Resources, Conservation and Recycling xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture

Rosanne C. Wielemaker[a,*], Jan Weijma[a,b], Grietje Zeeman[a,b]

[a] Sub-department of Environmental Technology, Wageningen University & Research, PO Box 17, 6700AA Wageningen, The Netherlands
[b] Lettinga Associates Foundation (LeAF), Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form 5 September 2016
Accepted 8 September 2016
Available online xxx

Keywords:
Urban Agriculture
New Sanitation
Urban metabolism
Urban Harvest Approach
Nutrients
Organic matter

ABSTRACT

To maintain the city as a viable concept for human dwelling in the long term, a circular metabolism needs to be adopted that relies on recovering, reusing and recycling resources, in which output ('waste') from one metabolic urban conversion equals input for another. Urban Agriculture (UA) and source-separation-based New Sanitation (NS) are gaining momentum as measures for improved urban resource management. UA aims to localize food provisioning while NS aims to reorganize wastewater and organic waste management to recover valuable and crucial resources. The objective of this paper is to assess the match between the supply by NS systems and the demand from UA for nitrogen, phosphorus and organic matter, in terms of quantity and quality, to foster a circular metabolism. The research is contextualized in the city of Rotterdam. The methodology used is based on the Urban Harvest Approach (UHA), developed previously for the urban water cycle. Novel to this research is adapting the UHA to nitrogen, phosphorus and organic matter loads for two practiced UA typologies (ground-based and rooftop) and four NS concepts for the treatment of domestic urine, feces and organic kitchen waste. Results show that demand for nutrients and organic matter from UA can be minimized by 65–85% and a self-sufficiency of 100% for phosphorus can be achieved, while partial self-sufficiency for nitrogen and organic matter. This research reveals that integration of NS and UA maximizes urban self-sufficiency.

1. Introduction

Cities depend on regional and global hinterlands for the supply of water, energy, nutrients and materials and for the disposal of wastes (Agudelo-Vera et al., 2012b; Brunner, 2007; Hodson et al., 2012; Kennedy et al., 2007), deeming cities hotspots for resource conversion. This conversion presently follows a linear metabolism from high quality resource inputs and low quality waste outputs (Fig. 1a). Few resources are currently recovered for reuse. This linear metabolism leads to two major challenges: first, cities' high rate of consumption puts stress on resource availability (e.g. phosphorus, fossil fuels), and second, the disposal of vast amounts of waste causes pollution (e.g. water and resource contamination, biodiversity loss, deforestation, and pollution in air, water and land). Cities currently import large quantities of food not only from their hinterlands, but also from locations across the globe. At the same time, they produce low or even negative value waste loads containing disposed and excreted nutrients. These are often mixed and collected via large-scale engineered infrastructures that endorse this linear tendency and make it difficult to effectively recover resources (Balkema et al., 2002; Hodson et al., 2012). With more than half of the world's population currently residing in cities, this linear tendency is further intensified (United Nations, 2014).

As hotspots of resource conversion, however, cities also present an excellent opportunity to adopt a high-impact circular metabolism, in which output ('waste') from one process equals input ('resource') for another. As opposed to the current linear urban metabolism, a circular urban metabolism aims to recover and reuse (recycle) resources within or between urban functions to reduce both the external input of virgin resources and the output of waste (Agudelo-Vera et al., 2012b) (Fig. 1b). To move towards a circular urban metabolism, resource input-output flows of urban functions need to be identified, described and matched in terms of quantity and quality. New Sanitation and Urban Agriculture are currently gaining global interest individually as measures to improve urban resource management (Degaardt, 2003; Metson and Bennett, 2015; Mougeot, 2006; Vernay et al., 2010). Linking these two urban functions could lead to mutual benefit in terms of resource cycling, especially for fertilizers.

* Corresponding author.
E-mail address: rosanne.wielemaker@wur.nl (R.C. Wielemaker).

http://dx.doi.org/10.1016/j.resconrec.2016.09.015
0921-3449/© 2016 Published by Elsevier B.V.

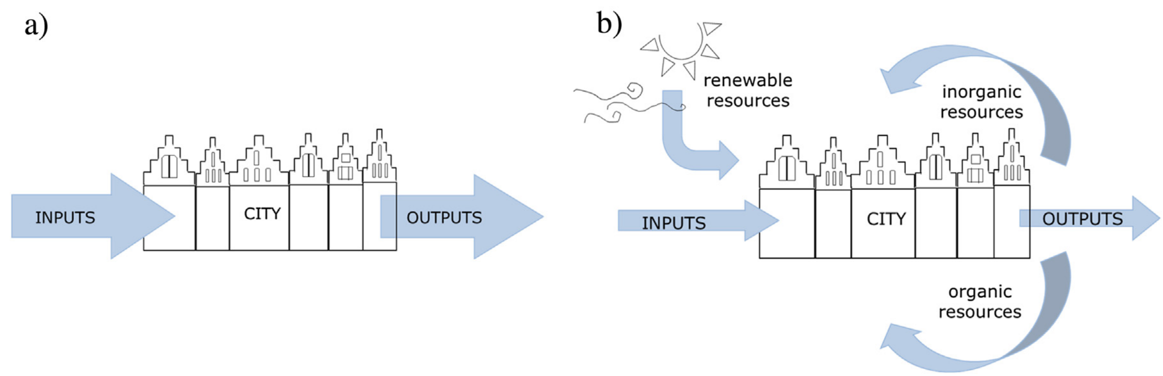

Fig. 1. a) A linear metabolism of inputs and outputs. b) A circular metabolism reuses, recycles and recovers resources from urban waste streams, reducing resource inputs and outputs.

1.1. Urban Agriculture

Urban Agriculture (UA) is the *local* production of food within (peri-)urban areas, which in addition fosters education, employment, community building and/or closing organic resource cycles (Mougeot, 2000; Smit et al., 2001). UA involves intensive cultivation/breeding methods that yield a diverse selection of flora and fauna, and integrates it with the local urban economic, social and ecological systems; thus, UA assimilates a plurality of activities, locations, scales, purposes and engagement. Exemplary of this variety, UA can include low-tech and high-tech production systems, such as community gardens, rooftop farming, indoor controlled environment agriculture, and animal husbandry.

1.2. New Sanitation

Sanitation is the promotion of hygiene via the management and treatment of wastes, and includes both the physical and organizational structure (Brikké and Bredero, 2003; Mihelcic et al., 2011). New Sanitation (NS) is a new paradigm for the collection, transport, treatment, and recovery of solid waste and wastewater (e.g. urine deviated vacuum toilets, anaerobic digesters, struvite ($Mg(NH_3)PO_4$) precipitation) with the aim to recover resources (i.e. water, nutrients, organic matter), increase efficiency, reduce energy costs, and/or offer solutions to waste management (Kujawa-Roeleveld and Zeeman, 2006; Lens et al., 2001; Maurer et al., 2012; Zeeman, 2012). NS systems minimize transport and are therefore locally-oriented systems (source, recovery and reuse are in close proximity) and the technical design serves this aim. The design varies with the local context but often includes source separation of waste and wastewater streams, collecting organic kitchen waste, black water (urine and feces), grey water (shower/bath, sink, laundry, dish washer) and/or urine separately. Depending on the types of streams separated and the local context, NS concepts can be configured for treatment and recovery to achieve reuse or discharge parameters. The respective recovery and removal efficiencies of the sanitation technologies determine the quantity of nutrients that can be harvested and the quality of the product for human and environmental hygiene.

1.3. Linking Urban Agriculture and New Sanitation

Re-establishing a partnership between agriculture and sanitation is not a new phenomenon. Various studies have looked at the possible cycling between sanitation and crop production including: wastewater reuse/irrigation for crop production (Beuchler et al., 2006; Smit and Nasr, 1992; Strauss, 2001), treatment, recovery and reuse of fertilizers from wastewater (Jenkins, 2005; Lens et al., 2001; Mihelcic et al., 2011; Tervahauta et al., 2013; Tidåker et al., 2006), reuse of urine (Maurer et al., 2003, 2006), bioavailability of recovered products to crops (Jönsson et al., 2004; Oenema et al., 2012), guidelines on urine and feces reuse in agriculture to ensure safe handling (Heinonen-Tanski and van Wijk-Sijbesma, 2005; Jönsson et al., 2004), risks of micro-pollutants, pathogens and heavy metals (Heinonen-Tanski and van Wijk-Sijbesma, 2005; Tervahauta, 2014; Winker et al., 2009), policymaking for resource recovery (van der Hoek et al., 2016) and the link between UA and sanitation systems as an economic and food security measure in developing countries (Cofie et al., 2013; Kone, 2010; Streiffeler, 2001).

The feasibility, however, to match input and output flows between UA and NS systems at the urban scale is not known. To start, data on the quantity and quality of the input demands from UA systems is lacking, as UA is very diverse in practice and for the most part unregulated (Belevi and Baumgartner, 2003; Martellozzo et al., 2014). This diversity results in varied fertilization practices and therefore requires that UA typologies be clearly defined to identify respective input and output flows. Second, although data on the quantity and quality of the products produced by NS systems has, and continues to be, researched, the extent of their reuse potential in UA is uncertain (e.g. plant availability, nutrient ratios, pathogen and micro-pollutant contamination) (Lens et al., 2001; Tervahauta et al., 2013; Zeeman and Kujawa-Roeleveld, 2011).

1.4. Scope of research and research objectives

The scope of this research focuses on the recovery of nitrogen (N), phosphorus (P) and organic matter (OM) from domestic wastewater and organic kitchen waste to determine the extent to which these resources can cover the demand from UA, in Rotterdam, the Netherlands (population 620,000) (Gemeente Rotterdam, 2013). The reason for this focus is threefold. First is the global concern regarding resource depletion and environmental pollution due to current consumption and disposal trends of nutrients, N and P, and OM (Carter, 2002; Cordell and White, 2011; Galloway et al., 2004). Second is the increased regional interest in the Netherlands for the professionalization of UA and the recovery of resources from waste streams (Green Deal Stadsgerichte Landbouw, 2013). Third is Rotterdam's interest in improving local resource management and implementing UA (Cityportal Rotterdam, 2014; Gemeente Rotterdam, 2012). In fact, Rotterdam currently houses a few leading UA initiatives in the Netherlands, including: Uit Je Eigen Stad, Rotterdamse Munt, Rotterzwam, and De DakAkker.

The objective of this study is to model combined UA and NS systems to evaluate the degree to which N, P and OM input-output flows can be matched and quantify the degree of self-sufficiency.

Please cite this article in press as: Wielemaker, R.C., et al., Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.09.015