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Document type : *Article de périodique (Journal article)*

Référence bibliographique

Lompo, Désiré Jean-Pascal ; Compaoré, Emmanuel ; Sedogo, Michel Papaoba ; Melapie, Martina ; Bielders, Charles ; et. al. *Horizontal flows of nitrogen, potassium, and carbon in urban vegetables gardens of Bobo Dioulasso, Burkina Faso.* In: *Nutrient Cycling in Agroecosystems*, (2018)

DOI : 10.1007/s10705-018-9949-z

Nutr Cycl Agroecosyst
https://doi.org/10.1007/s10705-018-9949-z

ORIGINAL ARTICLE

Horizontal flows of nitrogen, potassium, and carbon in urban vegetables gardens of Bobo Dioulasso, Burkina Faso

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Received: 19 January 2018 / Accepted: 7 September 2018

Abstract Little is known about matter flows in intensive small scale production systems of urban agriculture in West Africa as an important criterion to assess their sustainability and environmental externalities. This study therefore investigated nutrient management practices in six selected urban vegetable gardens of Bobo Dioulasso, the second largest city of Burkina Faso. Nitrogen (N), potassium (K), and carbon (C) fluxes were quantified and nutrient balances calculated for three gardens representing typical commercial gardening + field crops and livestock systems (cGCL) and three gardens representing commercial gardening + semi-commercial field crop systems (cGscC). Inputs in all gardens exceeded the amounts recommended by the extension service by up to 709% for N and 434% for K leading to horizontal annual surpluses of 1013 kg N ha^{-1}, 879 kg K ha^{-1}, and 25 t C ha^{-1}, while total balances were only positive for N and K, but negative for C. In both systems, apparent nutrient use efficiency was highest for K (85% and 54% for cGCL and cGscC) followed by N (66% and 44%). Management recommendations should be geared towards increasing N efficiencies by better tailoring nutrient supply to crop demands.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10705-018-9949-z) contains supplementary material, which is available to authorized users.

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Keywords Matter balance · Nutrient use efficiency · Vegetable production · West Africa

Introduction

During the past decade several authors have emphasized the growing importance of urban-and peri-urban agriculture (UPA) contributing to feeding the rapidly increasing urban population of developing countries (Drescher et al. 2006; Levasseur et al. 2007; Prain and Lee-Smith 2010; Karg et al. 2016). This is particularly the case in sub-Saharan Africa, where the population share living in urban areas due to social inequality, infrastructural deficiencies, warfare in rural areas and population growth is predicted to increase from 45% in 2011 to 66% in 2050 (UN-Habitat 2014). In several cities of Burkina Faso UPA is practiced on a multitude of small plots that have developed from the colonial period (Freidberg 2003) into today's complex systems with often elaborate post-production value chains. In special cases such as the dry season production of fresh strawberries (*Fragaria* × *ananassa* Duchesne) in Burkina's capital Ouagadougou, these can directly link farmers' intensively managed gardens (100–300 m^2 size, Bellwood-Howard et al. 2015) with consumers in 1000 km distant Accra, the coastal capital of Ghana.

In addition to fulfilling market demands UPA is also practiced as a survival strategy by families with low purchasing power and restricted access to food (Armar-Klemesu 2000; RUAF 2005; van Veenhuizen and Danso 2007). Its positive side effects are an improvement of urban environments through recycling of solid and liquid waste, greening of neighborhoods, and in some cases even an improvement of the micro-climate through the existence of irrigated green spaces (RUAF 2005). At the political level UPA has been credited to play a significant role in achieving Millennium Development Goals (MDGs) such as "Eradication of extreme poverty and hunger", "Promotion of gender equality and empowerment of women", "Combat of HIV–AIDS and other diseases", and "Ensuring environmental sustainability" (van Veenhuizen and Danso 2007). Therefore, a growing number of international development agencies, research centers, and civil society organizations foster UPA as part of urban policy and development programs (Castillo 2003).

UPA farming systems are typically much more intensive than rural ones (Smith et al. 1996; Rosendahl et al. 2009) with higher nutrient inputs that may lead to accumulation of surpluses in the soil and substantial losses by leaching and volatilisation (Drechsel et al. 1999; Huang et al. 2006, 2007; Wang et al. 2008; Diogo et al. 2010; Predotova et al. 2011). From Niamey (Niger) Diogo et al. (2010) reported annual horizontal (partial, omitting vertical fluxes such as leaching and gaseous losses) balances of 9936 kg C ha^{-1}, 1133 kg N ha^{-1}, and 312 kg K ha^{-1} indicating low fertilizer use efficiencies and an important risk for negative environmental externalities (Gruhn et al. 2000; Smaling et al. 2006; Predotova et al. 2010). Consumer health may also be threatened because of excessive applications of pesticides on vegetables and the use of microbially or heavy metal contaminated irrigation water and municipal waste (Anikwe and Nwobodo 2002; Singh et al. 2004; Amoah et al. 2006, 2005; Abdu et al. 2011, 2012).

Recently, research has been undertaken to reduce negative impacts of UPA on the environment and consumer health. In this context calculations of matter balances can help to optimize nutrient application, increase nutrient use efficiency, and to serve as an indicator of potential land degradation (Cobo et al. 2010). During the last two decades in several sub-Saharan African countries, several studies have been conducted about the effects of nutrient management in rural farming systems (Bationo et al. 1998; Smaling et al. 1993; Stoorvogel et al. 1993), but much less is known about nutrient fluxes in intensive UPA production systems. This study therefore aims at contributing to close this knowledge gap through nutrient monitoring in vegetable gardens of Bobo Dioulasso, a typical major city of the West African country of Burkina Faso. UPA vegetable production in this city represents 15% of the total national vegetable production (Sy 2011) and contributes significantly to provisioning Ouagadougou (Karg et al. 2016).

Materials and methods

Study site

Our 18-months study was conducted in Bobo Dioulasso (4°20′W, 11°09′N), the second largest city of Burkina Faso, located in the western part of the country at 360 km of Ouagadougou, the capital city. Its surface is approximately 14,000 ha with a total population of 310,000 inhabitants in 1996 and 490,000 in 2006 (INSD 2008, 2010). The local climate is tropical, Sudano-Guinean with a dry season from November to May and a rainy season from May to October. Annual rainfall varies between 800 and 1000 mm, distributed in 75–85 rainy days (PANA 2003).

Bobo Dioulasso is partitioned by the creek Marigot Houet flowing from the south to the north-east of the town. Despite its high load of liquid and solid wastes, pathogens and hazardous chemicals, the creek provides irrigation water for one-third of the local urban gardens (Kinané et al. 2008). These comprise hundreds of small plots of 25–100 m^2 size on 24% of the city quarter areas which are characterized by a large variety of vegetable rotation systems with multiple harvests per year.

Description and selection of gardens

Abdulkadir et al. (2012) had classified the UPA households (HHs) of Bobo Dioulasso based on resource endowments, the degree of integration of vegetable, field crop and animal production, and the production orientation. The resulting four groups comprised 'commercial gardening + field crop and livestock' (cGCL), 'commercial gardening + semi-commercial crop' (cGscC; partly home consumption, partly market-oriented), 'commercial livestock + subsistence field cropping' (cLsC) and 'commercial field cropping' (cC; Table 1). To be able to study Bobo Dioulasso's urban gardening systems in more detail, only the two groups categorized as cGCL and cGscC were taken into account for detailed monitoring of matter flows in this study. To this end, three HHs were selected from each of the two groups based on the accessibility of the garden and the willingness of the gardener to cooperate during the entire duration of the study.

The cGCL systems comprised a combination of commercial vegetable gardening, field cropping and livestock production. Total average garden area per HH was about 797 m^2 while total field area (not studied further) averaged 4.6 ha, and there were on average 4.4 Tropical Livestock Units (TLU). The vegetable garden contributed most to HH income, with moderate to large shares also from field crops and livestock activities. Only 10% of the HHs in this group earned a regular salary and 25% generated moderate to low earnings from occasional unskilled off-farm activities (Abdulkadir et al. 2012).

A typical cGscC HH also comprised market-oriented gardening activities, but these were combined with semi-subsistence field cropping. Average garden size was about 737 m^2 comparable to that of the cGCL system, while field size was with an average of 2.4 ha rather small and gardening was the main contributor to total HH income. Field cropping activities contributed moderately to HH income while contributions from occasional and regular off-farm employment were low (Abdulkadir et al. 2012).

Quantification of horizontal N, K and C flows and calculation of balances

In each of six selected gardens (three per system, Table 1), six representative plots (in total 36 plots) were chosen and the management practices such as sowing and planting, irrigation, type and application rates of fertilizers used for the 4–5 consecutive crops

Table 1 Main characteristics of the selected gardens in the two urban and peri-urban agricultural production systems in Bobo Dioulasso, Burkina Faso

Production system	Garden location	Irrigation water source	Main vegetables
cGCL	Kodeni 1	Well	Cabbage, lettuce, carrot
	Dogona 1	River	Cabbage, lettuce, carrot, tomato
	Dogona 2	River	Cabbage, lettuce, carrot, tomato
cGscC	Kuinima	Well	Cabbage, lettuce, carrot, tomato
	Kodeni 2	Well	Cabbage, lettuce, sorrel
	Kodeni 3	Well	Cabbage, lettuce, pepper

cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop planted per plot were closely monitored from March 2008 to September 2009. Plot based horizontal balances of N, K, and C were calculated by subtracting outputs from inputs using a soil surface partial horizontal balance (SSPHB) approach (Diogo et al. 2010; Supplementary Material—EXCEL data). Phosphorus data were incomplete and therefore omitted from flow analysis.

Plot-based inputs (IN1) of soil amendments (mineral fertilizers, animal manure, and solid urban waste) were quantified for each crop. To this end the amount of amendment applied was weighted, a sample was taken, air dried, and analyzed for its concentration of N, K, and organic carbon (Corg). The total amount of N, K, and C applied were obtained by multiplying the total amount of the applied amendment (dry weight) by the nutrient concentration in the sample. From April 2008 to February 2009 in each garden nutrients added via irrigation water (IN2, containing seasonally varying proportions of wastewater) were determined by quantifying twice per week the amount of water applied to the selected plots. Two water samples of each 1 l volume were taken once per week and pooled by cropping cycle. Immediately after collection, the water samples were acidified with one drop of 0.1 M HCl and stored frozen until analysis for N and K concentrations. Nutrient inputs through irrigation water were estimated by multiplying the nutrient concentration in the water source by the total amount of water applied. Carbon input via photosynthesis (IN3) was estimated from vegetable harvests by assuming that roots and root exudates represent 50% of the total carbon in the harvest (Nguyen 2003). As a consequence, the total net C input via photosynthesis was assumed to approximate the harvested parts multiplied by 1.5. Additional C as well as N and K inputs via atmospheric deposition (IN4) and biological N_2 fixation (IN5), both were considered to be small given lacking industry and dust storms in this part of the Sudano-Guinean zone, were estimated from the literature (Table 2).Thereby it was taken into account that dust deposits in the Sahel decline in N–S location with increasing distance from the source areas of the Bodélé depression near Bilma (Niger; Herrmann et al. 1997; Ozer 2002), but may locally increase by factor 2 in the presence of fall-out obstacles such as trees, buildings or hills. Sedimentation and deep capture were not accounted for as all fields were terrassed.

Nutrient removals through crop harvests (OUT1) were quantified plot-wise by weighing the fresh matter obtained from a randomly chosen 1 m^2 area, oven-drying it at 65 °C to constant weight, and multiplication by the analysed C, N, K, and the total area of the harvested plot. Weed biomass was with < 10 kg DM ha^{-1} negligible due to frequent weeding and thus mineralization on the spot as well as release of fixed carbon as CO_2 (Supplementary Material—Figs. 1–3). Visual inspection did not indicate leguminous weeds which would have contributed to biological N_2 fixation and thus N-addition to the systems under study. Outputs via leaching (OUT2) and gaseous losses (OUT3) were taken from the literature whereby these data vary widely for different cultivation systems, year of study, and location (Table 2). Terrassed garden surfaces in Bobo Dioulasso are typically divided into small plots in the form of micro-watersheds averaging about 3 m^2, in order to keep water inside the plots and to limit water erosion. Therefore, nutrient and carbon losses via water erosion (OUT4) were assumed to be null.

Calculation of nutrient apparent use efficiency (NUE)

NUE was defined as the amount of nutrients accumulated in the product and calculated as:

$$NUE = \frac{\sum O}{\sum I} \times 100$$

where 'O' is the output by the product and 'I' the sum of the measured inputs (Hedlund et al. 2003).

Sample analysis

At the beginning and the end of the experiment, three composite soil samples per garden were taken at 0–20 cm depth to examine possible changes in soil fertility parameters during the time of study. Soil samples were analyzed for pH in 1:2.5 soil:water (weight:weight). Organic carbon in soil samples, organic amendments and plants were determined according to Walkley and Black (1934). After digestion total N in irrigation water, inorganic and organic amendments, household waste and plants samples was determined colorimetrically with an auto-Analyzer

Table 2 Nutrient flows parameters taken from the literature to estimate total matter balances in UPA gardens of Bobo Dioulasso, Burkina Faso

	Nutrient flow	N (kg ha^{-1} year^{-1})		K (kg ha^{-1} year^{-1})		C (kg ha^{-1} year^{-1})		Literature
		cGCL	cGscC	cGCL	cGscC	cGCL	cGscC	
Input	Atmospheric deposition[a]	5.0	5.0	22.0	22.0	23.0	23.0	Herrmann et al. (1997), Ozer (2002), FAO (2005) and Diogo et al. (2010)
	Biological N_2-fixation[b]	6.9	6.9	0.0	0.0	0.0	0.0	De Jager et al. (2001)
Output	Leaching[c]	107	85	20	18	NA	NA	Predotova et al. (2011) and Werner et al. (unpubl.)
	Gaseous losses[d]	419	347	0.0	0.0	36,400	22,800	Lompo et al. (2012)

cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop; NA, not available

[a]Given its lacking industry and location in the Sudano-Guinean zone Bobo-Dioulasso likely receives only minor depositions of N but rather large depositions of Sahelian dusts rich in K given city-specific sedimentation obstacles such as buildings and trees (Herrmann et al. 1997; Ozer 2002)

[b]The data are sketchy as BNF by free living bacteria such as *Azospirillum* varies widely depending on pH and C release in the rhizosphere

[c]Data in an unpublished Ph.D. thesis of Bley (1996) indicate N leaching on an Arenosol in Sahelian millet to amount to annually 12–28 kg N ha^{-1}. A more relevant dataset of year-round cultivated UPA fields which we have used here has been published by Predotova et al. (2011), but it was from a below average rainfall year. Wick micro-lysimeter data collected by Werner et al. (2018) in UPA systems on a Petroplinthic Cambisol with a loamy silt texture in N-Ghana indicate leaching ranges of 40–220 kg N ha^{-1} (wet season) and 10–100 kg N ha^{-1} (dry season)

[d]This dataset is very robust as time series were reflecting day temperature highs and night temperature lows as well as repeated cropping cycles in the same gardens of Bobo Dioulasso

(Technicon AAII, Malton, ON, Canada). Total K was obtained by flame emission spectroscopy (Varian ICP-OES, Varian Inc., Palo Alto, CA, USA) in ashed plant samples and in soils after extraction with an unbuffered 0.01 M solution of silver-thiourea (AgTU) at the prevailing soil pH.

Statistical analysis

Data were analyzed using SPSS 18.0 (IBM Corp., Armonk, NY, USA) whereby the Kolmogorov–Smirnov test was used to test for normal distribution of residuals. Means were compared using *t* test for normally distributed data and else the Mann–Whitney Test. Confidence intervals were calculated at $P < 0.05$.

Results

Crop types, horizontal flows and partial balances of N, K, and C

Crop types and N, K, and C input rates

During the monitoring period (March 2008–September 2009), cabbage (*Brassica oleracea* L.) and lettuce (*Lactuca sativa* L.) were commonly produced in both systems. In addition to these two crops, carrot (*Daucus carota* L.) and tomato (*Solanum lycopersicum* L.) were produced in the cGCL system while sorrel (*Rumex acetosa* L.) and sweet pepper (*Capsicum annuum* L.) were recorded for the cGscC.

Within the cGCL system, highest N rates of up to 638 kg ha^{-1} were applied to cabbage followed by tomato and carrot, while for the cGscC pepper received up to 971 kg N ha^{-1} followed by cabbage and lettuce. In both production systems cabbage

Table 3 Amounts (kg ha^{-1} cropping $cycle^{-1}$) of nitrogen (N), potassium (K) and carbon (C) applied in the form of mineral and organic fertilizers, to different vegetables during the 18 months experimental period in urban vegetable gardens of Bobo Dioulasso, Burkina Faso

HH group	Crop	N	K	C
cGCL	Cabbage	638 ± 301	642 ± 483	8915 ± 4082
	Carrot	396 ± 236	234 ± 61	2710 ± 2710
	Lettuce	196 ± 18	293 ± 62	3643 ± 3643
	Tomato	401 ± 261	229 ± 153	1148 ± 1149
cGscC	Cabbage	495 ± 253	774 ± 52	2965 ± 1019
	Sorrel	114 ± 36	116 ± 15	2347 ± 640
	Lettuce	163 ± 51	286 ± 182	756 ± 375
	Pepper	971 ± 373	595 ± 215	2526 ± 89

Data show means (n = 3) ± one standard error

cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop

received the highest K rate of 642 kg ha^{-1} for cGCL and 774 kg ha^{-1} for cGscC (Table 3).

Annual N inputs reached on average 2038 kg ha^{-1} for the cGCL and 1796 kg ha^{-1} for cGscC systems, and did not differ significantly between systems ($P = 0.61$). Mineral fertilizers were the source of N within the cGCL system while organic fertilizers (manure and waste compost) were the mains source of N in the cGscC gardens.

The amounts of C applied via organic fertilizers during a cropping cycle differed between crops within and across production systems. In both systems cabbage received the highest C input reaching 9 t ha^{-1} per cropping cycle for the cGCL and 3 t ha^{-1} for the cGscC systems (Table 3). Total annual C input for the cGCL system was with about 48 t C ha^{-1} significantly higher ($P < 0.001$) than 27 t C ha^{-1} for the cGscC. The main sources of C were organic fertilizers and photosynthesis. For both systems, C inputs from organic fertilizers were similar to those estimated for photosynthesis (data not shown).

Vegetable yields and N, K, and C exports

Maximum cabbage yield reached 7920 kg dry matter ha^{-1} for the cGCL system exceeding that of cGscC gardens which was about 5688 kg ha^{-1}. For the cGscC the amount of N exported by cabbage exceeded that of the cGCL. The amount K and C exported by cabbage for the cGCL were highest. Lettuce yields were with 5235 kg ha^{-1} substantially higher for the cGCL than with 1635 kg ha^{-1} for cGscC gardens. Tomato and carrot were grown only in cGCL gardens with yields reaching 7597 kg ha^{-1} for tomato and 8150 kg ha^{-1} for carrot. The respective N, K, and C exports were about 366, 241, and 3985 kg ha^{-1} and 380, 481, and 6403 kg ha^{-1}. Sorrel (*Rumex acetosa* L.) and pepper were exclusively grown only in cGscC gardens with maximum dry matter yields of about 4405 kg ha^{-1} and 3285 kg ha^{-1} (Table 4).

Horizontal balances of N, K, and C

Horizontal (partial) balances of N and K were positive for both production systems (Fig. 1), averaging 937 kg N ha^{-1} $year^{-1}$ and 631 kg K ha^{-1} $year^{-1}$ for the cGCL system and 1089 kg N ha^{-1} $year^{-1}$ and 1127 kg K ha^{-1} $year^{-1}$ for the cGscC system. Overall calculated surpluses were higher in the cGscC production system, but the differences were not statistically significant ($P = 0.69$ for N and $P = 0.21$ for K). For both systems, C balances were also positive ranging from 17 to 32 t C ha^{-1} $year^{-1}$ and significantly higher for the cGCL system ($P < 0.001$).

Apparent nutrient use efficiency and soil fertility status

K use efficiency was highest reaching 85 and 54% for the cGCL and the cGscC, respectively. Nitrogen use efficiency was about 66% for the cGCL and 44% for the cGscC. Across the two systems nutrient use efficiencies were statistically equivalent (Fig. 2). For the cGCL system soil Corg, pH (H_2O) and total N did

Table 4 Average biomass (kg DM ha^{-1}) and amounts of carbon N, K and C (kg ha^{-1} cropping $cycle^{-1}$), exported by different vegetables cultivated during the 18 months experimental period in the selected urban vegetable gardens of Bobo Dioulasso, Burkina Faso

HH group	Crop	Biomass	N	K	C
cGCL	Cabbage	7920 ± 5664	215 ± 170	304 ± 215	3084 ± 2178
	Carot	8150 ± 5391	380 ± 72	481 ± 28	6403 ± 800
	Lettuce	5235 ± 2145	118 ± 40	153 ± 33	1134 ± 33
	Tomato	7597 ± 3100	366 ± 185	241 ± 109	3985 ± 1719
cGscC	Cabbage	5688 ± 3942	241 ± 101	360 ± 120	3024 ± 922
	Lettuce	1635 ± 540	71 ± 20	122 ± 32	630 ± 144
	Pepper	3285 ± 193	75 ± 8	159 ± 18	1392 ± 174
	Sorrel	4405 ± 1588	81 ± 66	86 ± 65	772 ± 608

The yield data show the mean values of three plots ± one standard error

cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop

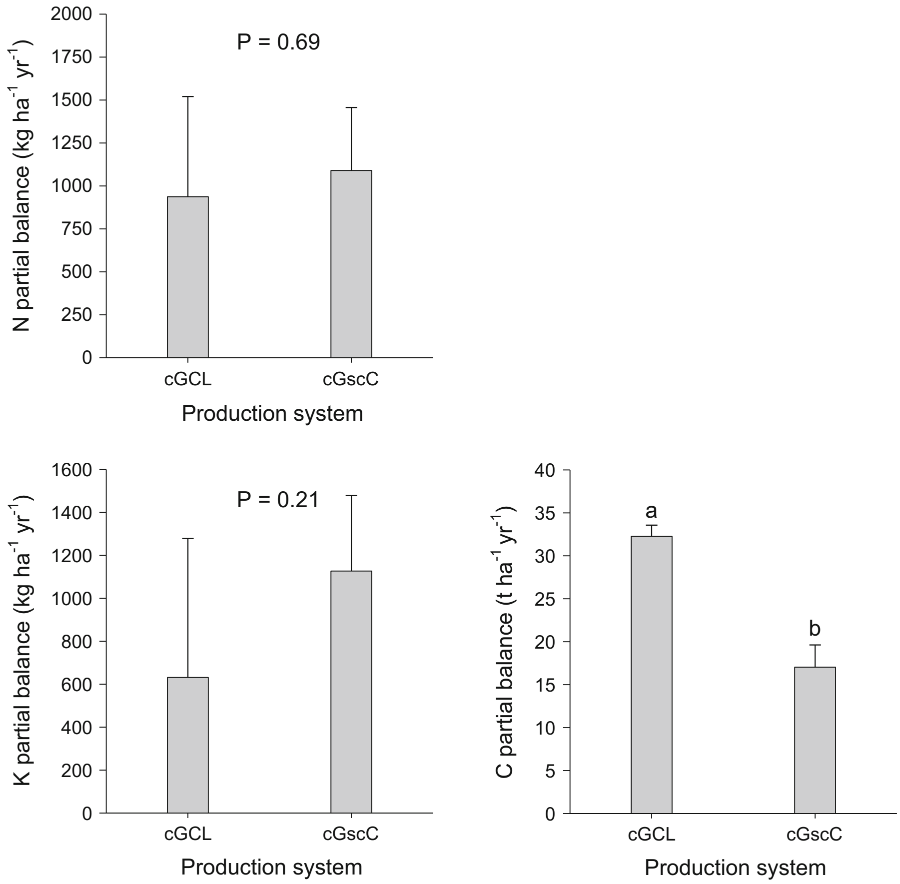

Fig. 1 Annual partial balances of nitrogen (N), potassium (K) and carbon (C) in cGCL (n = 3) and cGscL (n = 3) urban vegetable gardens during the 18 months experimental period in Bobo Dioulasso (Burkina Faso). Data show means plus one standard error. Bars followed by different letters are significantly different at P < 5%. cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop system

not change significantly during the 18 months experimental period, but for the same period soil C/N increased significantly ($P = 0.002$) from 12.2 to 15.7, while total K decreased significantly ($P = 0.011$) from 3878 to 2475 mg K kg^{-1}. For the cGscC system soil parameters did not significantly change over time

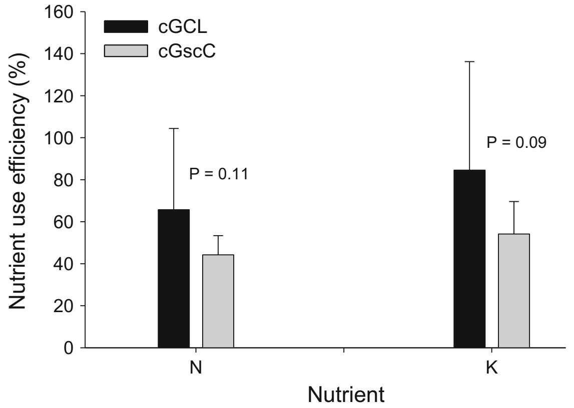

Fig. 2 Nutrient use efficiency of nitrogen (N) and potassium (K) in cGCL (n = 3) and cGscL (n = 3) urban vegetable gardens during the 18 months experimental period in Bobo Dioulasso, Burkina Faso. Bars show means plus one standard error. cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop systems

except for the C/N ratio which changed significantly from 14 to 12 ($P = 0.016$).

Discussion

In both production systems average input rates reached 971 kg N ha^{-1} and 595 kg K per cropping cycle thereby greatly exceeding the recommended rates for vegetables in the Sudano-Sahelian zone which vary crop-specific from 70 to 140 kg N ha^{-1} and 100 to 150 kg K ha^{-1} (d'Arondel de Hayes and Traoré 1990). Similar results were reported by Diogo et al. (2010) for urban vegetables gardens in Niamey. The input rates recorded in our study are comparable to those reported by Hedlund et al. (2003) and Diogo et al. (2010) for urban farms in Vietnam and Niamey.

These inputs resulted in positive partial balances reaching annual averages for both systems of 1013 kg N ha^{-1}, 879 kg K ha^{-1}, and 25 t C ha^{-1} whereby N and K leaching losses may be underestimated in our study because rainfall was higher in Bobo's Sudanian zone compared to the low leaching losses measured in Niamey in a dry study year (Table 2). Similar positive nutrient balances ranging from 31 to 882 kg N ha^{-1} and 9 to 770 kg K ha^{-1} were reported by Hedlund et al. (2003), Huang et al. (2007) and Khai et al. (2007) for UPA systems elsewhere. This is in sharp contrast to the negative nutrient balances often reported for rural agricultural systems in sub-Saharan Africa (Stoorvogel et al. 1993; Anthofer and Kroschel 2000; Haileslassie et al. 2006; De Jager et al. 2001) and is probably due to the fact that UPA systems are largely market-oriented allowing investments in soil amendments. Another fact is the ready availability of urban waste as effective, partly composted inputs at no or only nominal cost. Furthermore, urban gardens are typically small sized which reduces the absolute quantities of fertilizers required and facilitates their regular purchase and application.

The results of our study indicate that livestock husbandry may have contributed significantly to nutrient management practices in the cGCL system which suggests an unusual coupling between crop and animal production. Different observations were made by Hedlund et al. (2003) in their nutrient flow studies of smallholder UPA farms in southern Vietnam.

The surpluses of N and K combined with the prevailing sandy texture of the UPA soils may lead to leaching losses especially from July to September when rainfall is strongest (Predotova et al. 2011). Excessive fertilizer application can also increase disease susceptibility and reduce produce quality of vegetables (Hochmuth et al. 1991; Wang et al. 2008; Assogba-Komlan et al. 2007). Our levels of chemical soil fertility were much higher than those widely reported from rural production systems throughout the region (Bationo et al. 1998) indicating substantial effects of inputs on soil fertility.

While the horizontal balance approach provides information for nutrient management planning (Mikkelsen 2005), it does not account for possible nutrient losses via leaching, erosion, nitrification, denitrification, and volatilization, which can be substantial in the agro-ecological context of Bobo Dioulasso (Predotova et al. 2010; 2011). Therefore, the determination of total nutrient balances would give a much better indication of the scope that improved management approaches have in enhancing nutrient use efficiencies. In our study we used the few available data from the literature to estimate nutrient flow components not controlled by our farmers (atmospheric inputs) or not determined by us (leaching and gaseous losses; Table 2) in order to establish full balances of N, K and C for the two production systems. The results indicate positive N and K balances but negative C total balances for both cGCL and cGscC systems (Table 5).

Table 5 Annual total balances of nitrogen (N), potassium (K), and carbon (C) in cGCL and cGscL urban vegetable gardens in Bobo Dioulasso (Burkina Faso) from March 2008 to September 2009

HH group	N	K	C
cGCL	433 ± 584	496 ± 647	− 3606 ± 1316
cGscC	658 ± 367	991 ± 352	− 5335 ± 2593
F-prob. of group effect	0.55	0.21	0.27

Data show means (n = 3) ± one standard error

cGCL, commercial gardening + field crops + livestock; cGscC, commercial gardening + semi-commercial field crop

These did not significantly differ between systems (Table 5) reflecting the variability of input management within the gardens of both clusters. Our balance results will certainly depend on the validity of the literature data taken, but the ranges shown (Table 2) provide evidence that the conclusions should be rather robust and change no more than would be expected between high and low rainfall years and soil types ranging from leached Arenosols to Cambisols. For the same vegetable production systems, Lompo et al. (2012) recorded annual gaseous CO_2–C losses of up to 35,862 and 22,364 kg ha^{-1} for the cGCL and the cGscC, respectively, representing 106% of the C horizontal balance in both systems. This underlines the importance of C inputs to sustain intensive urban vegetable gardening activities in Bobo Dioulasso with its year round high temperature and apparently biologically very active soils.

Conclusions

The positive horizontal N and K balances of our study indicate that current nutrient inputs in urban vegetable gardens of Bobo Dioulasso are much higher than nutrient removal by crop uptake. Even if leaching and volatilization losses were not quantified in our study, data from similar studies suggest that such losses would not substantially affect the conclusions with respect to N and K. The strongly negative total C balances underline the need for continued application of organic soil amendments to sustain soil organic matter and thus long term productivity of irrigated urban agricultural soils in the Sudano-Guinean zone of West Africa.

Acknowledgements The authors are grateful to the Volkswagen Stiftung, Hannover, Germany, for supporting this research financially under the Urban Food project (No. I/82 189).within the collaborative program ‘Resources, their dynamics, and sustainability–capacity–development in comparative and integrated approaches. We also would like to thank INERA, Burkina Faso, for comprehensive infrastructural support and to Dr. Sheick Ahmed Khalil S. B. Sangaré for a helpful companion study. We also express our gratitude for a very careful review process during which numerous critical comments of an anonymous reviewer and the journal editor were addressed.

References

Abdu N, Agbenin JO, Buerkert A (2011) Phytoavailability, human risk assessment and transfer characteristics of cadmium and zinc contamination from urban gardens in Kano, Nigeria. J Sci Food Agric 91(15):2722–2730

Abdu N, Agbenin JO, Buerkert A (2012) Fractionation, mobility and bioavailability of cadmium and zinc in urban vegetable gardens of Kano, Northern Nigeria. Environ Monit Assess 184:2057–2066

Abdulkadir A, Dossa LH, Lompo DJP, Abdu N, van Keulen H (2012) Characterization of urban and peri-urban agroecosystems in three West African cities. Intern J Agric Sust 10(4):289–314

Amoah P, Drechsel P, Abaidoo RC (2005) Irrigated urban vegetable production in Ghana: sources of pathogen contamination and health risk elimination. Irrig Drain 54:S49–S61

Amoah P, Drechsel P, Abaidoo R, Ntow W (2006) Pesticide and pathogen contamination of vegetables in Ghana’s urban markets. Arch Environ Contam Toxicol 50(1):1–6

Anikwe MAN, Nwobodo KCA (2002) Long term effect of municipal waste disposal on soil properties and productivity of sites used for urban agriculture in Abakaliki, Nigeria. Bioresour Technol 83:241–250

Anthofer J, Kroschel J (2000) Macro nutrient balances of two *Mucuna* cultivars in *Mucuna*/maize systems in the forest savannah transitional zone of Ghana. In: Deutscher Tropentag 2000. Hohenheim, Germany

Armar-Klemesu M (2000) Urban agriculture and food security, nutrition and health. In: Bakker N, Dubbeling M, Guendel S, Sabel Koschella U, de Zeeuw H (eds) Growing cities, growing food, urban agriculture on the policy agenda. DSE, Feldafing, pp 99–118

Assogba-Komlan F, Anihouvi P, Achigan E, Sikirou R, Boko A, Adje C, Ahle V, Vodouhe R, Assa A (2007) Pratiques culturales et teneur en éléments anti nutritionnels (nitrates et pesticides) du *Solanum macrocarpum* au sud du Bénin. Afr J Food Agric Nutr Dev 7:21

Bationo A, Lompo F, Koala S (1998) Research on nutrient flows and balances in West Africa: state of the art. Agric Ecosyst Environ 71:19–35

Bellwood-Howard I, Häring V, Karg H, Roessler R, Schlesinger J, Shakya M (2015) Characteristics of urban and peri-urban agriculture in West Africa: results of an exploratory survey conducted in Tamale (Ghana) and Ouagadougou (Burkina Faso). International Water Management Institute (IWMI), Colombo

Bley J (1996) Experimentelle und modellanalytische Untersuchungen zum Wasser- und Nährstoffhaushalt von Perlhirse (*Pennisetum americanum* L.) im Südwest-Niger. PhD Thesis Universität Hohenheim, Stuttgart, Germany, 132 p

Castillo GE (2003) Livelihoods and the city: an overview of the emergence of agriculture in urban spaces. Prog Dev Stud 3(4):339–344

Cobo JG, Dercon G, Cadisch C (2010) Nutrient balances in African land use systems across different spatial scales: a review of approaches, challenges and progress. Agric Ecosyst Environ 136:1–15

d'Arondel de Hayes J, Traoré G (1990) Cultures maraîchères en zone Soudano-Sahélienne. Recueil de fiches techniques: CIRAD-IRAT, INERA, Montpellier, France

De Jager A, Onduru D, van Wijk MS, Vlaming J, Gachini GN (2001) Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya. Agr Syst 69:99–118

Diogo RVC, Buerkert A, Schlecht E (2010) Horizontal nutrient fluxes and food safety in urban and peri-urban vegetable and millet cultivation of Niamey, Niger. Nutr Cycl Agroecosyst 87:81–102

Drechsel P, Quansah C, Penning De Vries F (1999) Stimulation of urban and peri-urban agriculture in West Africa: characteristics, challenges, need for action. In: Smith OB (ed) Urban agriculture in West Africa. Contributing to food security and urban sanitation. Ottawa, Canada and Wageningen, Netherlands. http://www.idrc.ca/en/ev-33700-201-1-DO_TOPIC.html. International Development Research Centre (IDRC), Technical Centre for Agricultural and Rural Cooperation (ACP-EU). Accessed 10 Sept 2018

Drescher AW, Iaquinta DK, Holmer RJ (2006) Urban homegardens and allotment gardens for sustainable livelihoods: management strategies and institutional environments. In: Nair PK, Kumar B (eds) A time tested example of sustainability. Advances in agroforestry 3. Springer, Dordrecht, pp 317–338

FAO (2005) Bilan des éléments nutritifs du sol à différentes échelles. Application des méthodes intermédiaires aux réalités Africaines. Organisation des Nations Unies pour l'Alimentation et l'Agriculture. Bulletin FAO Engrais et Nutrition Végétale 15. Rome, Italy

Freidberg S (2003) French beans for the masses: a modern historical geography of food in Burkina Faso. J Hist Geog 29(3):445–463

Gruhn P, Goletti F, Yudelman M (2000) Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. 2020 Vision. http://www.ifpri.org/sites/default/files/publications/brief67.pdf. Accessed 10 Sept 2018

Haileslassie A, Priess J, Veldkamp E, Lesschen J (2006) Smallholders' soil fertility management in the central highlands of Ethiopia: implications for nutrient stocks, balances and sustainability of agroecosystems. Nutr Cycl Agroecosyst 75(1):135–146

Hedlund A, Witter E, An BX (2003) Assessment of N, P and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam. Europ J Agron 20:71–87

Herrmann L, Stahr K, Sponholz B (1997) Identifizierung trockenzeitlicher und regenzeitlicher staubquellen im östlichen Westafrica. Würzburger Geogr. Arb 92:189–211

Hochmuth G, Maynard D, Vavrina C, Hanlon E, Simonne E (1991) Plant tissue analysis and interpretation for vegetable crops in Florida. University of Florida, Gainesville, FL, USA. http://edis.ifas.ufl.edu/pdffiles/EP/EP08100.pdf. Accessed 10 Sept 2018

Huang B, Shi X, Yu D, Öborn I, Blombäck K, Pagella TF, Wang H, Sun W, Sinclair FL (2006) Environmental assessment of small-scale vegetable farming systems in peri-urban areas of the Yangtze River Delta Region, China. Agric Ecosyst Environ 112(4):391–402

Huang SW, Jin JY, Bai YL, Yang LP (2007) Evaluation of nutrient balance in soil–vegetable system using nutrient permissible surplus or deficit rate. Commun Soil Sci Plant Anal 38:959–974

INSD (2008) Recensement général de la population et de l'habitation de 2006 du Burkina Faso. Ministère de l'Économie et des Finances, Ouagadougou

INSD (2010) Evolution de la population des principales villes du Burkina Faso. Institut National de la Statistique et de la Démographie (INSD), Ouagadougou, Burkina Faso. 25/06/2010

Karg H, Drechsel P, Akoto-Danso EK, Glaser R, Nyarko G, Buerkert A (2016) Foodsheds and city region food systems in two West-African cities. Sust Urban Rural Dev 8(12):1175. https://doi.org/10.3390/su8121175

Khai NM, Ha PQ, Öborn I (2007) Nutrient flows in small-scale peri-urban vegetable farming systems in Southeast Asia: a case study in Hanoi. Agric Ecosyst Environ 122:192–202

Kinané ML, Tougma A, Ouedraogo D Sonou M (2008) Urban farmers' irrigation practices in Burkina Faso. Urban Agriculture Magazine, pp 25–26

Levasseur V, Kouame C, Pasquini MW, Temple L (2007) A review of urban and peri-urban vegetable production in West Africa. Acta Hort 762:245–252. https://doi.org/10.17660/actahortic.2007.762.23

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

Mikkelsen R (2005) Nutrient use efficiency: using nutrient budgets. West Nutr Manag Conf 6:2–7

Nguyen C (2003) Rhizodeposition of organic C by plants: mechanisms and controls. Agron 23:375–396

Ozer P (2002) Dust variability and land degradation in the Sahel. Belgeo 2:195–210. https://doi.org/10.4000/belgeo.16124
PANA (2003) Synthèse des études de vulnérabilité et d'adaptation aux changements climatiques: étude de cas du Burkina Faso. In: Atelier de formation sur les Programmes d'Action Nationaux pour l'Adaptation (PANA), Ouagadougou, Burkina Faso
Prain G, Lee-Smith D (2010) Urban agriculture in Africa: what has been learned? In: Prain G, Lee-Smith D, Karanja N (eds) African urban harvest. Springer, New York
Predotova M, Gebauer J, Diogo RVC, Schlecht E, Buerkert A (2010) Emissions of ammonia, nitrous oxide and carbon dioxide from urban gardens in Niamey, Niger. Field Crops Res 115:1–8
Predotova M, Bischoff WA, Buerkert A (2011) Mineral-nitrogen and phosphorus leaching from vegetable gardens in Niamey, Niger. J Plant Nutr Soil Sci 174(1):47–55
Rosendahl I, Laabs V, Atcha-Ahowe C, James B, Amelung W (2009) Insecticide dissipation from soil and plant surfaces in tropical horticulture of southern Benin, West Africa. J Environ Monit 11(6):1157–1164
RUAF (2005) Urban micro-farming as a complementary strategy for mitigation of the HIV-AIDS pandemic. In: Proceedings of the visit to Johannesburg and Cape Town, 17–25 Aug 2005, South Africa. http://www.ruaf.org/publications/gardens-hope-urban-micro-farming-complementary-strategy-mitigation-hiv-aids-pandemic. Accessed 10 Sept 2018
Singh KP, Mohan D, Sinha S, Dalwani R (2004) Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area. Chemosphere 55:227–255
Smaling EMA, Stoorvogel JJ, Windmeijer PN (1993) Calculating soil nutrient balances in Africa at different scales: II. District scale. Fertil Res 35:237–250
Smaling E, Toure M, De Ridder N, Sanginga N, Breman H (2006) Fertilizer use and environment in Africa: friends or foes? Background paper: African fertilizer summit: nourish the soil, feed the continent, 9–13 June 2006, Abuja, Nigeria
Smith J, Ratta A, Nassr J (1996) Urban agriculture: food jobs and sustainable cities. United Nations Development Program, New York
Stoorvogel JJ, Smaling EMA, Janssen BH (1993) Calculating soil nutrient balance in Africa at the different scales. Fertil Res 35:227–235
Sy M (2011) Financement de l'agriculture urbaine et périurbaine: Etat des lieux et stratégies alternatives. Le cas de l'Afrique de l'Ouest Francophone. Paper presented at: Atelier d'Experts, 23.09.2011, Casablanca. http://www.uac-m.org/fileadmin/user_upload/public/9_Highlights/2011/Creative_WS/atelierUAC_2_-Sy.pdf
United Nations Human Settlements Programme (UN-Habitat) (2014) The state of African cities 2014: re-imagining sustainable urban transitions; United Nations Human Settlements Programme (UN-Habitat): Nairobi, Kenya
van Veenhuizen R, Danso G (2007) Profitability and sustainability of urban and peri-urban agriculture. Agricultural management, marketing and finance. FAO Occasional Paper no 19. Food and Agriculture Organization of the United Nations, Rome, Italy
Walkley A, Black IA (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37:29–37
Wang HJ, Huang B, Shi XZ, Darilek JL, Yu DS, Sun WX, Zhao YC, Chang Q, Öborn I (2008) Major nutrient balances in small-scale vegetable farming systems in peri-urban areas in China. Nutr Cycl Agroecosyst 81:203–218
Werner S, Akoto-Danso E, Manka'busi D, Steiner C, Häring V, Buerkert A, Marschner B (2018) Nutrient leaching and balances in urban agriculture in Northern Ghana: effects of waste water irrigation, mineral fertilization and biochar application. Nutr Cycl Agroecosyst. Special issue **(under review)**