Contextual match-making in waste biomaterials management for peri-urban agriculture

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Abstract: Peri-urban agriculture is constrained by inadequate space and insufficient inputs. The objective of this paper was to estimate volumes of peri-urban agriculture waste materials generated and match it with identified users who need them in Kampala City (Uganda) as either animal feeds or manure. The mass of manure from animals and the crop residues generated were determined using the standard manure potential of animals and crop to residue (C:R) ratio methods respectively. The required baseline number of animals and crops grown in Kampala was obtained from secondary data. Of the 263,449 livestock animals in Kampala, a potential of 11,499 Mt of manure can be generated that can sustain 858 farmers each occupying 0.4 ha of land and using 13.33 Mt of manure each on their field. This manure when used as fertilizers for the common crops grown in Kampala (Maize, Bananas and Beans), it can meet nutrient requirements of 135 ha of maize or 99 ha of Bananas or 132 ha of beans. The potential crop residues from the major crops amount to 4,162 Mt and can meet nutrient requirements of 20,033 broiler chickens or 18,117 beef cattle or 18,237 pigs annually. Utilizing the bio wastes generated in Kampala as agriculture inputs can therefore be a remedy to the high costs of fertilizers and animal feeds as well as protecting the environment against gaseous emissions resulting from the poor disposal of these wastes.
Keywords: match-making in agriculture, waste management, agribusiness, peri-urban agriculture, farming, Uganda

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1 Introduction

In Sub-Sahara Africa (SSA) boosting the agricultural sector is one of the ways to reduce poverty. This is because millions of residents both urban, and rural based depend on it for their livelihoods (Nabulo et al., 2012). However, rising food prices make the formal food supply unaffordable to most of the urban poor whose number continues to rise with urbanization (Stewart et al., 2013). Besides, sustaining food production in urban centers is not easy since farming is less profitable compared to other economic activities in these areas (Wästfelt and Zhang, 2018). The annual urbanization rate of Uganda stands at 6.75%, a rate higher than that of most SSA countries of 4% (Muchadenyika and Waiswa, 2018; Henderson et al., 2017). This rate is most likely to be associated with water scarcity, soil nutrient deletion, and pollution of ecosystems (Magwaza et al., 2020). As a result, this leads to emergence of highly vulnerable communities with a vast majority of dwellers living in slums (Ahmed, 2016; Floater et al., 2014). By 2050, Uganda will be among the most urbanized

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countries in Africa with a large proportion of its population food insecure (UN-Habitant, 2012). This thus calls for efforts to introduce agriculture in the cities which was initially considered a rural function (Diehl et al., 2020).

Urban and peri-urban agriculture (UPA) is one of the ways that can be used to address the problem of food insecurity in urban areas. It is defined as an industry located within and on the peripherals of the town or city which grows, processes and distributes a diversity of food and non-food products to the urban areas (Prain and Lee-Smith, 2010). UPA can be a means of solving a number of urban social, environmental, and health issues (Weidner et al., 2019). This is because the industry contributes to sustainable growth of metropolitan regions through provision of green infrastructures, urban markets, and improving social inclusion (Duvernoy et al., 2018). UPA can be practiced from allotments and gardens, rooftop gardens, integrated greenhouses, and complex indoor plant factories (Ayambire et al., 2019; O'Sullivan et al., 2019). The industry competes for resources (land, water, energy and labor) that would have been used for other purposes by the population (Mahajan, 2015). A sustainable UPA system (Figure 1) should incorporate waste management, healthy food and green environment all interlinked together.

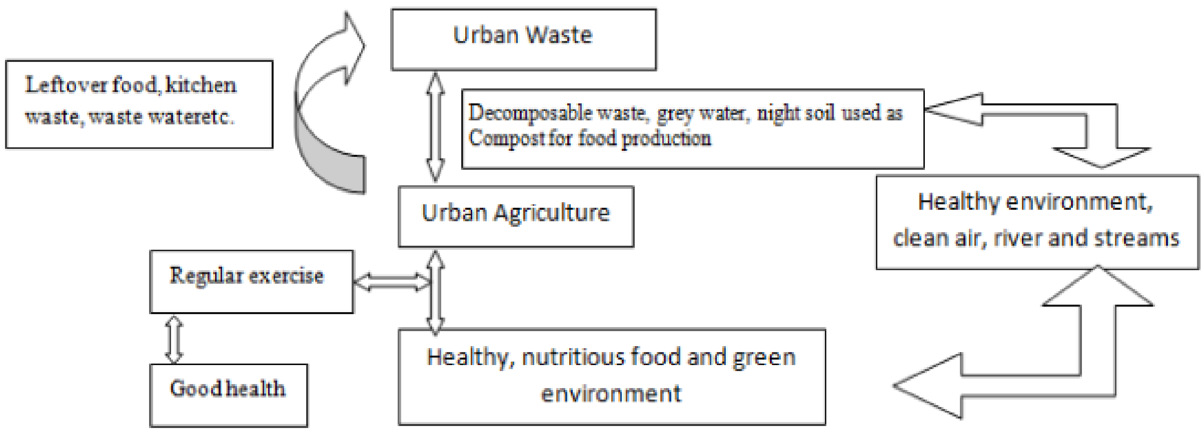

Figure 1 Sustainable UPA system model (Dhital et al., 2016).

Uganda, and specifically Kampala is well known for UPA because it was one of the first cities in SSA to establish by-laws that recognized, and formalized urban agriculture within city boundaries (Gore, 2018). Currently over 35% of the households in Kampala engage in some form of urban agriculture (Komakech et al., 2014a). Of these, 70% earn up to USD 330 while 10% earn up to USD 1680 per annum, prices that are far higher than national income per capita (David et al., 2010). Unfortunately, in Uganda, as it is the case with most of SSA countries, UPA is given less support as many urban authorities associate it with backwardness and a source of blemish on the urban landscape. This less support could be associated to lack of understanding of the ecological, social, and economic impacts of urban agriculture (Chandra and Diehl, 2019). However, UPA is valuable to SSA cities and it is important for city authorities to integrate it into land use planning and zoning processes (Azunre et al., 2019). For example, Bryld (2003) reported that 70% of the poultry food consumed in Kampala was produced within and around the city's boundaries. UPA also reduces food insecurity by increasing access to food especially to the urban poor populations (Armanda et al., 2019; Liang et al., 2019). In Uganda, however, UPA is facing several challenges some of which are as a result of rapid urbanization. Examples of these challenges include space limitations due to rapid population growth, declining water quality, high costs of feeds for livestock producers and productivity losses due to flooding (Sabiiti et al., 2014).

Rapid urbanization is also associated with increased amount and types of wastes generated (Anupam and Kumar, 2013). In the case of Kampala city, organic waste is the largest fraction of the waste generated with only 40% of the waste collected and taken to Kiteezi land fill while the remaining 60% is discarded of in an environmentally un friendly way (Komakech et al., 2014b). The poor management of this waste causes health and environmental challenges (Komakech et al., 2016). UPA plays a crucial role in the reduction of volumes of organic wastes (Buechler et al., 2006) through utilization of some of the waste as animal feed (Komakech et al., 2014a) and as a fertilizer/ soil conditioner (O'Sullivan et al., 2019; Komakech et al., 2015). In spite of this, there is lack of knowledge by the urban farmers on the fertilizer value of crop residues and solid organic wastes generated from households and markets (Graefe et al., 2008). The main objective of this work was therefore, to estimate volumes of peri-urban agricultural waste materials that are generated and point out the areas in Kampala City (Uganda) where they can be of value.

2 Peri-urbanization in Uganda

According to Budiyantini and Pratiwi (2016), a peri urban area has both rural and urban characteristics with mixed land uses that are both socially and economically integrated into an urban function. In Uganda, gazetted cities, municipalities, and town councils are defined as urban areas according to the Local Government Act 2000 (Mbabazi and Atukunda, 2020). By 2023, Uganda will have 16 cities including Kampala, the oldest and the capital city, and 15 newly created cities of Fortportal, Arua, Gulu, Jinja, Mbarara, Mbale, Masaka, Hoima, Entebbe, Lira, Kabale, Moroto, Nakasongola, Wakiso and Soroti (Draku, 2019). The location of some of these cities on the map of Uganda is shown in Figure 2. The creation of these cities is associated with a number of challenges such as creation of slums and informal settlements, poor solid waste management, weak urban economy, deteriorating urban environment, among others (Mbabazi and Atukunda, 2020). The physical expansion of cities also makes agricultural land subject to land tenure transformations due to competition from different land uses (Wästfelt and Zhang, 2018). The reduction/loss of the agricultural land from a city's land use system undermines its social, economic, and ecological sustainability (Ayambire et al., 2019).

Figure 2 A map showing Uganda's major cities (Available at https://en.wikipedia.org/wiki/List_of_cities_and_towns_in_Uganda#Cities).

2.1 Aspects of UPA agriculture in Uganda

There is a range of agricultural activities involved in UPA agriculture which include crop, forestry, livestock, poultry and aquaculture production practiced from the smallest roof top gardens to large cultivated open spaces (Thebo et al., 2014). According to Goldstein et al. (2016), urban farms can be classified into unconditioned and conditioned ground based farms as well as unconditioned and conditioned building integrated farms (Figure 3). UPA can be viewed as a primary production process of an urban food system which includes processing, packaging and distribution of produce all interacting with urban material and resource streams (Weidner et al., 2019). A number of products are generated from these activities which include but not limited to fruits, vegetables, dairy products, herbs, meat, fish and firewood that are used for consumption and commercial purposes (Stewart et al., 2013). In the urban and peri urban areas of Kampala, three-quarters of the farmers farm on small plots around their homesteads while the others mainly farm on the wetlands (Prain and Lee-Smith, 2010). These farms are characterized by high levels of crop production and mainly local livestock farming (David et al., 2010). Urban agriculture increases access to local food production hence saving transport costs and time (Chandra and Diehl, 2019). Therefore, multi-functional urban land uses that integrate rather than separating agriculture from other land uses could be a critical adaptation for the sustainability of future cities (Diehl et al., 2020).

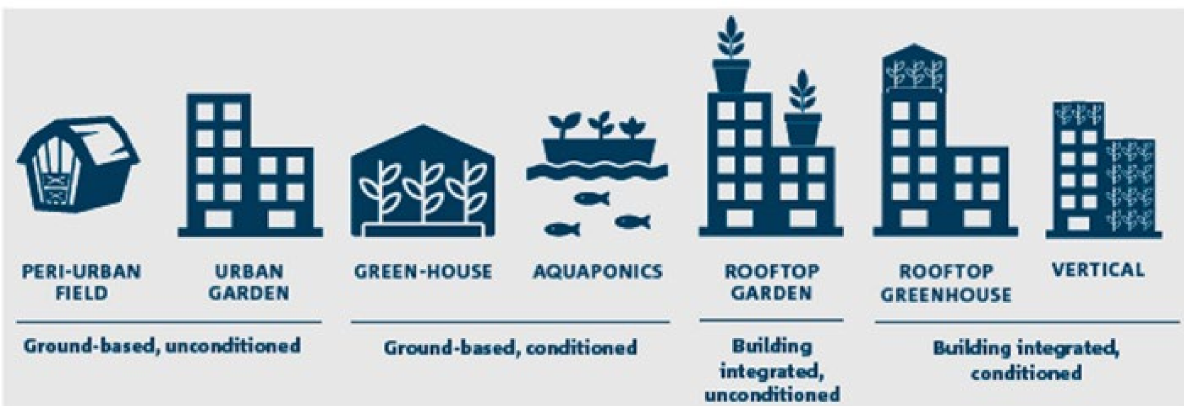

Figure 3 Range of farm types that make up UPA agriculture (O'Sullivan et al., 2019).

2.1.1 Livestock farming

Livestock production within the urban and peri urban areas of Uganda is increasingly becoming popular (Katongole et al., 2013) with poultry, cattle and pigs production dominant (Lee-smith, 2010). This can be attributed to increased demand for animal protein in and around urban areas as a result of increasing economic status of the inhabitants (Lupindu, 2017). According to UBOS (2010), there were 4,400,814, 5,372,174 168,431,371, 1,679,508 and 1,514,489 cattle, goats, chicken, pigs and sheep respectively in the urban and peri urban areas of Uganda. Predominantly local breeds are reared mainly under free range or grazed system. A few farmers practice zero grazing and bird cages mainly with improved breeds (Prain and Lee-Smith, 2010). The preference for local breeds is due to their stronger resistance to disease outbreaks and harsh environment as well as their low feed requirement (Ssewanyana et al., 2008). UPA livestock is characterized by small holder farmers with the average farm size not exceeding 0.05 ha (Sabiiti et al., 2014). The two most constraining factors to livestock production are feed scarcity and high cost of feeds (David et al., 2010; Katongole et al., 2013; Kiggundu et al., 2014). Thus, there is an increased pressure on essential feed ingredients in order to meet the high demand for animal products in a sustainable production system (Janković et al., 2020; Khan et al., 2016).

The high costs involved in provision of these feeds is a constraint to large scale livestock production in low and middle income countries (Admasu et al., 2019). According to Ssepuuya et al. (2017), feeds contribute up to 80% of total production costs in poultry farming with protein feeds alone contributing up to 70% of these costs. The costs are also increasing with time. For instance, the cost of fish meal from silver cyprinid locally known as Mukene in Uganda increased from UGX 2,000 per kg (USD 0.57) in 2005 to UGX 3,500 per kg (USD 1.00) in 2017 (Ssepuuya et al., 2017). The global prices for soybean meal, fish meal, and maize also increased by 16%, 12%, and 10% respectively between 2017 and 2019 (World Bank, 2020). In urban and peri urban areas of Buikwe, Jinja and Mayuge, feed scarcity was also reported as the most constraining factor to dairy production where the natural pastures alone could not sustain production without any supplementations (Atuhaire et al., 2014). Also associated with these feeds is the high competition for consumption from humans, and aquaculture (Gunya et al., 2019) which makes their supply unsustainable (Parolini et al., 2020). To cope up with the issue of feed scarcity, majority of the cattle farmers scavenge for food resources from the neighborhoods and markets while others end up grazing their animals in swamps (Kiggundu et al., 2014). Livestock production produces large quantities of animal wastes that poses both health and environmental challenges. Hence there is need for this waste to be adequately managed (Manyi-Loh et al., 2015).

2.1.2 Crop production

In the urban and peri urban areas of Uganda, farmers grow multiple crops, some of which include bananas, cassava, sweet potatoes, beans and maize (David et al., 2010). A report by UBOS (2010) indicted that there were 2162692, 1249822, 1156208, 512816, 1353833 Mt of banana, cassava, sweet potatoes, beans and maize respectively in the peri urban areas of Uganda by the time of the census. The area under cultivation for most of the households is between 0.0005 - 3 ha (Sabiiti et al., 2014). The individual farm plot for most peri-urban areas is between 0.04 - 0.51 ha (Chandra and Diehl, 2019). Backyard gardening is the commonest technique for growing crops especially vegetables and this is normally done in pots, sacks, food towers polythene bags and ridges. Backyard gardening has been reported to reduce households' expenditures on food and hence increase food security (Ayambire et al., 2019). There is thus need for city authorities to create awareness about backyard gardening as well as encourage landlords to allow its practice on their housing premises (Ayambire et al., 2019). According to Mugisa et al. (2017), crop production was reported as the main source of livelihood income for farmers in central Uganda. The sources of nutrients for crop production include chemical fertilizers, animal manures, plant compost and solid city wastes (De Bon et al., 2010) with only 3.2% of the farming households using the chemical fertilizers (Sheahan and Barrett, 2017). Key constraints to crop production in these areas include unreliable rainfall, declining soil fertility, reducing land for farming, and lack of technical knowledge (David et al., 2010). High costs have been reported as the most constraining factor to acquisition of mineral fertilizers to improve on the fertility of crop lands (Nigussie et al., 2015) and in this regard, fertilizer application rate is still less than 1 kg ha^{-1} per farm family per year (Tenyhwa et al., 2015). Irrigation of fields is limited to vegetables like *nakati*, cabbages, tomatoes and *sukuma wiki* while fertilizers are mainly applied to crops like bananas and maize (Mugisa et al., 2017).

2.1.3 Aquaculture

Increasingly, sources of protein in urban settings are very expensive for the vast majority of dwellers that live on meager incomes. Fish is an important part of the African agro-food system which contributes directly to nutrition and food security. However, fish is becoming scarce and expensive thus reducing its consumption (Aruho et al., 2018). For instance, fish consumption in East Africa (where Uganda is part) is 4.8 kg fish/person/year and the lowest on the continent (Chan et al., 2019). Fish for human consumption can be obtained from capture fisheries (harvesting of naturally reproducing fish) or from aquaculture (breeding and farming under controlled conditions) (Belton et al., 2018). Like most African countries, Uganda's domestic fish supply is still dominated by capture fisheries much as these are at their limit due to over exploitation (Chan et al., 2019). A sharp decline in fish harvests from Lake Victoria has motivated a need for aquaculture expansion in order to bridge a gap between production and demand for fish (Ronald et al., 2014). Without aquaculture, fish consumption in SSA countries is predicted to decline at a rate of 5.6 kg fish/person/year (Kaminski et al., 2018). There is a considerable potential to expand aquaculture in the urban and peri urban areas of Uganda due to available land and natural sources of water like springs, streams and aquifers that can provide quality water suitable for the aqua-species. Using earthen ponds to culture fish is still the commonest method used in aquaculture production in most urban areas of Uganda (Matthew, 2015).

The rearing of the fish in some places is incorporated with plants (aquaponics) in a soil free system for crop production (Diehl et al., 2020). The aquaponics systems use the nutrient rich wastewaters to fertilize horticulture crops (O'Sullivan et al., 2019), and this aids removal of waste products in aquaculture ponds (Love et al., 2015). Commonly reared fish species include North African catfish (*Clarias gariepinus*), Nile tilapia (*Oreochromis niloticus*), lung fish (*Protopterus amphibious*) and Carp (*Cyprinus carpia*) (Matthew et al., 2015). There are tremendous efforts by the Government of Uganda and international donors to increase the country's fish production by enforcing laws that limit capturing immature fish from the capture fisheries and encouraging aquaculture. The predominant fish species reared in aquaponds is the African cat fish (Bukenya, 2017). This is due to the tolerance of this fish species to a certain degree of water pollution, and resistance against diseases (Chandra and Diehl, 2019). On average, the pond area is 404 m^2 and mainly this is due to limited land area for expansion (Sabiiti et al., 2014). For optimum weight gain and food conversation ration within the ponds, a stocking density of 2570 fry per m^3 is recommended (Ronald et al., 2014). The average price of 1 kg of a farm raised cat fish is USD 1.74 as compared to USD 0.95 for a similar cat fish from wild harvest (Bukenya, 2017). Fish from aquaculture is considered to be of a higher quality than that from the capture fisheries hence contributing to its high demand (Sabiiti et al., 2014). Although, the full growing cycle of catfish from fish seed to harvest-ready size is about two months, this can be shortened by practicing pond rotation system which allows harvesting every two weeks (Chandra and Diehl, 2019). However, the major hindrance to production of these fish is lack of locally produced high quality fish feed (Chan et al., 2019; Gabriel et al., 2007).

According to El-Sayed et al. (2015), between 50% to 99% of feed ingredients used in aqua-feed production for most of the SSA countries are imported. Use of alternative protein sources such as earthworms, and insects can be a solution to the commercially expensive fish feeds. According to Weidner et al. (2019), feeding organic waste to insects and then feeding the insect larvae to fish can improve the overall sustainability of aquaponics operations. Thus, the use of insects or earthworms as an alternative protein sources in aquaculture feeding is an opportunity to provide environmental services through cleaner technologies (Parolini et al., 2020; Byambas et al., 2019) hence promoting circular economy (Chia et al., 2019).

3 Use of wastes for peri urban agriculture

There are many approaches of utilizing and managing crop residues (Figure 4). The most common approaches include composting, use as animal feeds and for energy production (Abou-Hussein and Sawan, 2010).

However, in most of the developing countries, many of the wastes are underutilized and they are left to rot or burnt openly (Sabiiti, 2011). This is associated with negative environmental impacts like greenhouse gas emissions and pollution of both surface and subsurface water sources. In this aspect, use of these wastes in UPA presents an opportunity for cities to preserve the urban environment while promoting economic and social benefits (Ayambire et al., 2019). Feeding animals on food/crop wastes is one of the most important strategies of coping with feed scarcity among the urban and peri urban livestock farmers of Kampala (Katongole et al., 2013). Use of crop residues as livestock feeds in Uganda has captured much attention and this can be attributed to increased pressure on land that reduces the area of grazing, leading to over grazing and hence reducing grasslands available for livestock feeds (Swidiq et al., 2012). In the urban and peri urban zones of Masaka and Kamuli, crop peelings for banana, yam, pumpkin and pawpaw are used as animal feeds (Dione et al., 2015) while those from bananas, potatoes and crop residues (maize stovers) are mainly used as pig and cattle feeds in Kampala (Table 1).

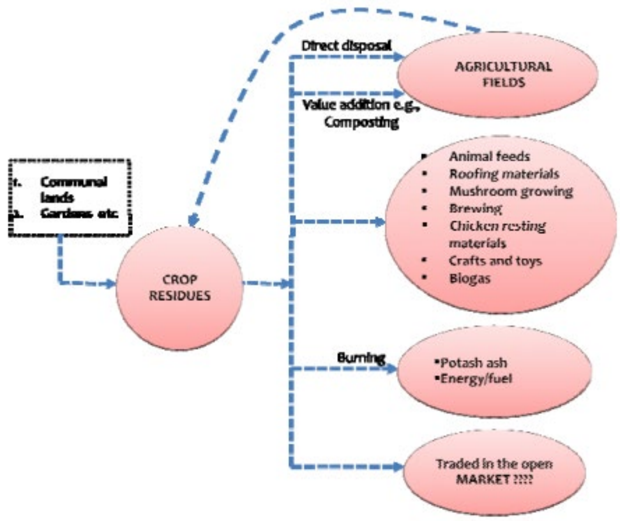

Figure 4 Ways of utilizing crop residues (Tenyhwa et al., 2015)

Table 1 Contribution of wastes to the animal feeds in Kampala

Feed source	Contribution (%)
Peels (banana, potatoes, cassava)	60
Food waste	20
Market waste	9
Crop residues	11

Note: Source form Komakech et al. (2014a)

The crop residues are rich in macro minerals like Iron, Zinc, Calcium and Manganese and nutrients such as crude protein, carbohydrate, lipid and crude fiber (Table 2). Feeding these peels to animals therefore provides them with the minerals and nutrients that are vital for their proper growth.

Table 2 Nutrient composition of crop residues commonly used as animal feeds

Crop residue	Proximate composition (g 100g^{-1} dry residue)			
	Crude protein	Lipid	Crude fiber	Carbohydrate
Maize stovers	9.15	-	32.33	-
Sweet potato peels	4.67	-	9.50	-
Banana peels	10.44	8.40	11.81	43.40
	Chemical composition (mg 100g^{-1} dry residue)			
	Calcium	Iron	Zinc	Manganese
Maize stovers	6.48	185.44	0.88	1.53
Sweet potato peels	7.59	13.13	0.14	0.54
Banana peels	19.86	15.15	1.77	9.05

Note: Source from Romelle et al. (2016), and Yusuf et al. (2017)

Organic wastes can be developed into soil amendments and fertilizers that are tailored to the needs of urban urbans through composting (O'Sullivan et al., 2019; Sabiiti, 2011) or vermicomposting (Jjagwe et al., 2019; Weidner et al., 2019) processes. The use of composted/vermicomposted organic manure as a soil conditioner is the most viable way for farmers to maintain their fields in a productive state. However, this is limited by lack of knowledge by the farmers about the potential of this manure together with its inefficient collection (Nigussie et al., 2015). Applying composted crop residues and animal manure in combination with conservation tillage practices improves soil structure through moisture retention and improvement of soil biological properties (Okoboi and Barungi, 2012). Their use also reduces soil erosion, increases the soil's organic matter and nutrients (Tenyhwa et al., 2015) and plays a role in carbon sequestration (Ndhlovu and Banadda, 2017). In addition, recycling of organic wastes into fertilizers and soil amendments could reduce the costs of waste treatment while creating local business opportunities on the other hand (O'Sullivan et al., 2019). The use of solid compost waste, sludge, wastewater and agro- industrial wastes as inputs in UPA agricultural production reduces the over dependency on inorganic fertilizers whose prices keep fluctuating (Drechsel and Dongus, 2010).

Wastewater is greatly used for production of vegetables, fruits fodder and aquaculture (De Bon et al., 2010). Bugolobi wastewater treatment plant receives about 400 m^3 day^{-1} of feacal sludge. After treatment, about 70% of the sludge is landfilled or discharged to the environment (Diener et al., 2014). This sludge has potential for biogas production by anaerobic digestion or incineration to produce energy or used as an ingredient in animal feeds. It can also be used as a component in building construction as well as organic fertilizer. According to a study by Diener et al. (2014) in Kampala-Uganda, 58% of the farmers interviewed were willing to use feacal sludge as a soil conditioner if it was available. Chicken manure is also a potential feed for fish (Gabriel et al., 2007) and can replace the expensive conventional feeds like fish meal that is competed for by both humans and livestock.

4 Matching bio wastes demand and supply in peri urban agriculture

Different agricultural sectors (crop, livestock and aquaculture) produce varying types and quantities of wastes. Some of these wastes are generated in larger quantities and in different places compared to others. This causes situations where some places have lots of wastes produced but no use for the waste. On the other hand, places that need the waste do not have the waste thus creating a mismatch between the supply and demand of this waste. A case in point is the waste generated from animal production in Kampala City.

Animal population in Kampala city according to Komakech et al. (2014a) are 63 sheep, 3,076 goats, 3,849 cattle, 9,007 pigs and 247,454 poultry birds. These livestock animals excrete manure whose composition is given in Table 3.

Table 3 Composition of manure from different livestock animals

Manure source	Average animal weight (kg)	Total manure (kg day^{-1})	Total solids (g kg^{-1})	Nitrogen (% TS)	Phosphorus (% TS)	Potassium (% TS)
Dairy cattle	425.60	55.50	139	0.52	0.26	0.41
Beef cattle	363.20	22.01	147	0.67	0.57	0.45
Pig	63.00	4.99	103	0.62	0.47	0.44
Sheep	27.00	1.09	201	1.04	0.47	0.95
Goat	63.00	3.16	325	1.09	0.61	1.15
Layer chicken	2.00	0.12	249	1.28	1.07	0.58
Broiler chicken	0.91	0.07	252	1.32	0.82	0.59

Note: TS- total solids, Source from Barker et al. (2002)

Using the findings by Komakech et al. (2014a) and the data presented in Table 3, and taking an assumption from the national livestock census of 2008 that 34% of the cattle are milked and hence 66% are for beef and that the ratio of layer chicken to broilers is 5:12 an estimated manure potential and the corresponding nutrients per year for cattle, poultry, pigs, goats and sheep respectively can be obtained (Table 4). According to Dongmo et al. (2010), a typical urban farmer uses approximately 40 kg of manure on a bed of 12 m^2. Sabiiti et al. (2014) reported that the average plot land for a peri urban farmer in Kampala is 0.4 ha. Therefore, this implies that in Kampala, a peri urban farmer uses about 13.33 t of manure on his field. From these assumptions, the number of farmers benefiting from manure accumulated per type of animal can be estimated. The nutrient composition of manure for the different animals is converted into the fertilizer potential of maize, bananas and beans (since these are the commonly grown crops in the peri urban areas of Kampala according to David et al. (2010). Sunday and Ocen (2015) reported that the recommended fertilizer application rate for maize is 120 kg ha^{-1} of Nitrogen (N), 60 kg ha^{-1} of Diphosphorus Pentaoxide (P_2O_5) and 60 kg ha^{-1} of Potassium oxide (K_2O). The fertilizer application rate recommended for bananas is 200 kg ha^{-1} of NPK (17:17:17) (Sunday and Ocen, 2015) while for optimal production of beans an application rate of 150 kg ha^{-1} of NPK (17:17:17) is recommended (Muturi et al., 2016). The conversion factors for Phosphrous (P) from P_2O_5 and Potassium (K) from K_2O are 0.436 and 0.83 respectively (Kaizzi et al., 2012). The number of hectares of maize, bananas and beans that can be fertilized by the accumulated manure annually can be estimated (Tables 4 -6).

Table 4 Potential of animal manure and estimated maize plantation area that can be fertilized in Kampala.

Animal type	Total dry manure (Mt $year^{-1}$)	Number of farmers	N (Mt $year^{-1}$)	Maize (ha)	P (Mt $year^{-1}$)	Maize (ha)	K (Mt $year^{-1}$)	Maize (ha)
Cattle	6,683	501	39.25	327.08	26.68	223.81	28.60	395.63
Poultry	1,918	144	25.00	208.33	17.71	124.77	11.24	155.49
Pigs	1,690	127	10.48	87.33	7.94	57.70	7.44	102.92
Goats	1,153	86	12.57	104.75	7.03	51.09	13.26	183.43
Sheep	5.04	-	0.05	0.43	0.02	0.17	0.05	0.66
Total	11499.04	858	87.35	727.92	59.38	457.54	60.59	838.13

Table 5 Estimated size of banana plantations that can be fertilized by the available manure in Kampala.

Animal type	Total manure (Mt $year^{-1}$)	N (Mt $year^{-1}$)	Bananas (ha)	P (Mt $year^{-1}$)	Bananas (ha)	K (Mt $year^{-1}$)	Bananas (ha)
Cattle	6683	39.25	196.25	26.68	305.96	28.60	172.29
Poultry	1918	25.00	125.00	17.71	203.10	11.24	67.71
Pigs	1690	10.48	52.40	7.94	91.06	7.44	44.82
Goats	1153	12.57	62.86	7.03	80.62	13.26	79.88
Sheep	5.04	0.05	0.26	0.02	0.28	0.05	0.29
Total	11499.04	87.35	436.76	59.38	681.02	60.59	364.99

Table 6 Estimated size of bean plantations that can be fertilized by available manure in Kampala

Animal type	Total manure (Mt $year^{-1}$)	N (Mt $year^{-1}$)	Beans (ha)	P (Mt $year^{-1}$)	Beans (ha)	K (Mt $year^{-1}$)	Beans (ha)
Cattle	6683	39.25	261.67	26.68	407.95	28.60	229.72
Poultry	1918	25.00	166.67	17.71	270.80	11.24	90.28
Pigs	1690	10.48	69.87	7.94	121.41	7.44	59.76
Goats	1153	12.57	83.80	7.03	107.49	13.26	106.51
Sheep	5.04	0.05	0.34	0.02	0.37	0.05	0.39
Total	11499.04	87.35	582.35	59.38	908.02	60.59	486.66

The manure from animals in Kampala can therefore, meet the nutrient requirements of 134.91 ha of maize or 98.85 ha of bananas or 131.80 ha of beans. According to Komakech et al. (2014a), 60% of the generated waste in Kampala is discarded away. Therefore, from Table 4, it implies that annually, 6899 Mt of animal wastes, 52 Mt of Nitrogen (N), 37 Mt of Phosphorus (P) and 36 Mt of Potassium (K) are discarded off. The presence of these wastes in the environment poses a threat to land, air and water quality through pollution. A proper manure management strategy starts with identifying and understanding this manure as a resource that contains nutrients (NPK) for crop production and the negative impacts of this manure to air , water and land (Osolo et al., 2015). Providing these wastes to crop producers would solve the problem of declining soil fertility and at the same time protecting the environment.

About 336,000 Mt of wastes are disposed of to landfills in Kampala-Uganda (Komakech et al., 2014b) and of these, 91% are organic in nature (Mboowa et al., 2017). These wastes have a potential of 5900, 900 and 600 Mt of nitrogen (N), phosphorous (P) and potassium (K) respectively (Komakech et al., 2014b) and an average gross energy of 19.26 MJ kg^{-1} on a dry matter (DM) basis (Mboowa et al., 2017). Poultry litter for example, contains less than 9% water content and it can be burnt directly to generate fuel without any further treatments and thus can be used as cheap and available energy (Jayathilakan et al., 2012). Energy drives the development of agricultural production practices which in return contribute to economic development of human society (Liang et al., 2019). About 90% of the total energy consumed in Uganda is from biomass whose main sources are agro forestry products (Adeyemi and Asere, 2014). The gross calorific value of these agro forestry species ranges between 14.3 – 25.4 MJ kg^{-1} on a dry matter basis (Gravalos et al., 2016). This implies that the energy that can be produced by 1 kg of agro forestry biomass products can be obtained from only 0.74

kg of organic wastes. According to Mboowa et al. (2017), if the organic materials that are land filled at Kiteezi are processed into biogas, 11.56 MJ kg^{-1} DM would be produced. This shows that the organic wastes that are disposed of by most of the farmers are potential energy producers and can effectively reduce the over dependence on biomass that is expensive and not environmentally sustainable. According to Kabyanga et al. (2018), adoption of biogas technology by small holder farmers in Uganda, can reduce the purchase of cooking fuel in addition to saving labour time for wood collection. Peelings from bananas, mango and pineapple can also be used in the production of Bioethanol and Biodiesel (Raji and Onu, 2017). This will reduce on the use of staple food materials like corn and wheat in production of bioethanol and over depending on diesel fuel. Utilizing these wastes by the farmers to produce energy will aid in improved and efficient production processes such as operation of irrigation pumps, packaging of their produce and automated operations like feeding livestock.

The organic wastes that are disposed of are made of vegetable wastes, crop peelings and residues, animal droppings, manure and food wastes. These wastes are produced from different production systems whose input demands for efficient production differ. For livestock production, for example, feeds are reported to be limiting factor for production due to scarcity and high costs (David et al., 2010). According to Sabiiti et al. (2014), 73.8% of the wastes produced are vegetable matter (banana peels, sweet potato vines and cabbage leaves) where by a sack of banana peels, sweet potato vines or cabbage leaves is sold between USD 4-6. These vegetable wastes are usually from crop producers who in most cases just dump them off in an environmentally unfriendly manner. According to UBOS (2010), 24,567, 2,879, 1,054 and 796 Mt of maize, beans, banana, cassava, sweet potatoes are produced in Kampala per year. The amount of waste generated from these crops (Table 7) can be estimated using crop to residue ratio (C:R) method with C:R values as given by (Tenyhwa et al., 2015).

Table 7 Estimates of residues produced from different crops in Kampala

Crop	Residue type	C:R	Residue (Mt)
Maize	Stovers	2.00	490.00
	Bran	0.92	227.85
Total			717.85
Beans	Trash	0.70	46.90
	Straws	0.60	40.20
Total			87.10
Banana	Leaves	0.179	515.34
	Steam	0.179	515.34
	Peels	0.179	515.34
Total			1546.02
Cassava	Rhizome	0.49	516.40
	Haulms	0.70	737.80
Total			1254.2
Sweet Potatoes	Peels	0.20	238.80
	Vines	0.40	318.40
Total			557.20
Grand Total			4161.87

All these residues are potential feeds to livestock animals like cattle, pigs, sheep, goats and poultry as they contain both micro and essential nutrients necessary for growth of the animals. The commonly used residues for animal feeds are banana peels, maize stovers and sweet potato peels (Katongole et al., 2013). The composition of these residues is given in Table 2 and from this the nutrient potential of these residues can be derived (Table 8).

Table 8 Nutrient potential of crop residues commonly used as animal feeds.

Crop residue	Potential proximate nutrients (Mt $year^{-1}$)			
	Crude protein	Crude fiber	Lipid	Carbohydrate
Maize stovers	44.84	158.42		
Sweet potato peels	11.15	22.69		
Banana peels	53.80	60.86	43.30	223.66
	Potential chemical nutrients (Mt $year^{-1}$)			
	Calcium	Iron	Zinc	Manganese
Maize stovers	0.032	0.909	0.004	0.08
Sweet potato peels	0.018	0.037	3.3×10^{-4}	0.06
Banana peels	0.102	0.078	0.06	0.047

Availing these residues to livestock farmers can solve the problem of feed scarcity at a low cost in exchange for money to the crop producers. The nutrient requirements (Table 9) for the common animals kept in Kampala can be used to estimate the number of animals (Table 10) that can be sustained by the crop residues commonly used as animal feeds.

Table 9 Nutrient requirements for different livestock animals

Animal type	Nutrient required per animal type (kg $year^{-1}$)				
	Crude protein	calcium	Iron	Zinc	Manganese
Broiler chickens	5.48	1.19	0.02	0.01	$7.3x10^{-3}$
Beef cattle	6.06	0.26	$1.83x10^{-4}$	$1.10x10^{-4}$	$1.46x10^{-4}$
Pigs	6.02	0.22	0.02	0.02	$9.13x10^{-4}$

Note: Source from Dale (1994), ICAR (2013), and Dierenfeld et al. (2014)

Table 10 Estimated animals that can be sustained by crop residues

Crop residue	Number of animals		
	Broiler chickens	Beef cattle	Pigs
Maize stovers	8,182	7,399	7,448
Sweet potato peels	2,034	1,840	1,852
Banana peels	9,817	8,878	8,937
Total	20,033	18,117	18,237

Therefore, considering protein being the major nutrient requirement for growth of animals, it implies that 20,033 broiler chickens, 18,177 beef cattle and 18,237 pigs can be fed annually by the crop residues generated in Kampala.

5 Conclusions

With the increasing urban population in Uganda, issues related to food insecurity are most likely to increase. Peri-urban agriculture can play a big role in availing the food to this urban population at an affordable price. However, the efficient production of both livestock and crops from this kind of agriculture is hindered by factors such as feed scarcity, high energy costs and declining soil fertility. The wastes that are generated from the agricultural activities end up in landfills, just dumped or in most cases underutilized. Making use of these wastes by matching it to the needs of the different production sectors can highly boost the peri-urban agricultural sector through provision of clean renewable energy, crop fertilizers and livestock and aquaculture feeds. However, there is still a low adoption rate by the population of the technologies that turn these wastes into useful products. Some of these technologies are aerobic composting, vermicomposting and anaerobic decomposition of the wastes. Extending and building capacity of the farmers on how to use these simple waste treatment technologies is anticipated to greatly increase the outputs from the agricultural activities with low cost inputs. This in turn will protect the environment from the emissions that are associated with these residues when improperly managed. Our study findings therefore indicate that systematic matching of bio-wastes to identified users would ensure that beneficial nutrients be captured to enhance agricultural productivity.

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