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Increasing nutrient use efficiency through improved feeding and manure management in urban and peri-urban livestock units of a West African city: A scenario analysis

Rodrigue V.C. Diogo [b], Eva Schlecht [a,*], Andreas Buerkert [b], Mariana C. Rufino [c,d], Mark T. van Wijk [d]

[a] Animal Husbandry in The Tropics and Subtropics, University of Kassel and Georg-August-Universität Göttingen, Steinstrasse 19, 37213 Witzenhausen, Germany
[b] Organic Plant Production and Agroecosystems Research in The Tropics and Subtropics, University of Kassel, Steinstrasse 19, 37213 Witzenhausen, Germany
[c] International Livestock Research Institute, P.O. Box 30709, Nairobi 00100, Kenya
[d] Plant Production Systems Group, Wageningen University, P.O. Box 430, Wageningen, The Netherlands

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ABSTRACT

In many African cities urban and peri-urban agriculture (UPA) plays a major role in creating jobs and contributing to food security. However, many small-scale UPA systems are characterised by excessive nutrient inputs to the livestock unit and poor handling of manure. To assess the impact of improved feeding and manure management on nutrient use efficiency within the cattle unit, simulation modelling was used to compare three typical UPA farm types in Niamey, Niger, that comprised: animal husbandry alone (AH), animal husbandry plus gardening (AH+G), and animal husbandry plus gardening plus millet cultivation (AH+G+M). Improved feeding increased annual body weight gain and milk offtake from cattle and reduced the amount of nitrogen (N) excreted in urine, thereby lowering the risk of N emissions. With improved manure management, dry matter (DM) and nutrients recycled per animal and year, and potentially available for cropping, ranged from 321–690 kg DM, 8–22 kg N, 1.2–2.5 kg phosphorus (P), and 3.0–5.6 kg potassium (K) in AH as well as AH+G+M farms compared to 221–479 kg DM, 5.0–14.0 kg N, 0.7–1.6 kg P, and 2.0–4.0 kg K in AH+G farms. These amounts were up to 2.2-, 2.5-, 1.9- and 1-fold higher than the quantities of DM, N, P and K recycled under current practices. Feeding dairy cattle according to their requirements will enhance milk and meat production; if coupled with regular manure collection and low-cost covering of manure heaps, substantial amounts of nutrients are recycled to cropland and vegetable gardens and environmental pollution is reduced.

1. Introduction

Urban and peri-urban agriculture (UPA) contributes substantially to the food supply of the rapidly expanding population of West African cities, which grew from merely 4% in 1930 to 40% of the total population in 1990 and is estimated to reach 63% by 2020 (Drechsel et al., 2005; Veenhuizen and Danso, 2007). Depending on the commodity, UPA production systems cover 5% (urban) to 36% (peri-urban) of a city's total food supply and up to 90% of its demand for perishable vegetables (Drechsel and Dongus, 2010), while for milk and meat from small ruminants and cattle respective figures range from less than 25% (peri-urban) to more than 55% (urban) and from 5% (urban) to 10% (peri-urban; Drechsel et al., 2007). Ruminant livestock production in and around cities entails a massive flow of roughages as well as of concentrate feeds from rural areas to the cities (Amadou et al., in preparation). An excessive and wasteful offer of feed beyond the animals' requirements for maintenance and production leads to low nutrient use efficiencies especially in smallholder UPA livestock units: in livestock holdings in Niamey, Niger, daily feed offers entailed surpluses of 0.8–19.7 g nitrogen (N), 1.4 g phosphorus (P), and 0.2–15.2 g potassium (K) per sheep or goat, and an excess of 2.1–28.5 g N, 0.3 g P, and 4.3–21.5 g K per head of cattle (Diogo et al., 2010b). Of these surplus nutrients, which ended up as feed refusals in the manure heap, 49–82% NH_3–N and 19% N_2O–N were subsequently lost through gaseous emissions as well as runoff and leaching (whereby up to 0.3% N, 1.3% P and 16% K) during dung storage (Predotova et al., 2010a). The application of large amounts of manure dry matter (14–77 t DM ha^{-1}) to urban vegetable gardens (Diogo et al., 2010a) gave rise to annual gaseous emissions of nitrogen and carbon (C) of 48–53 kg N ha^{-1} and 20–25 t C ha^{-1}, and to leaching losses of mineral N (2.2–7.3 kg ha^{-1}) and mineral P (0.7 kg P ha^{-1}; Predotova et al., 2010b, 2011). Apart from these environmental threats through greenhouse gas emissions and pollution of soils and water bodies, the oversupply of nutrients

* Corresponding author.
E-mail address: tropanimals@uni-kassel.de (E. Schlecht).

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to both UPA livestock and crop production systems also bears risks for human health (Dijkstra et al., 2007; Payen and Gillet, 2007; Amponsah-Doku et al., 2010; Drechsel and Dongus, 2010; Röhrig and Goldbach, 2010).

It is therefore crucial to increase the nutrient use efficiency in UPA livestock units through appropriate feeding and manure collection and storage practices (Rufino et al., 2007; Predotova et al., 2010a; Tittonell et al., 2010). To determine the potential benefits of such measures for typical UPA livestock holdings in West Africa, we employed modelling and scenario analyses using a 24-months set of on-farm data from Niamey. Departing from the parameterisation of the models LIVSIM (Rufino et al., 2009) and HEAPSIM (Rufino et al., 2007), these tools were used to (i) estimate benefits of improved livestock feeding and (ii) identify nutrient (N, P and K) efficient manure management practices for three different farm types operating under urban and peri-urban conditions.

2. Methods

2.1. Farming systems

The study was conducted in Niamey, Niger, which is characterised by semi-arid climate with a cool dry season (November–February) followed by a hot dry season (March–May) and a unimodal rainy season (typically June–October) with a precipitation of 400–600 mm yr^{-1} (World Climate, 2008). During the study period, however, some rains were recorded in May (Fig. 1). Daily average temperature peaks at 34 °C in May and drops to 25 °C in December. The natural vegetation in the town periphery is a woody savannah dominated by *Acacia* sp., *Balanites aegyptiaca* L., and *Prosopis* sp. While sand-dune derived flats are predominantly sown to rainfed millet (*Pennisetum glaucum* L.), the tiger bush vegetation on lateritic plateaus is increasingly replaced by a patchwork of *Guiera senegalensis* J.F. Gmel. and heavily eroded barren areas (Leblanc et al., 2007). With its fast growing population of currently one million inhabitants (INS, 2008), Niamey has a high demand for fresh vegetables, and most of the available urban arable land is used for intensive vegetable gardening, accompanied by peri-urban cultivation of pearl millet and sorghum (*Sorghum bicolor* L.), both often loosely intercropped with cowpea (*Vigna unguiculata* L.). Many UPA households practice intensive sheep ('Bali Bali' Sahel type breed) and goat ('Ara Ara' Sahel type breed)

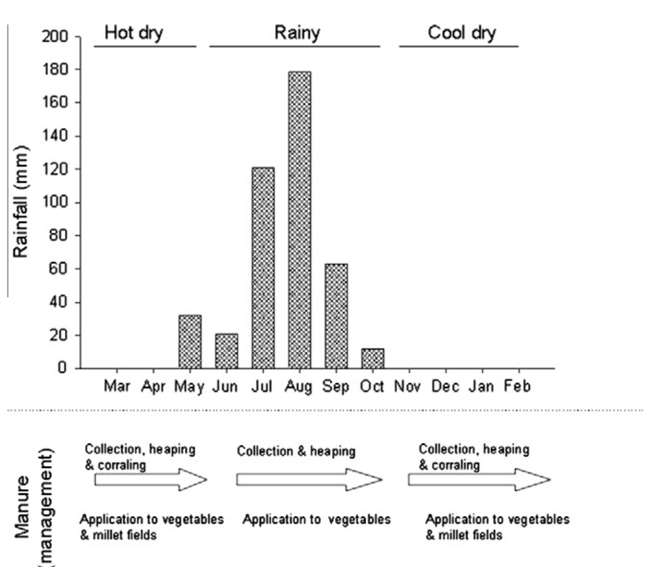

Fig. 1. Rainfall patterns and manure management in the smallholder urban and peri-urban farming systems of Niamey, Niger, during January 2006–2008.

husbandry or keep dairy cattle, mostly local Azawak and White Fulani breeds (Graefe et al., 2008). Especially in the late dry and early rainy season, urban and peri-urban livestock husbandry is constrained by high prices of roughage feeds such as bush hay, millet crop residues, and cowpea hay. The livestock manure is typically piled up in the sun- and rain-exposed courtyard for 2–4 weeks (Table 1) prior to its application to vegetable gardens and/or millet fields (Graefe et al., 2008). While manuring of vegetable plots occurs throughout the year, many peri-urban millet fields are typically manured during December to May or corralled with sheep/goats and cattle during the cool and hot dry season (Fig. 1).

Based on the degree of integration of animal husbandry and crop production (Graefe et al., 2008) three typical UPA farm types were selected for the model explorations: (i) animal husbandry alone: AH ($n = 5$); (ii) animal husbandry and gardening: AH+G ($n = 3$); and (iii) animal husbandry, gardening and millet cultivation: AH+G+M ($n = 5$). After initial determination of the total land size, livestock numbers and manure management practices of each household (Table 1), the households were visited once a week and data of all inputs (feeds offered to cattle, daily time of cattle on pasture) and outputs (milk offtake, i.e., amount of milked milk, excluding milk suckled by the calf which is reflected in the calf's BW changes; live animal sales, sales and consumption of meat; amount of manure collected; time of manure storage before application to crops) were collected through interviews and quantitative measurements over 24 months (January 2006–January 2008). Representative samples of feeds offered and of manure were taken at regular intervals, and submitted to proximate analysis (Section 2.4).

2.2. Models used for simulations

For the scenario analysis we used two dynamic models which were parameterised with data from Niger and Uganda. The model LIVSIM (LIVestock SIMulator; Rufino et al., 2009) simulates reproduction, growth and milk production of cattle based on the animals' genetic potential, feed availability, and quality, and excretion of faces and urine. Since LIVSIM is so far only calibrated for cattle, only this livestock species was considered in the modelling approach. HEAPSIM describes the dynamics and nutrient cycling efficiencies of major plant nutrients and C during manure collection and storage (Rufino et al., 2007). The models were run over a period of 2 yr to evaluate (i) the effects of improved feeding on livestock productivity indicators (LIVSIM), and (ii) the effects of the present manure management (uncovered heap, long storage time) versus improved handling (shortened storage time, covered heap,) on the amounts of recyclable DM, N, P, and K at the farm level (HEAPSIM). A monthly time step was used to estimate the rate of change in the quantity of nutrients and DM in the manure heap.

2.2.1. Models parameterisation and testing

In this study LIVSIM was parameterised for the Sahelian zebu (*Bos indicus*) breed 'Azawak' using experimental data of Ayantunde et al. (2001) from Niger, complemented with literature data on growth parameters of female Azawak cattle (Annex Table A1). For validation data from Mali (Schlecht et al., 1999) was used. In both studies the animals grazed natural Sahelian pastures offering various grasses as well as tree and shrub foliage. In two trials Ayantunde et al. (2001) evaluated the effect of timing and duration of grazing on diet selection, eating time, forage intake, body weight (BW) changes, and faecal output of 64 young Azawak males weighing 222–274 kg. Trial 1 was conducted in the rainy season when forage quality was high; trial 2 took place in the dry season when forage quality was low. From this set of data specific seasonal values for roughage quality (785–854 g OM kg^{-1} DM; 11.7–31.8 g N kg^{-1} DM; 6.1–9.1 MJ ME kg^{-1} OM; OM digestibility