}$ | 196$^{b}$ | 528$^{b}$ | 6958$^{bc}$ | 0.6$^{b}$ | 2782$^{b}$ | 1.4 |
| | Sikasso | 35 | 6.4$^{c}$ | 390$^{c}$ | 143$^{c}$ | 455$^{c}$ | 4283$^{c}$ | 0.3$^{c}$ | 4755$^{c}$ | 1.4 |
| Carrot | Kano | 7 | 4.7$^{a}$ | 349 | 52 | 296 | 169$^{a}$ | 0.6 | 7078 | 0.7 |
| | Bobo | 2 | 14.2$^{bc}$ | 174 | 100 | 215 | 1856$^{b}$ | 0.5 | 6850 | 2.3 |
| | Sikasso | 5 | 6.7$^{ac}$ | 116 | 9 | 38 | 0$^{c}$ | 0.5 | 4052 | 1.6 |
| Cabbage | Bobo | 2 | 10.6$^{a}$ | 594$^{a}$ | 226$^{a}$ | 348$^{a}$ | 2311$^{a}$ | 2.2 | 2265$^{a}$ | 4.5 |
| | Sikasso | 2 | 8.0$^{b}$ | 68$^{b}$ | 13$^{b}$ | 20$^{b}$ | 0$^{b}$ | 0.8 | 6743$^{b}$ | 1.2 |
| Amaranthus | Kano | 37 | 2.8 | 142 | 31 | 210 | 96 | 0.1 | 2995 | 0.9 |
| Tomato | Bobo | 2 | 10.3 | 297 | 201 | 235 | 126 | 0.5 | 3185 | 3.2 |

[1] Number of crop cycles over the whole study period and gardens in each city.

Within columns, same crops with different letters across the cities are statistically different (Kruskal-Wallis test and Bonferroni multtest, $P<0.05$). Average number of days per crop cycle (± standard deviation) of the three cities for lettuce = 41 ± 3.6; carrot = 100 ± 12.6; cabbage = 96 ± 10.6; amaranthus = 28 ± 3.5; tomato = 90 ± 20.5; n= 6, 2 and 6 in Kano, Bobo and Sikasso, respectively.

cycle was statistically similar ($P>0.05$) across all three cities but differed for the other crops.

### 3.4. Vegetable yields and nutrient outputs

Only lettuce and carrot were found to be commonly grown in the three cities. Vegetable yields of different crops across the cities are given in Table 6. Dry matter yields of similarly cultivated vegetables were statistically similar for lettuce in Bobo and Kano and both differed statistically ($P<0.05$) from yields in Sikasso. Carrot yield in Bobo was 3 times higher than in Kano, but similar to that of Sikasso. Carrot yields were statistically similar ($P>0.05$) in Kano and Sikasso. Cabbage was present only in Bobo and Sikasso and their yields were not statistically different and ranged from 6.0 to 15.2 t DM ha$^{-1}$ in Bobo and 6.44 to 9.55 t DM ha$^{-1}$ in Sikasso. The largest average N outflow (Table 6) was observed in cabbage at Bobo (447 kg ha$^{-1}$ per crop cycle) and Sikasso (438 kg ha$^{-1}$). Aggregated annual average nutrient exports through harvested edible parts (OUT1) were 524, 899, and 795 kg N ha$^{-1}$ in Kano, Bobo and Sikasso, making up 80%, 67% and 90% of N outflow in the respective city (Fig. 3). A similar trend was observed for P and K. Nutrient output via harvested products was statistically similar ($P>0.05$) across all cities. Outflows of N through crop residues constituted 9%, 26% and 3% of total N exports in Kano, Bobo and Sikasso, respectively. These trends, in terms of percentages, were similar for the other major nutrients, and these are similar in Kano and Sikasso, but differ in Bobo ($P<0.05$). Dry matter yields of edible parts and residues were significantly correlated ($P<0.01$) with nutrient outputs in the harvested parts (data not shown). Leaching contributed to 7% of N and 3% K output in Kano and 3% each of N and K outputs in Sikasso. Nitrogen and K output via leaching as well as gaseous N losses were not statistically different across the cities. The calculated erosion loss was negligible in Kano, but Bobo and Sikasso showed annual losses of 2 kg N ha$^{-1}$, 1 kg P ha$^{-1}$, and 6 kg K ha$^{-1}$, respectively.

### 3.5. Nutrient balances

Except for K in Kano and Sikasso, partial balances of N and P in the three cities were positive (not shown). Taking all (manageable and environmental) flows into consideration, full balances were positive for N and P across all cities except K in Kano and Sikasso (Fig. 4). Average annual N surpluses were 279, 1127 and 74 kg N ha$^{-1}$ in Kano, Bobo and Sikasso, respectively. Annual deficits of 222 and 187 kg K ha$^{-1}$ were observed in Kano (range from –1793 to 2402) and Sikasso (range from

Table 6: Average dry matter yields (t $ha^{-1}$) and average nutrient removal (per crop cycle) of major vegetables cultivated in UPA gardens of the three studied cities.

| City | Vegetable | Crop cycle (#) | Yield | Nutrient removal (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | | | | N | P | K |
| Kano (n=6) | | | | | | |
| | Lettuce | 18 | 3.8 ± 2.47 | 117 ± 72.0 | 23 ± 16.3 | 270 ± 237.3 |
| | Amaranth | 37 | 2.8 ± 1.57 | 107 ± 81.8 | 16 ± 10.4 | 224 ± 145.0 |
| | Carrot | 7 | 4.7 ± 2.38 | 95 ± 71.1 | 25 ± 15.8 | 173 ± 142.0 |
| Bobo (n=2) | | | | | | |
| | Lettuce | 10 | 3.9 ± 1.37 | 147 ± 71.1 | 28 ± 13.8 | 286 ± 128.2 |
| | Carrot | 2 | 14.2 (11.46–16.97) | 332 (255.5–409.0) | 65 (58.4–71.3) | 736 (602.5–868.9) |
| | Cabbage | 2 | 10.6 (6.0–15.21) | 447 (215.8–678.9) | 65 (34.3–96.1) | 529 (254.5–802.5) |
| | Tomato | 2 | 10.3 (7.07–13.52) | 368 (253–483.5) | 65 (44.6–85.2) | 206 (141.4–270.3) |
| Sikasso (n=6) | | | | | | |
| | Lettuce | 35 | 8.0 ± 4.22 | 287 ± 121.4 | 53 ± 23.1 | 572 ± 241.3 |
| | Carrot | 5 | 9.3 ± 2.61 | 103 ± 61.9 | 24 ± 12.0 | 236 ± 82.5 |
| | Cabbage | 2 | 8.0 (6.44–9.55) | 438 (344.3–531.8) | 34 (26.9–41.6) | 370 (290.8–449.2) |

Minimum and maximum values in parenthesis for n<5, otherwise standard deviation. Average number of days per crop cycle (± standard deviation) across all three cities for lettuce = 41 ± 3.6; carrot = 100 ± 12.6; cabbage =96 ± 10.6; amaranthus = 28 ± 3.5; tomato = 90 ± 20.5.

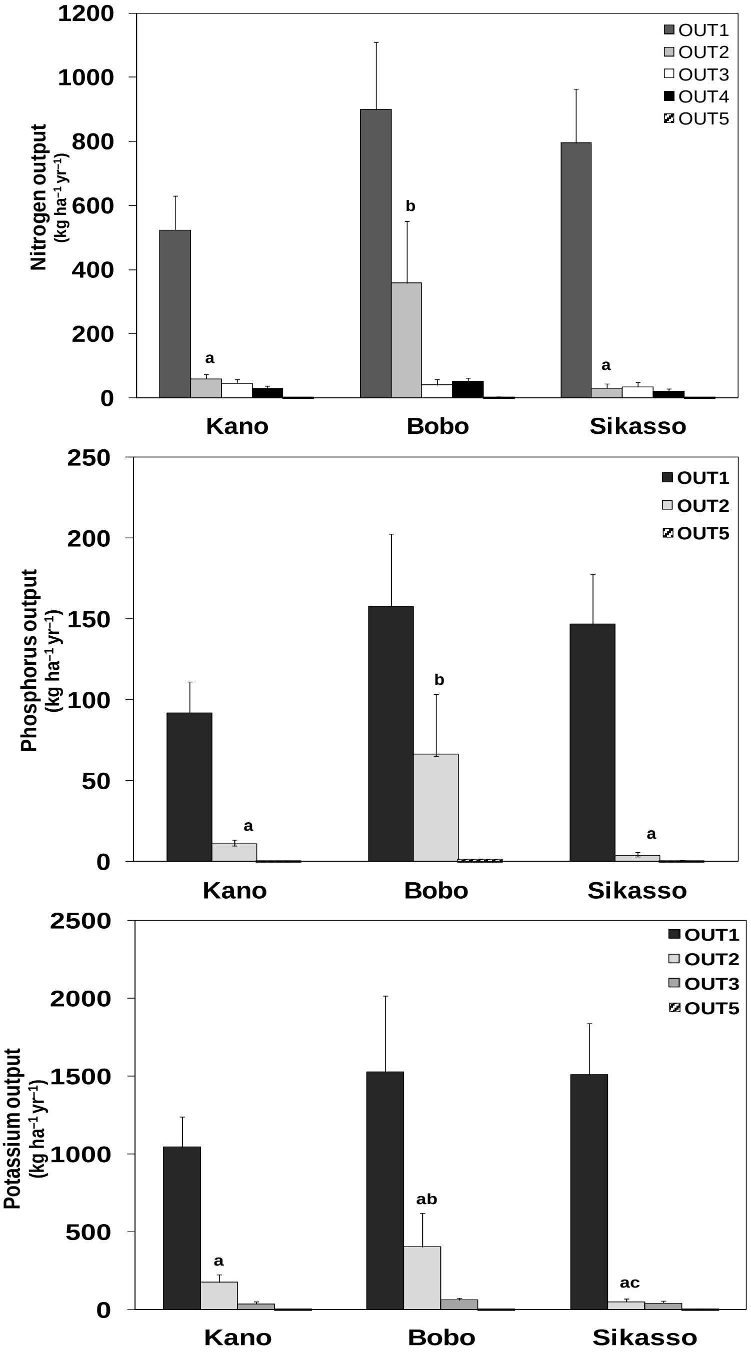

Fig. 3: Aggregated annual nutrient output in gardens of Kano (n=6), Bobo (n=2) and Sikasso (n=6) during a 24 months monitoring period. Data represent means plus one standard error. Bars with different letters are statistically different (Kruskal-Wallis test and Bonferroni multtest, P<0.05) across the three cities, and those without letters have no statistical difference between them. OUT1 = harvested product (edible part); OUT2 = residue; OUT3 = leaching; OUT4 = volatilization; OUT5 = erosion losses. OUT5 is hardly visible because of the large scale of the y-axis.

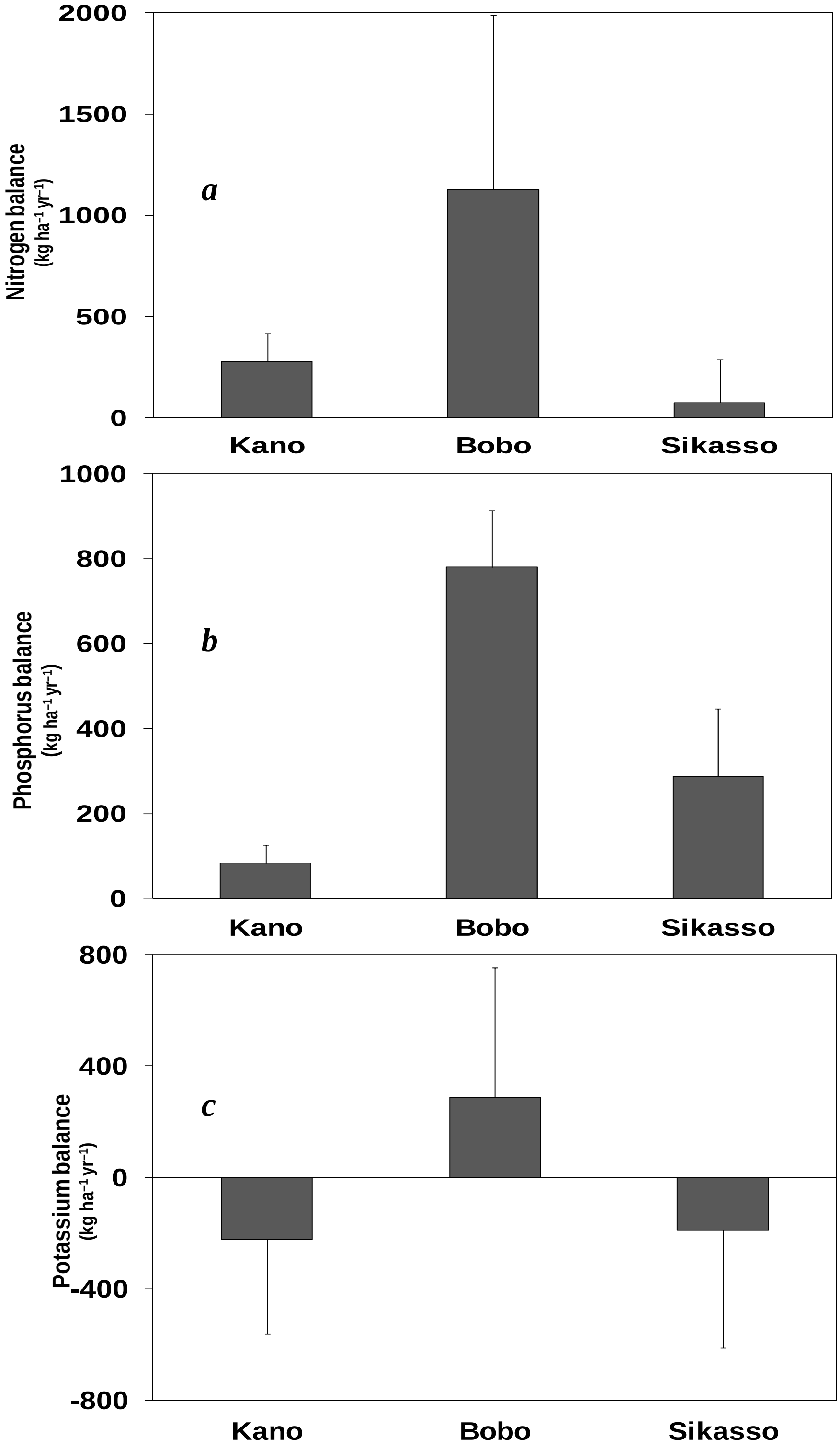

Fig. 4: Full annual (a) nitrogen, (b) phosphorus and (c) potassium balances in UPA gardens of Kano (n=6), Bobo (n=2) and Sikasso (n=6) during a 24 months monitoring period. Data represent means plus one standard error.

–854 to 2028). Potassium output as harvested product and residue in both cities exceeded its input as fertilizer resulting in a negative partial as well as full K balance.

### 3.6. Nutrient use efficiencies

Calculated nutrient use efficiencies (NUE) were higher for N in Kano and Sikasso than in Bobo, because of higher N inputs in the latter city (Table 7). Phosphorus use efficiencies were moderate in Kano and low in Bobo and Sikasso as a result of higher P inputs in the two latter cities. Potassium use efficiency was very high in Kano (120%) and Sikasso (110%) due to high K outputs compared to their low input especially as mineral fertilizer. In general, the N and K were utilized more efficiently in Sikasso (87%) and Bobo (85%), respectively than in Kano. This is because of the higher yields obtained per crop cycle which almost balanced the N and K inputs in Sikasso and Bobo, respectively. This was further confirmed by a positive and significant correlation ($P<0.01$) between total dry matter yields and the N OUT1 in Sikasso.

### 3.7. Economic performance indicators

Vegetable production gave a positive gross margin in all three cities. Average annual gross values (GV) per $m^2$ of vegetable production were statistically similar in Kano and Sikasso (Table 8). Variable costs (VC) were statistically similar in Kano and Bobo and both cities differed statistically from Sikasso. Gross margins (GM) were highest in Bobo at US\$3.83 $m^{-2}$ compared to US\$0.92 $m^{-2}$ realized in Kano. Gross margins were statistically similar ($P>0.05$) in Kano and Sikasso, and both cities differed ($P<0.05$) with Bobo. Across the different production seasons, gross margin differed statistically in the three cities and show the highest average return in Bobo and Sikasso in the cold dry season. Gross margin was lowest in the hot dry season in all three cities (Table 8). Across all cities, cabbage and carrots were more profitable per square meter compared to other crops. Gross margin of cabbage was highest in Bobo (US\$2.2 $m^{-2}$) and did not statistically differ from that of Sikasso (Table 5). Farm gate prices of lettuce yielded lower gross margin in Kano (US\$ 0.2 $m^{-2}$), which differed statistically ($P<0.05$) from the benefits realized in Bobo and Sikasso.

Table 7: Nutrient (N, P, K) use efficiency (NUE, %) of UPA gardens in the three West African cities studied.

| | N | | | P | | | K | | |
|---|---|---|---|---|---|---|---|---|---|
| | Kano | Bobo | Sikasso | Kano | Bobo | Sikasso | Kano | Bobo | Sikasso |
| Input ($kg\ ha^{-1}\ yr^{-1}$) | 922 | 2468 | 947 | 180 | 1005 | 438 | 1020 | 2278 | 1420 |
| Output ($kg\ ha^{-1}\ yr^{-1}$) | 583 | 1257 | 826 | 103 | 224 | 151 | 1225 | 1933 | 1565 |
| ***NUE*** | ***63*** | ***51*** | ***87*** | ***57*** | ***22*** | ***34*** | ***120*** | ***85*** | ***110*** |

N = nitrogen, P = phosphorus, K = potassium. n= 6, 2 and 6 in Kano, Bobo and Sikasso, respectively.
Input as organic and inorganic fertilizers; output as harvested products and residue, i.e. IN1–IN2 and OUT1–OUT2. NUE was calculated from equation (3).

Table 8: Average economic flows across 24 months monitoring periods (US \$ $m^{-2}$ $yr^{-1}$) and gross margins (US \$ $m^{-2}$) across the different seasons in the three studied cities.

| | Gross value (GV) | Variable cost (VC) | Gross margin (GM) |
|---|---|---|---|
| Kano (n=6) | $1.27^{ac}$ | $0.35^{a}$ | $0.92^{c}$ |
| Bobo (n=2) | $4.36^{b}$ | $0.53^{ab}$ | $3.83^{b}$ |
| Sikasso (n=6) | $1.47^{c}$ | $0.10^{c}$ | $1.37^{ac}$ |

| | Gross margin | | |
|---|---|---|---|
| | Cold dry (CD) | Hot dry (HD) | Rainy (RS) |
| Kano (n=6) | $0.32^{a}$ | $0.14^{ab}$ | $0.51^{ab}$ |
| Bobo (n=2) | $2.23^{bc}$ | $0.14^{b}$ | $2.18^{c}$ |
| Sikasso (n=6) | $0.91^{c}$ | $0.54^{c}$ | $0.44^{b}$ |

GM=GV−VC; Within columns and across cities, means with the different letters are statistically different (Kruskal-Wallis test and Bonferroni multtest, $P<0.05$).
1 US\$ = 150 Nigerian Naira; 475 FCFA during the period of the study.

### 3.8. Nutrient balance implications for soil nutrient pools

Nutrient balance studies are used to understand the implication of nutrient surpluses or deficits on changes in soil stocks. From the resulting balances it was derived that the annual change in the soil P pool amounted to 8%, 24% and 19%; and for the K pool –2%, 6% and –1% in Kano, Bobo and Sikasso, respectively (Table 9). Nitrogen surplus in Bobo resulted in an annual N increase of 42%, which is not realistic given the different processes that affect N transformation in the soil. Despite nutrient surpluses, changes in the soil nutrients were not so obvious in all cities. In Kano, soil property changes were more obvious in the different seasons of cultivation with a slight decrease in total nitrogen (TN, 1.6–0.9 g $kg^{-1}$) (Table 10) in the cold dry seasons of the first (CD1) and second (CD2) monitoring periods. However, there was slight increase in total P (TP) and a slight decrease in total K (TK) and pH across the seasons of the two years. A slight decrease of nutrients occurs during the rainy seasons: RS1 and RS2. This was attributed to larger inputs of nutrients through wastewater irrigation in the dry periods and leaching of the soil nutrients due to rainfall. Unfortunately, data is not available for Bobo and Sikasso for the years 2009 and 2010 across all the seasons to calculate soil stock changes. However, these soil stock changes can be derived from soil data collected in 2007 and 2008. This resulted in the following: for the cold dry seasons of Bobo and Sikasso, TN was stable in both

Table 9: Annual change in soil nutrient stock of UPA gardens in the three West African cities.

| | Change (%) | | |
|---|---|---|---|
| City | N | P | K |
| Kano (n=6) | 8 | 8 | –2 |
| Bobo (n=2) | 42 | 24 | 6 |
| Sikasso (n=6) | 2 | 19 | –1 |

N = nitrogen; P = phosphorus; K = potassium.

years although TP showed a slight increase in Bobo (from 0.9 to 1.4 g $kg^{-1}$) and a slight decline in Sikasso in the second year (from 0.5 to 0.4 g $kg^{-1}$). Total K declined n both cities while organic carbon content was slightly increased in Bobo but remained quite stable in Sikasso (Table 10).

Table 10: Mean (± standard deviation) of soil properties (g $kg^{-1}$) across the different seasons of the study period.

| | | TN | TP | TK | OC | pH |
|---|---|---|---|---|---|---|
| Kano | CD1 (n=5) | 1.6 ± 0.2 | 0.8 ± 0.1 | 3.1 ±0.1 | 13.9 ±1.5 | 6.8 ± 0.3 |
| | HD1 (n=6) | 1.3 ± 0.5 | 0.8 ± 0.5 | 3.4 ±0.1 | 11.0 ± 3.6 | 6.8 ±0.5 |
| | RS1 (n=6) | 0.8 ± 0.4 | 0.6 ± 0.2 | 3.3 ±0.8 | 6.7 ±2.9 | 7.1 ±0.3 |
| | CD2 (n=6) | 0.9 ± 0.5 | 0.9 ± 0.5 | 1.7 ±0.6 | 9.8 ±5.2 | 6.7 ± 0.4 |
| | HD2 (n=6) | 1.3 ± 0.7 | 1.2 ± 0.6 | 2.2 ±0.6 | 13.3 ± 6.3 | 6.6 ±0.5 |
| | RS2 (n=6) | 0.8 ± 0.3 | 1.0 ± 0.6 | 1.3 ±0.3 | 12.2 ±2.3 | 6.6 ±0.5 |
| Bobo | CD1[1] | 0.9 | 0.9 | 2.1 | 11.6 | 6.1 |
| | CD2[1] | 0.9 | 1.4 | 1.2 | 14.5 | 6.8 |
| Sikasso | CD1[1] | 1.1 | 0.5 | 8.5 | 15.0 | 6.2 |
| | CD2[1] | 1.1 | 0.4 | 3.2 | 15.1 | 6.7 |

[1] Samples were collected once in cold dry seasons of 2007 (CD1) and 2008 (CD2).

TN = total nitrogen; TP = total phosphorus; TK = total potassium; OC = organic carbon.

# 4. Discussion

## 4.1. Nutrient balances and implications for soil fertility

Most UPA farmers sustain productivity with high nutrient inputs (Drechsel and Dongus, 2010). Nutrient management in UPA gardens of Kano, Bobo and Sikasso was characterized by large nutrient inputs mainly from organic sources and comprised of waste, wastewater and manure. Recent studies in plot-level urban and peri-urban vegetable production showed that similar systems were characterized by large nutrient imports with large positive balances such as in Niger, Ghana, China and Vietnam (Diogo et al., 2010a; Huang et al., 2007; Khai et al., 2007; Wang et al., 2008; Drechsel et al., 2004). In addition to nutrients supplied by soils, nutrient requirements of most vegetables range from 40 to 120 kg N $ha^{-1}$, 4 to 9 kg P $ha^{-1}$ and 8 to 167 kg K $ha^{-1}$ (La Malfa, 2011; Fox and Valenzuela, 2011). For the three cities, nutrient applications far exceed the range of nutrient requirements with average inputs of 135–530 kg N $ha^{-1}$, 29–203 kg P $ha^{-1}$ and 96–646 kg K $ha^{-1}$ per lettuce cycle, and similar trends were observed for the other vegetables cultivated in the three cities.

Harvested products constitute the highest outflow of nutrients from the production systems studied in the three cities, removing more than 50% of applied N and K. Lettuce dry matter yield was highest in Sikasso but those from Kano and Bobo were in the range of those obtained in high and low input systems of Niger (Diogo et al., 2010a). These yields reflected different amounts of inputs but in some cases, high yields were observed while applied nutrients were low. Another major factor for nutrient outflows is the nutrient concentration in crops. This is because nutrients accumulate in the vegetative plant parts (Terbe et al., 2011). This was observed for cabbage, where high yields and nutrient concentrations resulted in large exports of nutrients in Bobo and Sikasso. Potassium output in Kano was higher as compared to the other nutrients. Compared with Bobo, K input as mineral fertilizer was low in Kano and Sikasso. The negative K balance in the latter 2 cities was due to the large exports of K in the edible parts of the vegetables, especially the large concentrations of K in the leafy part of vegetables that were commonly cultivated in Kano such as amaranth and lettuce and several (35) lettuce cycles grown in Sikasso. This points to the relevance of K in the nutrition of leafy vegetables (Anonymous, 2003; PPIC, 2003; Terbe et al., 2010), and it is often identified as the limiting nutrient in similar garden-related studies (Song et al., 2011; Wang et al., 2008). Potassium efficiency was poor in both cities could be improved with better K management to avoid long-term K deficiencies in the system. Lower N and P efficiencies in Bobo were mainly through the use of large quantities of mineral and organic nutrient inputs compared to the other cities, with huge environmental implications.

Nutrient balance studies (partial and full) have gained widespread application in the study of farming systems and either cover all components of the farm or sub-systems within a farm (Brouwer and Powell, 1998; Van Den Bosch et al., 1998; Ramakrishna, 2004; Diogo et al., 2010a). Nutrient balance studies have been applied at different scales and range from plot-level to country and continental scales (Pathak et al., 2010; Smaling and Braun, 1996; Stoorvogel and Smaling, 1990). Annual surpluses calculated for P were 780 and 288 kg P ha$^{-1}$ in Bobo and Sikasso, respectively. Phosphorus balances in both cities exceed surpluses of 223 kg P ha$^{-1}$ reported for Niger (Diogo et al., 2010a) and 109–196 kg P ha$^{-1}$ in Vietnam (Khai et al., 2007), while that of K in Bobo (228 kg K ha$^{-1}$) was comparable to 312 kg ha$^{-1}$ in Niger and 20–306 kg ha$^{-1}$ in Vietnam, although the studies by the latter two authors reported partial balances. However, the average annual N balance of 1,127 kg ha$^{-1}$ in Bobo was comparable to 1,133 kg ha$^{-1}$ reported for high input systems of Niger (Diogo et al., 2010a), while values for Kano and Sikasso (279 and 74 kg ha$^{-1}$, respectively), fall within and close to the surplus range of 85–882 kg ha$^{-1}$ reported by the above authors for similar systems in Vietnam. In the present study, these values consider all the flows, and the positive N balance could be smaller when N leaching would correspond better to N application as well as to water input. This is not the case because the MONQI model actually underestimates leaching losses (Abdulkadir et al., 2012) by 18 to 22%, while up to 40% of total applied N could be lost due to leaching (Janssen and De Willigen, 2006; Zhao et al., 2010).

## 4.2. Implications of current nutrient management on environmental sustainability

Nutrient balances imply long-term consequences for the soil nutrient stock. Total nitrogen for gardens in the three cities was below the threshold level for good soil fertility of 2 g kg$^{-1}$ (Muya et al., 2011) while total phosphorus falls close to the range of optimal thresholds of 0.2–0.8 g kg$^{-1}$. From these balances, consequences for changes in the K pool seem not as severe as for P, because low P uptake by plants implies P build-up in the soils. Saturation of soil with P could, however, result in P leaching to ground and surface water with a possible eutrophication effect. Nitrogen surpluses across all cities may have only a slight implication on soil N status as N is highly labile and it remains difficult to draw conclusions concerning its availability in the long term (Schröder et al., 2010). The studied soils are fairly low in N implying that the excess N applied may be lost beyond the root zone. In Bobo, N content in well water was higher than in wastewater. This could be due to leaching of applied N in the gardens to the ground water, although the depth of the water table is not known to confirm this point. Cissé and Mao (2008) reported high concentrations of nitrate-N in well water of the Sikasso region in Mali and attributed this mainly to agricultural activities. Large amounts of N applied imply high losses to the environment. From a lysimeter study on intensively irrigated vegetables, Zhao et al. (2010) reported that 227 to 354 kg N leached per hectare from applications of 1110 and 1480 kg N $ha^{-1}$, respectively. In another study, wastewater application increased N input to vegetable production and increased the potential of N leaching to groundwater (Karam et al., 2002).

The study described in this dissertation shows that the current UPA vegetable production in the three cities is far from being sustainable. This is more pronounced in Kano and Bobo Dioulasso than in Sikasso because of higher efficiency of crop N uptake in the latter city. Nutrient use efficiencies were calculated from the partial balance method: these are limited to the studied nutrients and give no indication on agronomic or recovery efficiencies of the nutrients (Cassman et al., 2002). It also does not account for the nutrients supplied by the soil for a reliable estimate of the actual nutrient uptake by vegetables. Although several studies have been conducted to assess fertilizer requirements of temperate vegetables for optimal yields (La Malfa, 2011), limited work has been done to assess fertilizer requirements in tropical areas (Fox and Valenzuela, 2011). Furthermore, if these fertilizer requirements are formulated, these results have to be effectively disseminated for the judicious application of fertilizer nutrients. Maximal yields may not always be the best production targets, because there will always be a trade-off with environmental losses as well as farmers' willingness to adopt alternative options. Wastewater, manure and solid municipal waste provide favourable sources of nutrients for production, but over-application leads to oversupply of nutrients. To find a balance between these nutrient sources for vegetable production and their supply in UPA is a big challenge for the government and other stakeholders, as UPA gardening is difficult to regulate because it largely occurs in the informal sector.

## 4.3. Variations of economic indicators in UPA gardening

Diversity of vegetables produced per city is often driven by seasonal suitability (mainly temperature) and farmers' economic goals, because vegetables produced off season often bring higher economic returns (Diogo et al., 2011). This, however, requires extra labour accompanied by careful and good management to meet the desired production. When the three cities are compared, gross margins were higher in Bobo and Sikasso than in Kano. This may be attributed to higher yields and the cultivation of higher valued crops in the former two cities as compared to the latter city. Another factor is the lower variable costs of production in Bobo and Sikasso where labour was offset on a monthly basis. In Kano, labour costs of weeding and land preparation were paid for each farm operation; this, and the extra costs of hiring and fuelling motor pumps used in irrigating crops, resulted in higher variable costs. Gross margins were lowest in the hot dry season in all three cities compared with cold and rainy seasons. These discrepancies can be deciphered from the cultivation of high priced vegetables of mainly temperate origin during the cold dry periods. In contrast, hot temperatures hinder the cultivation of high value temperate vegetables and farmers are left with the option to grow indigenous vegetables of lower economic value. This is further driven by lower prices from the increased supply of the same vegetables when several UPA farmers decide to cultivate the same crops at the same time. Maximum temperatures were lower in Bobo and Sikasso, where a higher diversity of temperate vegetables was observed compared with Kano. These fluctuations show that UPA vegetable production systems are dynamic, and often driven by socio-economic and seasonal conditions (Drechsel and Dongus, 2010).

## 5. Conclusions

There are different drivers to agricultural intensification, the most important one being the need to increase productivity for an ever increasing population. This is the case in market-oriented urban and peri-urban vegetable cultivation, as a result of the significant role it plays in the livelihood of the urban farmers. However, current UPA nutrient management is practiced at the expense of the environment as a result of surplus nutrient applications in vegetable production. This study contributes to a better understanding of nutrient use in UPA gardening and gives an insight for designing suitable management options for sustainable production. This could be vegetable-specific management of fertilizer and water applications at the required amounts. However, policies cannot be effectively targeted and implemented without institutionalizing the UPA sector into city and agricultural plans.

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## Chapter 6

# General discussion

## 1. Diversity of UPA systems and methodology applied

Understanding the diversity of urban and peri-urban agriculture (UPA) is crucial for formulating policies or strategies appropriate for certain farming systems. Examples of the diverse UPA activities include cultivating crops, vegetables and keeping livestock within and around the cities. This constitutes the main income source of the farm household although it is often complemented with off-farm activities (Chapter 3). Although each farm is unique in its finest detail regarding farm management, classification into groups of similar farms facilitates the formulation of system-specific recommendations or options for intervention. The UPA farms were classified into distinct types across the studied cities and characterized through their socio-economic structure and resource endowment (Chapter 2 and 3). To address the environmental issues related to excess nutrient (N, P, K) input in UPA production, a sound knowledge of the nutrient flows for each farm component (garden, crop and livestock) is required. The farm types in Kano were assessed for their nutrient use efficiencies using the MONQI approach for calculating nutrient flows and balances (Chapter 4). The same approach was also applied for the nutrient budgets of only the garden components of the three cities. The results indicate an oversupply of nutrients in the current UPA production systems (Chapter 4 and 5). Findings further confirm the prevailing low nutrient use efficiencies of UPA systems in West Africa (Diogo et al., 2010a), and also compare well to the intensive vegetable-based UPA systems in Asia, e.g. Vietnam and China (Khai et a., 2007; Huang et al., 2008; Wang et al., 2008).

A regional typology was attempted across the three West African cities of Kano, Bobo Dioulasso and Sikasso to explore the similarities and differences in UPA activities. A statistical approach was selected to best fit the type and distribution of data collected (Chapter 1). The snow-ball approach (Goodman, 1961), used in the baseline survey, provided an unbiased method of farmer selection, but the initial selection of the first survey site was not devoid of subjectivity. Selecting particular criteria in collecting data and classifying them often depends on authors' discipline and objectives (Drechsel at al., 2005). Veenhuizen and Danso (2007) pointed out that the lack of institutional home for UPA in various countries and the diverse aims for which it is studied, hampers a consistent typology for the systematic comparison of research results. Another factor is the diversity of UPA, which makes the characterization and comparison of farming systems within the same city difficult (Chapter 3). For this reason, Mougeot (2000) suggested there is a need for a consistent typology based on data used in the various UPA studies for comparative analysis in order to generalize the development of strategies, action plans and policies across UPA systems in Africa.

## 1.1. The NUTMON approach

NUTMON toolbox has been widely applied for the quantitative analysis of nutrient management of different farming systems (Gachimbi et al., 2005, Kathuku et al., 2007, Kante et al., 2007). It is used as a diagnostic tool to indicate the status of soil fertility and economic performance of farming systems with particular reference to African soils. One of its weaknesses is the lack of application in simulation or dynamic modelling environment. As De Jager (2009) suggests, NUTMON provides a snap shot as a decision-support tool. Therefore it remains a poor indicator of long-term implications of the soil nutrient balances on the soil stock. This is because the dynamics of nutrient availability in the soil are not accounted for in static nutrient balance studies which limit the reliability of drawing conclusions on the state of the soil stock (Van den Bosch et al.; 1998; Shepherd and Soule, 1998). The methodology also suffered some drawbacks for estimating the ‘hard-to-quantify’ flows, especially the transfer functions used to estimate leaching and erosion losses (Faerge and Magid, 2007).

## 1.2. New concepts of NUTMON in MONQI and its application in the current study

The MONQI tool is largely based on the principle of NUTMON but with an expanded focus beyond soil fertility. It has a user-friendly interface that allows a user to add an unlimited number of questions to each activity in addition to the default database. It is currently applied in different projects that involve improvement of farm management and livelihoods of small-holder farmers (De Jager, 2009; Van Beek et al., 2009). It provides a structured presentation of results on nutrient flows and balances, so that it facilitates additional calculations for further statistical analysis. The transfer functions in the former NUTMON tool were removed from MONQI, but it also allows the eventual inclusion of some revised transfer functions (Lesschen et al., 2007) which were used in this study. In order to verify the strengths of these functions in calculating nutrient balances, a sensitivity analysis was carried out on the model parameters for estimating leaching and gaseous losses. These transfer functions still comprise uncertainties in estimating the environmental flows because they were sensitive to changes in the parameters that determine the flows. This holds particularly for the N flows as model outputs differ by 41.4% and 51.1% in values of leaching and gaseous losses of nitrogen in UPA gardens respectively, compared with experimental data obtained in Niger by Predotova et al. (2011). This indicates sources of error in this work (Chapter 4, 5) that may have resulted from the transfer functions that were developed from continent-level data. The application of this approach (MONQI) could be improved when expressions that approximate some of the plot-level processes such as leaching and volatilization of nutrients are developed.

Farm management data was collected from regular surveys (interviews) often complemented with measurements. During crop cultivation, interviews were conducted at the beginning and end of every harvest to narrow the interval of memory recall of the farmers. Livestock surveys were conducted every two months to gather information on livestock management-related issues. Because the livestock module is absent in MONQI, nutrient budgets were calculated only on the basis of management-related flows such as import of feed and export as livestock products and manure. Data on the quantity of manure produced by each livestock species were taken from the literature based on the length of time the animal stays in the stable (Schlecht el al., 1995). Estimating this time was challenging, especially for the small ruminants that roam the streets and compounds almost the entire day. Also, since nutrient import as feed and export as manure could not be estimated for grazing and scavenging of the livestock, it was assumed that input cancels out the output. This may be an over simplification as these measurements were not within the scope of this study. However, there are techniques to estimate feed intake from grazing (Decruyenaere et al., 2009; Peripolli et al., 2011), but it remains difficult to estimate intake from scavenging on communal lands and waste dumps. Nutrients used for growth and maintenance of the livestock were also not included in the model, nor were nutrients exported as live animals, which results in underestimation of the outflows. However, the positive nutrient balances obtained under the livestock keeping indicate that nutrients were supplied above the requirements as shown for similar production systems in Niger (Diogo et al., 2010b).

### 1.3. Sustainability indicators of UPA

Sustainability of UPA can be assessed from a multi-faceted perspective. The Framework for Evaluating Sustainable Land Management (FESLM) developed by the Food and Agricultural Organization (FAO) considers indicators like resource use efficiencies, creating job opportunities for communities and its associated perceived negative trade-offs (Drechsel and Dongus, 2010). In their work, Drechsel and Dongus (2010) assessed the five aspects in relation to productivity such as the use of urban resources, land tenure risks/eviction risks, profitability, environmental and human-health risks and social acceptability. In this study, the FESLM was adopted under four indicators that concern economic benefits, nutrient use efficiencies, and negative externalities on the environment and human health derived from the diverse UPA activities. Although the latter two are closely related to the accompanying risks of UPA activities in the use of waste water to irrigate crops, they are considered separately in this chapter because of other food safety issues such as the use of pesticides and contamination of livestock products with pathogens. The selected sustainability indicators will be discussed based on perceptions from this study and related outcomes from previous studies. The focus of sustainability on the social perspective was considered together with the economic benefits because of the complementary role of the two aspects (socio-economic).

### *1.3.1. Economic benefit*

Fig. 1 presents a summary of the sustainability of the studied UPA systems based on the selected indicators. Intensification is often driven by the economic benefits derived from UPA across the different farm types and gardens in West Africa (Chapters 4 and 5). This is also influenced by seasonality and variations in social, cultural or religious beliefs found within a city. Small livestock keeping in urban and peri-urban areas is a result of diversification in livelihood strategy for household income security (Rischkowsky et al., 2006b; Graefe et al., 2008). The immediate benefit of UPA livestock keeping may not be glaringly obvious (Chapter 4) because animals are kept mainly as insurance and serve other social roles in the society as well (Guendel, 2003). For example, sheep and goat keeping in West Africa are important because of their roles in religious festivities such as Tabaski[1]. The cattle keepers that are predominantly from the Fulani tribe (Chapter 3) largely depend on grazing their animals. Cattle are kept as a way of life as it serves most of their basic needs, such as food. Indigenous or local systems of keeping the livestock are still prevailing in the aspect of health and feeding strategies, but these aspects still lack novel technologies to enhance productivity (Schiere and Van der Hoek, 2001). The economic benefits in cLsC are mainly derived from little expenditure on feed supplements and other input related to crop cultivation (mineral fertilizer and biocides). Other benefits include the sale of milk and manure, and they largely depend on family labour in their production system. On the other hand, UPA gardening also provides immediate profits because of the short durations of time in cultivating vegetables, access to markets and the high value of most vegetables (Danso et al., 2002).

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[1] Annual Islamic festival that involves the slaughter of animals (sheep, goat, cattle, camel) to sacrifice, and which is commonly practiced in the three West African cities under study.

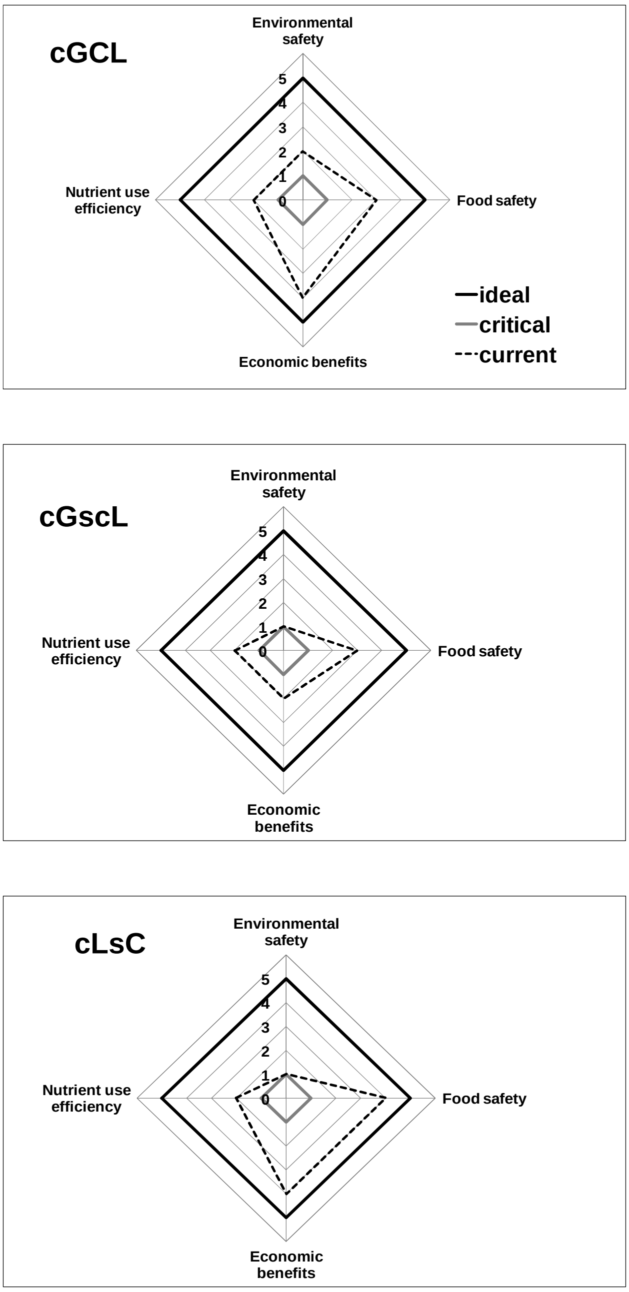

Fig. 1: Selected indicators showing the ideal, current and critical limits of Kano UPA practices on the overall sustainability scheme in cGCL: commercial gardening plus field crop-livestock, cGscL: commercial gardening plus semi-commercial livestock, and cLsC: commercial livestock plus subsistence field cropping farm types, respectively. Scales of 1 (critical) to 5 (ideal) were used for the sustainability indicators. Food safety scales were based on expert knowledge and results from heavy metal studies in wastewater irrigated gardens in Kano as well as the possible contamination of milk with pathogens in the cLsC farm types. Biocides and faecal pathogens were not quantified but were based on their qualitative risk assessments in the studied gardens.

### 1.3.2. Nutrient use efficiencies

Nutrient use efficiency (NUE) is often used as indicator to assess the sustainability of a nutrient on a farm. Efficient nutrient management remains a challenging task for agricultural production in most UPA systems in sub-Saharan Africa and Asia. The nutrient use efficiencies of the current UPA production systems in Kano (Chapter 4) and those under vegetable cultivation across the West African cities (Chapter 5) are poor. Supply of nutrients in excess of both crop and livestock needs indicated that other nutrient sinks may be present in the different components of the farms. In cGCL and cGscL, efficiency was low from nutrient balances because of the accumulation of nutrients in garden and field soils as well as in the livestock units (Chapter 4). This is similar to reports showing excess nutrient applications in intensive UPA vegetable growing systems in Africa and Asia (Diogo et al., 2010a, Khai et al., 2007; Huang et al., 2008). Similarly, nutrient losses were shown under similar livestock production systems (Diogo et al., 2010b). Cycling of nutrients in UPA farms is enhanced under integrated mixed crop-livestock systems (Lee-Smith, 2010). The farm types with cattle (cLsC) use the manure from their livestock to fertilize their crop fields and, in turn, feed the livestock with crop residues. This renders the system to be more efficient in nutrient cycling compared with the other farm types (Diogo et al., 2010b), but efficiency is compromised by poor manure handling and storage. The NUE indicated in Fig. 1 was based on the calculated values from nutrient budgets as well as speculations on how the overall efficiency will look like when the nutrient losses due to poor manure management were considered. The cLsC farm type will be less sustainable in nutrient use as presented in Fig. 1.

### 1.3.3. Environmental safety

Environmental safety was assessed from leaching and volatilization from UPA systems, and represents the findings from Chapter 4 (Fig. 1). All three systems deviate from the ideal situation due to oversupply of nutrients which increased the potential for losses to the environment. The cGCL farm type remains above the critical level while both cGscL and cLsC farm types reach a critical level. This was due to the low leaching and volatilization in cGCL as compared with the other farms types. This was more obvious for the livestock keepers in cLsC due to the large amounts of manure applied to their fields and a consequently high nutrient leaching. Because of the faster decomposition rates of manure and release of nutrients in the arid regions, nutrient losses are eminent if they are not efficiently taken up by the plant (Esse et al., 2001). For the same farm type, poor manure handling and storage increase the chances of emitting nitrous oxide and ammonia with profound greenhouse effects (Liebig et al., 2010). These losses could be reduced with proper manure management (Tittonell et al., 2010; Predotova et al., 2010).

### *1.3.4. Food safety*

Food safety remains a critical concern in the sustainability of UPA. Wastewater application is a common feature in most UPA vegetable production systems which meet the N, P, and K requirements of most crops (Ensink and van de Hoek, 2002). However, wastewater may also be contaminated with heavy metals as a result of indiscriminate industrial discharge especially in highly industrialized cities such as Kano (Binns et al., 2003; Abdu, 2010). A recent study on wastewater irrigation of urban gardens in Kano showed a build-up of heavy metals in the garden soils and also reported cadmium (Cd) and zinc (Zn) mobility from soil-crop systems. It shows that Cd was more labile than zinc, and accumulates in the edible portion of vegetables. Although the study indicated the consumption of these vegetables still poses a low risk to human health, continuous consumption may cause Cd and Zn build-up in the human tissues in the long-term (Abdu, 2010). The same study indicated no risks of heavy metal contamination in Bobo and Sikasso, which may be due to the smaller number of industries when compared with Kano. In another study, Cd and Zn were shown to accumulate in Brassica species with potential health risks from the consumption of these products as a result of wastewater vegetable production in Harare (Mapanda et al., 2007). In Ghana and Niger, quantitative assessments of microbial pathogens in wastewater irrigated UPA vegetables revealed unsafe amounts (Keraita et al., 2002; Diogo et al., 2010a). Contamination with pesticides and pathogens were also reported by Amoah et al. (2006) from market surveys of wastewater irrigated vegetables in Ghana. Based on these findings, similar trends can be expected for the UPA systems studied. In the current systems, heavy metals may pose low food safety risks, but risks could be moderate to high as a result of pathogens and pesticide use under vegetable production systems of the cGCL and cGscL farm types (Fig. 1). Farms in cLsC cultivate cereal crops and do not apply agro-chemical and wastewater in crop production. Little use of veterinary products (de-wormer) were recorded during the monitoring period and this makes the system food safe. However, milk contamination by faecal pathogens was found in UPA livestock keeping in South Africa from local milking practices (Lues et al., 2010), a similar situation may easily occur in cLsC.

In many developing countries, waste collection systems are in a deplorable state. As a result large portions of grey water from domestic sources are discharged into flowing streams from tributaries of city's street-side drains and gutters. Wastewater crop or vegetable cultivation ensures nutrient cycling within the city and reduces the burden of waste management on the limited infrastructure used for urban sanitation. Wastewater irrigation in UPA will prevail over rain-fed production as long as the urban population continues to expand because of the derived benefits it offers (Van der Hoek et al., 2002). However, water quality is compromised in cases of periodic or continuous discharge of industrial waste. This necessitates the enforcement of laws by city officials on the industries for waste treatment before discharge into streams may reduce the amounts of heavy metals in these streams. City's plans to manage wastewater require the involvement of stakeholders such as farmers, technical staff, industries and the general public through structured mobilization of social linkages, processes and methods. Indirectly, UPA offers part of the solution of wastewater management because when the wastewater is percolating through the soil a part of the nutrients and pathogens are removed before reaching the deeper groundwater (De Vries, 1972; Kadam et al., 2008). Creating awareness to farmers, and at the same time considering social constraints and perceptions of other stakeholders, is crucial to develop effective policies and guidelines to manage wastewater. There is also the need for available, simple, efficient, acceptable and cheap wastewater treatment techniques to improve the water quality such as sedimentation ponds in Accra set up by the International Water Management Institute (IWMI), Ghana.

Integrated assessments of UPA production systems in West Africa are accompanied by trade-offs with economic benefits in the different sustainability indicators. Besides the economic benefits offered to cGCL and cLsC systems, the other three indicators are compromised under the current UPA practices. The cLsC farm type is more sustainable in two indicators, but with a huge environmental trade-off (Fig. 1). This study shows that the current UPA production systems are far from perfect and it confirms that production is economically viable but operates under conditions that are critical to the environment. Reduced amounts of nutrient inputs (and other inputs such as pesticides/agro-chemicals) will enhance economic benefits derived from UPA gardening, and at the same time improve NUE, reduce negative environmental effects and improve food safety.

## 1.4. Present initiatives for UPA development in West Africa

Several studies have indicated the need for UPA to be included in the government structure. So far, some countries in east Africa have adapted such initiatives such as

Uganda and Kenya (Prain and Lee-Smith, 2010). Current initiatives for UPA development in West Africa are taken up by the Resource Centres on Urban Agriculture and Food security (RUAF) in Ghana, Senegal, Burkina Faso and Nigeria. These initiatives focus on ways to improve UPA production and marketing. In Bobo Dioulasso for example, training workshops and farmer field schools were organised by the Municipal Environment Commission and Rural Development Institute of the city. A local project on Multi-stakeholder Policy making and Action Planning on Urban Agriculture started in 2006 by the RUAF-FStT programme (http://www.ruaf.org/node/1132). It was recognised by the municipal authorities in Bobo Dioulasso. Similar projects under the same programme were also started to improve the livelihood of UPA farmers which revived vacant land for agriculture and drilled wells as water sources. In Lagos and Ibadan, Nigeria, the RUAF-CFF pilot project in 2007 (http:www.ruaf.iwmi.org/events.aspx) targeted a group of female gardeners by providing access to irrigation water (wells) and organising training on good management practices to improve the productivity of their vegetables. Farmers in Lagos were also provided with training on fish farming and micro-financial support. So far, these UPA programmes are active and widespread in the southern part of Nigeria, and involve stakeholders that represent government ministries, community chiefs, agricultural research institutes and farmers’ associations. Similarly in Sikasso, a development programme was initiated for the community women to grow vegetables on newly available land in swamp zones with better water management and land security under a swamp improvement project (Intercooperation, 2008: www.water-landpeople.net as cited by Graf, 2010). These programmes are more focused on vegetable and crop cultivation than on livestock keeping.

## 1.5. Current UPA nutrient management; future research focus

Understanding the current UPA nutrient management system and its limitations is crucial to formulate sustainable alternatives. A wealth of literature exists which recommends the improvement of the current UPA systems through its recognition and institutionalization into the government policy structure. Through these institutes, appropriate policy measures can be taken towards UPA improvement. Although it is a first step, there is little or no quantitative feedback to UPA farmers on ways to improve their management to reduce the associated externalities. Computer models on farming systems are increasingly used as decision-support tools to provide suitable alternative management options. For the UPA systems, these options can be identified when the major flows and processes are represented by a simple mathematical model. This model can be static to analyse farm management at a moment in time, or

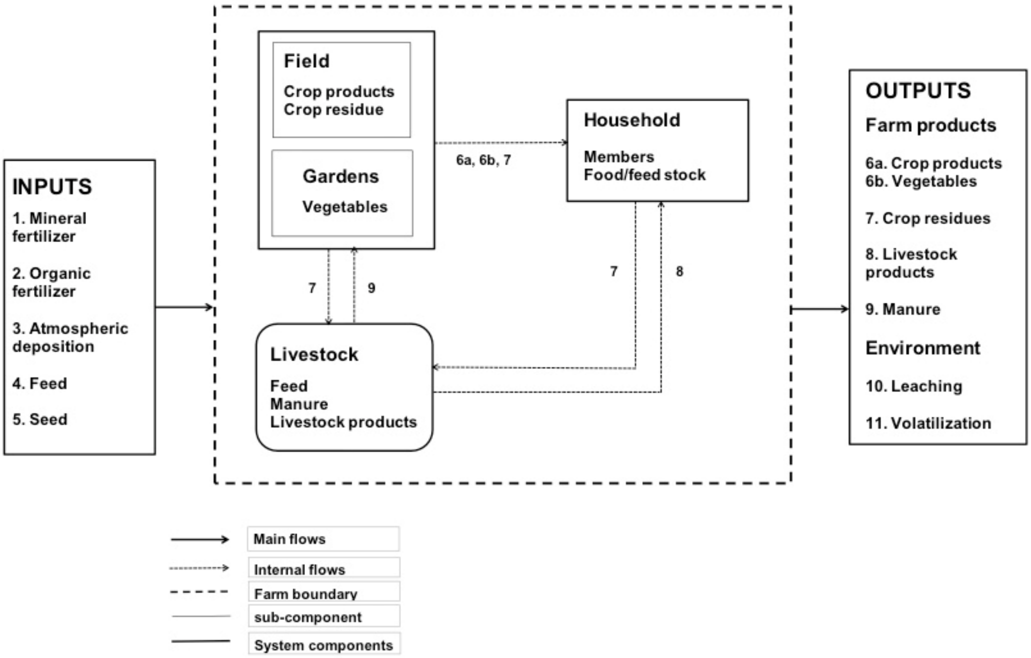

Fig. 2a: A typical UPA system diagram indicating the different components within the system and interaction between the farm components.

dynamic in order to make longer term projections. In this study, the MONQI toolbox was adapted to analyse the current nutrient management based on a detailed description of the data input for the different farming systems. The approach was applied to only three farm types in Kano, and vegetable production systems across the three cities studied. Fig. 2a gives a schematic overview of the three main system components for farm-level flows studied in Kano. The UPA farm types differ in the system components and interactions between the components (Chapter 4). For each of these components, a simple inflow-outflow model can be used to target appropriate interventions. A crop-based or vegetable-based model can be developed based on agronomic responses of the cultivated crops to applied nutrients and water. Likewise, a simple livestock module would include the quantity of feed offered, manure production and quality, and amount of nutrients needed for growth and maintenance of the different livestock species. The inclusion of the household module depends on the farm type and the possible interaction between the three components. An economic module could be included to calculate the cash flows in the different components. These include the costs of fertilizers, agro-chemicals, seed and labour inputs as well the economic values of the farm products.

Fig. 2b gives the same representation of nutrient flows in a typical vegetable production system. Other complex processes that occur in the soil system determine

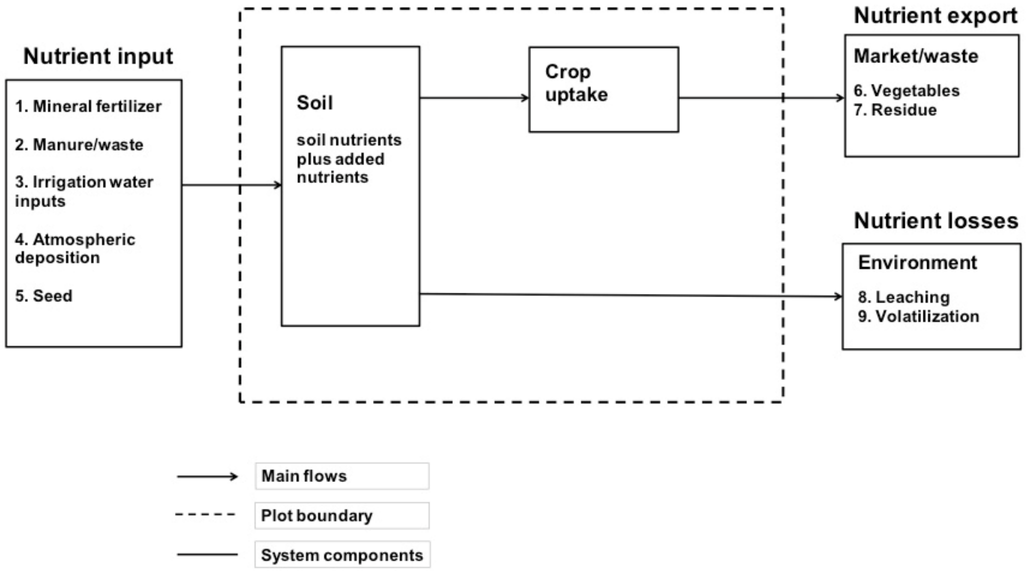

Fig. 2b: A diagram indicating the major nutrient flows in a typical UPA vegetable production system.

the availability of nutrients for crop use or not, such as decomposition rates of organic materials and inherent soil properties (Schröder et al., 2010). Data on nutrient losses can be obtained from a related study, with expressions that relate nutrient inputs to leaching and volatilization based on biophysical properties. Data available on current UPA management need to be complemented by on-farm trials to calibrate the model. Such a model can be used to obtain best technical options or alternative practices that sustain productivity and reduce nutrient losses, at the same time evaluating the economic trade-offs.

## 2. Conclusion and recommendations

The expansion of UPA will continue with increasing demand for food through urbanization, and due to the economic returns it provides to the farmers. Intensification in crop and livestock enterprise is likely to continue, and requires informed technical solutions to enhance efficiencies and maximize productivity. This study has indicated the poor nutrient use efficiency and management in current UPA systems with its negative environmental impacts. This contributes to learning and to the design of system-specific policies to reduce the associated environmental and health risks. To reduce such risks, UPA needs to be mainstreamed into government developmental plans, so that policy options on sustainable production technologies can be identified. These options need to be technically feasible, economically viable, and socially acceptable by stakeholders. Further research is therefore needed to focus on determining these options to better inform stakeholders and policies about a more sustainable UPA practice. Making recommendations for UPA systems may not be an easy task due to the complex nature in which it exists in West Africa. Specific recommendations from this study include:

- Create awareness on the environmental and economic implications of excess nutrient application. This could be properly disseminated by agricultural extension services in special UPA programmes to stakeholders and farmers.
- Appropriate fertilizer recommendation and application strategies for vegetable production systems should be devised and conveyed to farmers. This could improve nutrient supply to match crop requirements.
- Strict laws could be formulated against freely roaming animals in the streets of urban areas to reduce the accompanying nuisance. Other initiatives that improve the availability and supply of alternative livestock feeding strategies could be formulated to reduce the constraints of feeding livestock.
- Legislation against indiscriminate discharge of municipal waste into streams should be implemented. This could be achieved by improving urban waste disposal and recycling facilities as well as the promotion of technologies to improve wastewater quality and composting waste for agriculture. Simple methods of wastewater treatments could be employed to improve the quality of the irrigation water.
- Proper rationale to the storage and application of produced dung/manure in livestock holdings could be designed. This could be achieved through creating awareness among livestock owners on the beneficial role of manure in crop production as well as its negative role in the environment under poor storage. Livestock owners could be advised on the proper way to store manure and provide ways to make it accessible to farmers who grow crops but do not own livestock.

### *Concluding remark*

Having explored the different aspects of the current UPA practices, an integrated assessment for improving resource use efficiency becomes necessary. Efforts that integrate better resource management, improved economic benefits, environmental and food safety are required for UPA stakeholders. Achieving this will require the formal recognition of the UPA sector by city officials.

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# Summary

Urban and peri-urban agriculture (UPA) is defined as the cultivation of crops and keeping of livestock within and around cities. In addition to satisfying part of the cities' demand of fresh vegetables, crops and livestock products, it plays an important role in the livelihoods of the urban farmers. With the rapid urbanization in sub-Saharan Africa, UPA provides food and jobs for many urban dwellers. UPA makes use of a diverse range of urban resources such as labour, waste and wastewater to produce food and raise livestock, and is characterized by large nutrient imports into a farm or garden, often accompanied by environmental and human health risks. In view of recent concerns with respect to environmental hazards such as greenhouse effects and eutrophication of surface- and ground–water, this research focused on the quantitative assessment of nutrient flows as a basis for the development of policies that promote efficient use of nutrients and reduce the environmental risks associated with the current UPA practices, with specific objectives to:

1. Explore the diversity, typify and describe UPA systems in the three West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali) (Chapter 2 and 3).
2. Quantify flows of the major nutrients (N, P, K) and assess the economic performance of identified UPA systems in Kano, Nigeria (Chapter 4).
3. Quantify nutrient flows and financial indicators of UPA gardens in the three West African cities (Chapter 5).
4. Apply the NUTMON/MONQI methodology in the quantitative assessment of nutrient flows (Chapter 4 and 5).

Different methods were employed to achieve these objectives. These methods range from baseline interviews and regular surveys via on-farm measurements and statistical techniques to model application. From the baseline survey, data of 318 UPA households from the three cities (Kano: 99, Bobo Dioulasso: 111, Sikasso: 108) were subjected to categorical principal component analysis (CATPCA). The data were further classified using a two-step cluster analysis, and six major farm types were identified based on the degree of diversification of farm activities, farm resource endowment and production orientation. In each city, four distinct UPA systems were identified, of which three were common to the three cities. They include (in brackets the code and the percentages of the farms in Kano, Bobo Dioulasso and Sikasso, respectively) commercial gardening plus field crops and livestock (**cGCL**; 59%, 18%,

and 37%), commercial livestock plus subsistence field cropping (**cLsC**; 14%, 41%, and 7%), and commercial gardening plus semi-commercial field cropping (**cGscC;** 14%, 28%, and 30%). The fourth system was different in each location and was characterized as follows: commercial gardening plus semi-commercial livestock in Kano (**cGscL**; 13%), commercial field cropping in Bobo Dioulasso (**cC**; 13%) and commercial gardening in Sikasso (**cG**, 26%).

These systems were characterized based on their resource endowments, demographic household structure and contribution of the different components of UPA to household income. Across the cities, households with similar production systems were diverse in the distribution of their resources. In cGCL for example, garden sizes were smaller in Kano than in Bobo Dioulasso and Sikasso; a similar trend was observed for field and livestock sizes. Diversification to generate household income was explored in detail and differs within and between the farm types of the three cities. Market–oriented gardening is presently year-round and generates the largest contribution to household income. UPA was mainly conducted by farmers with little or no formal education and under poor legal protection. Production constraints were similar across the cities, i.e. high costs of inputs, water shortages and lack of fertilizer in the garden and field crop production systems, while feeding constraints and animal diseases were limiting production in livestock systems. These constraints, coupled with the lack of legal and institutional support, hamper the development of UPA in the studied areas.

Nutrient balances are useful indicators to assess the sustainability of farming systems. A positive balance indicates that nutrient inputs exceed outputs and the reverse is the case for a negative balance. Nutrient balances and economic performance were calculated for 16 households representing three identified UPA systems in Kano using the MONQI toolbox (formally known as NUTMON). Farm nitrogen (N) balances were positive at 56.6, 67.4 and 56.4 kg farm$^{-1}$ yr$^{-1}$ for cGCL, cGscL and cLsC farm types, respectively, indicating an excess supply of nutrients. The same trend was observed for phosphorus (P) and potassium (K) in all the farm types except for cGCL, where an annual negative K balance of 16 kg farm$^{-1}$ was found. Potassium inputs are limited under vegetable and crop production of cGCL and threaten long-term soil K availability in this system. Overall, the results indicated large annual surpluses of N and P in urban and peri-urban vegetable, crop and animal production systems in all the farm types which pose potential threats when these nutrients are lost to the environment. Commercially-oriented livestock keeping (cLsC) was economically more viable than the other farm types with an average annual positive gross margin (GM) and net cash flow (NCF) of \$9033 and \$935, respectively. Cropping activities within cGCL and cGscL had positive GMs ($1059 and $194) and NCFs ($757 and $206) but livestock activities in both farm types incurred financial losses. In many cases, small ruminants are kept for security, and sold in periods of cash needs. Other social aspects that prevail in West Africa such as annual religious festivities (such as Tabaski) are also drivers of keeping livestock. Livestock are fed (fattened) to be sold during this annual event, such that a substantive amount of feed is invested as nutrient input. The immediate economic returns of keeping small ruminants may not be glaring during short periods of monitoring, but rather in the longer term.

Market gardening is an important component of UPA in most parts of West Africa and farmers apply large quantities of nutrients to increase productivity with accompanying economic returns. Since market-oriented vegetable production is common across farm types in the three cities, it was explored for similarities and differences in management practices and economic performance. Soil nutrient balances that refer to the soil-plant systems and express the differences between applied and extracted nutrients, were investigated for UPA gardens in the three cities. For selected gardens (Kano: 6, Bobo Dioulasso: 2, Sikasso: 6), and using the MONQI toolbox, nutrient flows and balances were calculated for two years. Average annual N balances were positive for all gardens in the three cities: 279, 1127 and 74 kg ha$^{-1}$ in Kano, Bobo Dioulasso and Sikasso, respectively. The phosphorus balance was positive in all three cities, but in Kano and Sikasso the annual potassium balance was negative: 222 and 187 kg ha$^{-1}$, respectively. Nutrient use efficiencies (NUE: nutrient output in harvested produce and residues versus inputs in organic and inorganic fertilizers) were calculated by the partial balance method and expressed as percentages. Nutrient use efficiencies were 63%, 51% and 87% for N and 57%, 22% and 34% for P in Kano, Bobo Dioulasso and Sikasso, respectively. Phosphate use efficiencies were poor due to excess application in all three cities. However, K efficiency of 85% was observed in Bobo Dioulasso. In Kano and Sikasso’s gardens, K efficiencies of 120% and 110% were calculated respectively, indicating possible K mining with long term implications for soil K fertility. The average annual gross margins from gardening indicate the highest return ($3.83 m$^{-2}$) in Bobo Dioulasso, which differs statistically significantly ($P<0.05$) from returns obtained in Kano ($0.92 m$^{-2}$) and Sikasso ($1.37 m$^{-2}$).

UPA represents an important economic activity in the livelihood strategy of urban dwellers, because of its positive economic returns, but with huge environmental trade-offs as a consequence of excess nutrient application. On the one hand, UPA makes use of produced city waste for re-cycling of nutrients, therefore contributing to closing the urban waste-food production cycle; it also reduces the burden of waste management on city officials. On the other hand, large amounts of nutrients applied are prone to volatilization and leaching losses such as nitrous oxide or ammonia as well as nitrate that may be leached beyond the root zone with implications for groundwater quality. Unfortunately, UPA still remains largely in the informal sector and requires institutional support and formal recognition for target-oriented technology development and policy implementation. Processes that increase nutrient use efficiencies and reduce environmental pollution in UPA activities could be better explored to attain a more sustainable production.

This research explored the diversity of the UPA systems in the West African cities of Kano (Nigeria), Bobo Dioulasso (Burkina Faso) and Sikasso (Mali), and applied the concepts of nutrient budgeting to quantify the nutrient imports and exports in production systems. Considering the complexity and diversity exhibited by most UPA systems, the consistent and replicable typology developed in this study provides a basis to design system-specific technologies that improve management of urban resources and reduce the risks associated with the current UPA practices in West Africa. Efforts to better integrate resource management with measures to improve environmental and food safety are required of UPA stakeholders. Achieving this will require the formal recognition of the UPA sector by city officials by formulating realistic strategies for effective nutrient and water management. Specific recommendations from this research would be:

1. Recognize, formalize and integrate the UPA sector into the city and agricultural development plans in order to effectively disseminate research and development findings to stakeholders on the associated risks and economic benefits derived from the activities.
2. Formulate appropriate fertilizer recommendations and application strategies for vegetable production systems, taking into account the quantities of nutrients applied through wastewater applications, and convey these recommendations to UPA farmers. This could improve nutrient supply to match crop requirements.
3. Improve urban waste disposal and recycling facilities, and promote technologies to improve wastewater quality and to compost waste for agriculture.

# Samenvatting

Stadslandbouw wordt gedefinieerd als het telen van gewassen en het houden van vee in en rondom steden. Naast het voldoen aan de vraag van de bevolking naar verse groenten, overige levensmiddelen en veeteeltproducten, speelt stadslandbouw een belangrijke rol in het levensonderhoud van de stedelijke landbouwers. Bij de snelle verstedelijking in Sub-Sahara Afrika zorgt de stadslandbouw voor voedsel en werkgelegenheid voor vele stadsbewoners. Stadslandbouw maakt gebruik van een rijk scala aan stedelijke hulpbronnen, zoals arbeid, afval en afvalwater bij het produceren van voedsel en het houden van vee, en wordt gekarakteriseerd door een grote aanvoer van nutriënten naar het bedrijf of de tuin, vaak met risico's voor milieuverontreiniging en de menselijke gezondheid. Met het oog op recente zorgen met betrekking tot het milieu, zoals het broeikaseffect en de eutrofiëring van oppervlakte- en grondwater, ligt de nadruk in dit onderzoek op het kwantificeren van de nutriëntenstromen, met het doel beleid te formuleren dat leidt tot het efficiënt gebruik van nutriënten en het verkleinen van de risico's voor het milieu die samenhangen met de huidige praktijken in de stadslandbouw. De specifieke doelstellingen zijn:

1. Verkennen van de diversiteit, beschrijven en karakteriseren van de huidige stadslandbouwsystemen in drie West-Afrikaanse steden, namelijk Kano (Nigeria), Bobo Dioulasso (Burkina Faso) en Sikasso (Mali) (Hoofdstukken 2 en 3).
2. Kwantificeren van de stromen van de belangrijkste nutriënten (stikstof (N), fosfor (P) en kali (K)) en evaluatie van de economische prestaties van de geïdentificeerde stadslandbouwsystemen in Kano (Nigeria) (Hoofdstuk 4).
3. Kwantificeren van de nutriëntenstromen en de financiële indicatoren van stadslandbouw in de drie West-Afrikaanse steden (Hoofdstuk 5).
4. Toepassen van de NUTMON/MONQI methode bij de kwantitatieve evaluatie van de nutriëntenstromen (Hoofdstukken 4 en 5).

Om deze doelstellingen te realiseren, zijn verschillende methoden toegepast, variërend van interviews om de uitgangssituatie te definiëren en regelmatige surveys, via metingen op de bedrijven en statistische technieken tot toepassing van een model. Van de basissurvey zijn de gegevens van 318 huishoudens (Kano: 99, Bobo Dioulasso: 111, Sikasso: 108) geanalyseerd met de categorical principal component analysis (CATPCA). De gegevens zijn verder geclassificeerd via een twee-staps cluster analyse, en er zijn zes bedrijfstypen gedefinieerd op basis van de mate van diversificatie in bedrijfsactiviteiten, de beschikbare hulpbronnen op het bedrijf en de productieoriëntatie. In ieder van de drie steden zijn vier bedrijfssystemen geïdentificeerd, waarvan er drie in alle drie de steden voorkwamen. De onderscheiden bedrijfstypen zijn (tussen haakjes de code en het aandeel van de bedrijfstypen in het totale aantal bedrijven in elk van de drie steden): marktgerichte tuinbouw gecombineerd met akkerbouwgewassen en vee (**cGCL**; 59%, 18% en 37%), marktgerichte veehouderij gecombineerd met op zelfvoorziening gerichte akkerbouw (**cLsC**; 14%, 41% en 7%), en marktgerichte tuinbouw gecombineerd met semi-commerciële akkerbouw (**cGscC;** 14%, 28% en 30%). Het vierde type was verschillend in ieder van de drie steden en kan als volgt worden gekarakteriseerd: marktgerichte tuinbouw gecombineerd met semi-commerciële veehouderij in Kano (**cGscL**; 13%), marktgerichte akkerbouw in Bobo Dioulasso (**cC**; 13%), en marktgerichte tuinbouw in Sikasso (**cG**, 26%).

De bedrijfssystemen zijn gekarakteriseerd op basis van de beschikbaarheid van hulpbronnen, de demografische structuur van het huishouden, en de bijdrage van de verschillende componenten van stadslandbouw aan het totale inkomen van het huishouden. Soortgelijke bedrijven in de drie steden verschilden met betrekking tot de verdeling van hun hulpbronnen. In cGCL bijvoorbeeld, waren de tuinen van hetzelfde bedrijfstype kleiner in Kano dan in Bobo Dioulasso en Sikasso; een vergelijkbare trend is gevonden met betrekking tot de grootte van de akkerbouwpercelen en de veestapel. Diversificatie om inkomen voor de bedrijven te genereren is in detail geanalyseerd en verschilt binnen en tussen de bedrijfstypen in de drie steden. Marktgerichte tuinbouw wordt het hele jaar door bedreven en levert de grootste bijdrage aan het inkomen van de huishoudens. Stadslandbouw wordt voornamelijk bedreven door boeren met weinig of geen formele opleiding en onder een geringe rechtszekerheid. Beperkingen voor de productie waren gelijk in de drie steden, namelijk hoge kosten van de productiemiddelen, gebrek aan water en aan kunstmest in de tuinbouw- en akkerbouwsystemen, terwijl gebrek aan voedermiddelen en dierziekten beperkende factoren waren in de veehouderijsystemen. Deze beperkingen, gecombineerd met gebrek aan wettelijke- en institutionele ondersteuning bemoeilijken de ontwikkeling van de stadslandbouw in de studiegebieden.

Nutriëntenbalansen zijn nuttige indicatoren om de duurzaamheid van bedrijfssystemen te beoordelen. Een positieve balans betekent dat de aanvoer van nutriënten groter is dan de afvoer en het omgekeerde is het geval bij een negatieve balans. Nutriëntenbalansen en de economisch prestaties zijn berekend voor 16 huishoudens welke representatief waren voor drie van de in Kano geïdentificeerde bedrijfssystemen. Hierbij werd gebruik gemaakt van het MONQI (formeel aangeduid als NUTMON) instrumentarium. De stikstofbalans op bedrijfsniveau was positief, met waarden van respectievelijk 56.6, 67.4 en 56.4 kg bedrijf$^{-1}$ jaar$^{-1}$ voor cGCL, cGscL en cLsC, hetgeen wijst op een overmatige aanvoer. Een vergelijkbare trend werd gevonden voor fosfor (P) en kali (K), behalve voor cGCL, waarin een negatieve balans van 16 kg bedrijf$^{-1}$ jaar$^{-1}$ werd gevonden. De aanvoer van K is laag in de tuinbouw- en akkerbouwsystemen van cGCL, hetgeen een gevaar is voor de beschikbaarheid van kali op lange termijn in dit systeem. In z'n algemeenheid wijzen de resultaten op grote jaarlijkse overschotten van N en P in alle bedrijfstypen, in zowel de tuinbouw-, akkerbouw-, als veehouderijsystemen van de stadslandbouw, hetgeen risico's inhoudt wanneer deze nutriënten in het milieu terechtkomen.

Marktgerichte veehouderij (cLsC) was economisch meer levensvatbaar dan de andere bedrijfstypen, met een gemiddeld jaarlijks positief bruto bedrijfsoverschot (GM) en een netto cash flow (NCF) van respectievelijk $9033 en $935. Akkerbouwactiviteiten, in zowel cGCL als cGscL, leidden tot positieve GMs ($1059 en $194) en NCFs ($757 en $206), maar veehouderijactiviteiten in beide bedrijfstypen toonden negatieve financiële resultaten. In veel gevallen worden kleine herkauwers gehouden voor financiële zekerheid, en deze worden verkocht in perioden dat contant geld nodig is. Andere sociale aspecten die van belang zijn in West-Afrika, zoals jaarlijkse religieuze feesten (zoals Tabaski), spelen ook een rol bij het houden van vee. Vee wordt gevoerd (vetgemest) om te worden verkocht tijdens deze jaarlijkse gebeurtenis, zodat een substantiële hoeveelheid voer bijdraagt aan de nutriëntenaanvoer. De directe economische voordelen van het houden van kleine herkauwers zijn misschien niet gemakkelijk te zien door de relatief korte waarnemingsperiodes, maar waarschijnlijk wel op de langere termijn.

Marktgerichte tuinbouw is een belangrijke component van stadslandbouw in grote delen van West-Afrika en de boeren dienen grote hoeveelheden nutriënten toe in deze systemen om de productie te verhogen, met de daaraan gekoppelde economische voordelen. Aangezien marktgerichte tuinbouw voorkomt in alle bedrijfstypen in de drie steden, is deze activiteit verkend met betrekking tot verschillen en overeenkomsten in beheer en economische prestaties. De bodemnutriëntenbalansen, die betrekking hebben op het bodem-plant systeem en het verschil aangeven tussen de aanvoer en de onttrekking van nutriënten in de bodem, zijn onderzocht voor de tuinbouwsystemen in de drie steden. Voor de geselecteerde tuinbouwpercelen (Kano: 6, Bobo Dioulasso: 2, Sikasso: 6) zijn de nutriëntenstromen en de nutriëntenbalansen berekend voor twee jaren met behulp van het MONQI instrumentarium. De gemiddelde jaarlijkse stikstofbalansen waren positief voor alle tuinbouwpercelen in de drie steden: respectievelijk 279, 1127 en 74 kg N $ha^{-1}$ in Kano, Bobo Dioulasso en Sikasso. De fosfaatbalans was positief in alle drie de steden, maar in Kano en Sikasso was de jaarlijkse K-balans negatief, namelijk respectievelijk 222 en 187 kg $ha^{-1}$. De efficiënties van nutriëntengebruik (NUE: de afvoer van nutriënten in geoogst product en gewasresten als fractie van de totale aanvoer van nutriënten in organische en anorganische meststoffen) werden berekend via de partiële balansmethode en uitgedrukt in percentages. De efficiënties van nutriëntengebruik waren respectievelijk 63, 51 en 87% voor N en 57, 22 en 34% voor P in Kano, Bobo Dioulasso en Sikasso. De efficiënties van nutriëntengebruik waren laag voor P als gevolg van overmatige aanvoer in alle drie de steden. De efficiënties van nutriëntengebruik voor K was 85% in Bobo Dioulasso. In de tuinbouwpercelen in Kano en Sikasso werden K gebruiksefficiënties van 120% en 110% berekend, wijzend op een mogelijke uitputting van de K-voorraad in de bodem met gevolgen voor de lange-termijn K-bodemvruchtbaarheid. De gemiddelde jaarlijkse bruto opbrengsten van de tuinbouwpercelen waren statistisch significant ($P<0.05$) hoger (\$3.83 $m^{-2}$) in Bobo Dioulasso, dan in Kano (\$0.92 $m^{-2}$) en Sikasso (\$1.37 $m^{-2}$).

Stadslandbouw is een belangrijke economische activiteit in de strategie voor levensonderhoud van de stedelingen vanwege de positieve economische bedrijfsresultaten, maar met grote gevolgen voor het milieu als gevolg van de aanvoer van grote hoeveelheden nutriënten. Enerzijds maakt stadslandbouw gebruik van afval geproduceerd in de stad en draagt dus bij aan hergebruik van nutriënten en aan het sluiten van kringlopen in de stedelijke voedselproductie-afval cyclus; stadslandbouw vermindert ook de problemen van afvalbeheer voor de stedelijke ambtenaren. Anderzijds zijn de grote hoeveelheden nutriënten die worden aangevoerd onderhevig aan verliezen ten gevolge van vervluchtiging als stikstofoxiden en ammonia en ten gevolge van uitspoeling als nitraat tot beneden de wortelzone, met gevolgen voor de kwaliteit van het grondwater. Ongelukkigerwijs wordt stadslandbouw vooral bedreven in de informele sector en heeft behoefte aan institutionele ondersteuning en formele erkenning voor een doelgerichte technologieontwikkeling en formulering van beleid. Processen die leiden tot verhoging van de efficiëntie van nutriëntengebruik en vermindering van milieuverontreiniging in de stadslandbouw moeten beter worden onderzocht om tot een meer duurzame productie te komen.

Dit onderzoek heeft de diversiteit onderzocht binnen stadslandbouwsystemen in de West-Afrikaanse steden Kano (Nigeria), Bobo Dioulasso (Burkina Faso) en Sikasso (Mali), en heeft gebruik gemaakt van het concept van nutriëntenbalansen om de aanvoer en afvoer van nutriënten in de productiesystemen te kwantificeren. Gezien de complexiteit en diversiteit binnen deze stadslandbouwsystemen, vormt de consistente en reproduceerbare typologie die in deze studie is ontwikkeld een basis voor het ontwikkelen van systeem-specifieke technologieën die het beheer van stedelijke hulpbronnen verbeteren en leiden tot het identificeren van beheersmaatregelen die de risico's, die aan de huidige stadslandbouw in West Afrika kleven, verminderen. Om dat te realiseren is een formele bestuurlijke erkenning van de stadslandbouw als een belangrijke sector vereist, door het formuleren van realistische strategieën voor een effectief nutriënten- en waterbeheer. Specifieke aanbevelingen die kunnen worden geformuleerd op basis van dit onderzoek zijn:

1. Erken, formaliseer en integreer de stadslandbouwsector in de ontwikkelingsplannen voor de stad en voor de landbouw, teneinde een effectieve doorstroming van onderzoeks- en ontwikkelingsresultaten met betrekking tot de risico's en de economische prestaties van de stadslandbouw naar de belanghebbenden te bevorderen.
2. Formuleer geschikte adviezen voor bemestings- en toedienings-strategieën voor tuinbouwproductiesystemen, rekening houdend met de hoeveelheden nutriënten die worden toegediend met het afvalwater, en geef deze aanbevelingen door aan de boeren die zich met stadslandbouw bezighouden. Dit kan leiden tot een situatie waarbij de nutriëntenaanvoer beter is afgestemd op de nutriëntenbehoeften van de gewassen.
3. Verbeter de stedelijke afvalverwerkings- en hergebruikvoorzieningen en bevorder technologieën die leiden tot verbetering van de kwaliteit van afvalwater en tot het gebruik van compost in de landbouw.

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# Curriculum Vitae

Aisha Abdulkadir was born on May, 11, 1976 in Kaduna state, Nigeria. She attended Polytechnic Staff School in Kaduna for primary education and proceeded for secondary education in Federal government Girls' College Kazaure, Jigawa state, Nigeria, from 1989–1993. In 1994, she got admitted into Ahmadu Bello University Zaria, Nigeria for a five year Bachelor of Agriculture degree which she completed in October 2000. In 2001–2002, she joined the National Service Programme (National Youth Service Corp–NYSC) and assisted in teaching the basis of soil science in the Department of Agricultural Engineering of Kaduna Polytechnic for one year. She later got employed by the University of Ahmadu Bello University Zaria, Nigeria as an Assistant lecturer in the Department of Soil Science. She enrolled for an MSc in Soil Science in 2003 in the same department and completed in 2006 and got appointed as a Lecturer II in the same department upon completion of the MSc. She was involved in local organization of 31st SSSN annual conference and was a departmental representative for Agricultural mechanization scheme under the Institute for Agricultural Research (IAR), Ahmadu Bello University Zaria, Nigeria. Through the Volkswagen funded 'Urban Food' Project, she started a PhD at Wageningen University with Plant Production Systems Group in 2007 on nutrient flows in urban and peri-urban agriculture of secondary cities in West Africa (in Nigeria, Burkina-Faso and Mali).

# List of Publications

## Journal Papers

1. Wuddivira, H.N., **A. Abdulkadir**, and J. Tanimu. 2001. Prediction of Infiltration characteristics of an Alfisol in the Northern Guinea Savanna of Nigeria. Nigerian Journal of Soil Research. 2, 1– 5.

2. N. Abdu, A.A. Yusuf, **A. Abdulkadir**, U.L. Arunah, V.O. Chude and S.G. Pam. 2007. Zinc Soil Test Calibration based on 0.1N HCl Extractable Zinc and Cation Exchange Capacity from Upland Soils of Northern Nigeria. Journal of Agronomy 6 (1), 179–182.

3. N. Abdu, **A. Abdulkadir** and J.B. Jibril. 2009. Challenges and opportunities for solid waste management in urban interface of Kano, Nigeria. Waste Management. 29, 2603–2605.

4. Abdu, N., **A. Abdulkadir**, J.O. Agbenin and A. Buerkert. 2011. Vertical distribution of heavy metals in wastewater-irrigated vegetable garden soils of three West African cities. Nutrient Cycling in Agroecosystems. 89, 387–397.

5. Dossa, L.H., **A. Abdulkadir**, H. Amadou, C. Sangare, and E. Schlecht. 2011. Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. Landscape and Urban Planning. 102, 197–206.

6. **Abdulkadir, A**. 2011. Estimating Saturated Hydraulic conductivity from Soil properties of the Northern Nigerian Savanna. Biological and Environmental Science Journal for the Tropics. 8(4), 1–9.

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8. **Abdulkadir, A**., L.H. Dossa, D.J-.P. Lompo, N. Abdu, H. van Keulen.

2012. Characterization of urban and peri-urban agroecosystems in three West African cities. International Journal of Agricultural Sustainability. DOI:10.1080/14735903.2012.663559.

9. Hamadoun, A., L.H. Dossa, D.J-.P. Lompo, **Abdulkadir, A**. and E. Schlecht. 2012. A comparison between urban livestock production strategies in Burkina Faso, Mali and Nigeria in West Africa. Tropical Animal Health and Production. DOI: 10.1007/s11250-012-0118-0.

10. **Abdulkadir, A**., N. Abdu and I. Jibril. 2012. Application of Kozeny-Carman equation to estimate saturated hydraulic conductivity of Savanna soils of Northern Nigeria. Journal of Basic and Applied Sciences. 20 (1), 116–124.

**Submitted manuscripts**

**Abdulkadir, A**. and S.H. Takwa. 2011. Soil properties of a fallow field after 45 years of cultivation and fertilization in Samaru, northern guinea savanna, Nigeria. Tropical and Sub-tropical Agroecosystems. *Under Review.*

## PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

### Review of literature (4.5 ECTS)

- Urban and peri-urban agriculture, nutrient flows and balances

### Writing of project proposal (6 ECTS)

- Horizontal nutrient flows in urban and peri-urban agroecosystems of Kano, Northern Nigeria (2008)

### Post-graduate courses (3 ECTS)

- Linear models; PE&RC (2010)
- Introduction to R statistics; PE&RC (2010)
- Methodological training workshop for the Urban Food Project, Bobo-Dioulasso, Burkina Faso; DITSL/Germany and INERA/Burkina Faso

### Deficiency, refresh, brush-up courses (8.4 ECTS)

- Quantitative analysis of land use systems-QUALUS (2008)
- Systems analysis, simulation and systems management (2008)
- Quantitative analysis of cropping and grasslands systems-QUACGS (2009)

### Competence strengthening / skills courses (2.2 ECTS)

- PhD Competence assessment; PE&RC (2008)
- Scientific writing; WUR Language Centre (2008)
- Endnote demonstration; WUR library (2010)

### PE&RC Annual meetings, seminars and the PE&RC weekend (1.8 ECTS)

- PE&RC Day (2010)
- PE&RC Weekend (2010)
- Mini-symposium “The role of organic resources in soil fertility management” (2010)
- Global soil fertility workshop (2011)

**Discussion groups / local seminars / other scientific meetings (5.9 ECTS)**

- Statistics, maths and modelling (2008)
- Urban Food Project meetings and discussions at Wageningen-Netherlands, Witzenhausen-Germany and Kano, Nigeria (2008-2010)

**International symposia, workshops and conferences (6.9 ECTS)**

- Horizontal nutrient flows in urban and peri-urban agricultural systems of three West African Cities; poster presented at grantees meeting of the Volkswagen Foundation: resources, their dynamics, and sustainability-capacity-development in comparative and integrated approaches; Dar Es Salaam (2009)
- Nutrient flows and balances in urban and peri-urban agroecosystems in Kano, Nigeria; poster presented at the grantees meeting of the Volkswagen Foundation: resources, their dynamics, and sustainability-capacity-development in comparative and integrated approaches; Witzenhausen, Germany (2010)
- Exploring the diversity of urban and peri-urban agricultural systems in West Africa: an attempt towards a regional typology; poster presented at the Tropentag; Zurich, Switzerland (2010)

**Lecturing / supervision of practical's/ tutorials; 18 days (5.4 ECTS)**

- Fundamentals of soil physics at the Department of Soil Science; Ahmadu Bello University, Zaria, Nigeria (2007)

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