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An evaluation of the application of the circular production model in agriculture: case study of Nyanza district, Rwanda

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Introduction: This research explored the status of the application of circular economy (CE) principles in the agricultural sector in the Nyanza district of Rwanda.

Methods: A multi-methodological approach was used to collect mixed data from farmers and key stakeholders operating in two selected sectors of Muyira and Busasamana to evaluate the solid waste management value chain, assess the adoption of ecological latrines and explore farmers' perception on human waste fertilizers as a CE principle. Quantitative data was collected through interviews with a sample of 1244 farmers randomly selected from Busasamana ($n = 598$) and Muyira ($n = 646$). The data were interpreted according to the research questions and analysis was done using descriptive and inferential statistics.

Findings: The results indicated that waste management is still at a rudimentary stage in the localities studied, with a waste sorting rate of 2.2% and 1.1% but with a willingness of 96.9% in Busasamana and 99.5% in Muyira sector to sort waste from organic to non-organic at source. The majority of participants, represented by 80.3% of the surveyed farming households in Busasamana and 97.5% of their counterparts in Muyira generate between 1-2 sacks of household waste per week. Food-related waste was the most predominant in Busasamana households, accounting for 99.5% while Muyira farmer households generate both food and yard wastes in proportions of 58% and 41.6% respectively. It's worth knowing that waste is dumped in the domestic rubbish pits in the two sectors, with 88% and 77.9% in Busasamana and Muyira sectors. Furthermore, the research revealed the absence of a waste collection and transport provider and a landfill in the Muyira sector, while waste collection facilities are available in Busasamana. Low adoption rates of eco-friendly latrines were observed, as farmers trick to the use of traditional pit latrines at 98.2% of the households in Busasamana and 100% in Muyira sector. Muyira being far ahead of its Busasamana counterparts in toilet dislodging (67% vs. 33%).

Conclusion and recommendations: Greater involvement of all actors in the system to ensure the success of the application of CE practices and initiatives was recommended as well as awareness raising and capacity building on the use of ecological latrines.

KEYWORDS

circular economy, circularity in agriculture, human excreta, farmers' perceptions, waste management

1. Introduction

Food security remains an important challenge for Africa, whereby Africa needs to solve the increasing need for food due to explosive population growth combined with challenges from accelerated climate change. The African continent has the youngest population worldwide (Mathew, 2014) and it is predicted to have "more than half of the global population growth between now and 2050" (United Nations, 2015, para 3). At this moment, African countries are already suffering from high undernourishment, whereby one of the four undernourished people globally is coming from Africa (SOS, n.d.). This makes the African continent one of the most vulnerable regions for food security (Torquebiau et al., 2016). Not only is agriculture important for food security, it also contributes a large share to the economy of developing countries, particularly in Africa (Oxford Business Group, 2019). Rwanda is no different, agriculture remains a driver of its economic growth, employing over 80% of Rwanda's population and contributing 70% of the country's exports as well as 30% to the national GDP (Musabanganji et al., 2019). In the quest to improve the socio-economic standard of living of its people, Rwanda has made progress in implementing a wide range of economic policies and strategies, particularly in the agricultural domain, in order to boost the yield and meet the food needs of the entire population. According to the Rwandan National Agricultural Export Board (NAEB, 2018), increasing chemical fertilizer use has been an integral part of the Rwandan government's strategy to increase agricultural productivity—an essential element of the economic development of the country's "Vision 2020". To achieve this, the Ministry of Agriculture and Animal Resources (MINAGRI, 2021), testifies to the effectiveness of public initiatives with programs such as Girinka, whereby the initiative aims to introduce one cow per family to support family income, nutrition and manure for farming as well as providing subsidized chemical fertilizers. However, it remains to be seen how this increase in chemical fertilizer use will impact environmental pollution.

The use of chemical fertilizer is a conventional farming practice that fits within the traditional linear economy that is focused on "take-make-dispose". Chemical fertilizers distributed to Sub-Saharan Africa are known to be the world's most expensive fertilizers (AGRA, 2019) and improve productivity in the short term but are not able to improve the fertility of the soil in the long term (Kotschi, 2013). The circular economy has been identified as a solution to the traditional linear economy. According to a study by Kirchherr et al. (2017), which analyzed 114 different definitions of the circular economy (CE), the most prominent definition is formulated by the Ellen MacArthur Foundation (2013). The foundation (2013, p. 7) formulates a CE as "an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and within this, business models' '. More relevant to the objective of this study, Oosting et al. (2021) summarized how the CE for food in the tropics can be unpacked. Oosting et al. (2021, p. 273) summarized the CE in the following four elements "(1) utilize arable land and water bodies primarily to produce food for direct human consumption (2) avoid or minize food losses and waste, (3) recycle by-products (e.g. crop residues, co-products from processing, manure and excreta), inevitable food losses, and waste streams back into the food system, and (4) use animals to unlock biomass with low opportunity costs for humans into value-food, manure and ecosystem services".

The current vision of the Rwandan Government to transform subsistence farming into a monetized, technology-intensive commercial enterprise by 2050, by embracing the principles of a circular economy, has prevailed as a solution to resource depletion and the need to reduce the environmental impacts of the crop production system (Bradley, 2018; MINAGRI, 2018; The World Bank, 2019). This is aligned with the National Action Plan for the Circular Economy, which aims to promote organic fertilizers in Rwanda (Ministry of Environment., 2022). However, this conflicts with the country's crop intensification program (CIP) which emphasizes the intensive use of chemical fertilizers, resulting in soil infertility, environmental toxicity, and the production of unsafe food due to the accumulation of chemicals harmful because of the lack of alternatives (Uwayezu et al., 2018). This is consistent with the observations by Cioffo et al. (2016) that regenerating soil fertility was a major issue for Rwanda since farmers reported a steady decline in soil fertility over the long term. While the use of chemical fertilizers was also seen as favoring large farmers who can bear the cost, a shift to environmentally friendly organic farming has been proposed (Rwanda Environmental Management Authority, 2016). A study by Nijman (2020) concluded that circular economy practices among farming communities already exist in Rwanda through the utilization of organic waste as a fertilizer or through utilization of organic animal waste as an animal feed in Kamonyi District. However, the use of circular economy practices through the application of livestock manure, household waste and the traditional approach to composting which yields compost after 8 months did not seem to satisfy the two agricultural seasons in Rwanda (Uwayezu et al., 2018).

Therefore, an ecosan pilot project was introduced in Rwanda by the Netherlands Development Organization (SNV) to increase hygienic sanitation by applying circular economy practices, while addressing the need for agricultural inputs (Mukasine, 2015). An ecosan is a system that is developed to recover nutrients found in human excreta for safe agricultural re-use (Esrey, 2001; Andersson et al., 2016). The Rwandan government encouraged the use of ecological latrines by releasing a national sanitation policy together with the national sanitation policy implementation strategy (Karanja, 2019). Since then, a series of civil society organizations have opted for the construction of ecosan for rural schools and for their target population, with the aim of safely handling human feces and using them as a fertilizer (Aqua for All, 2018). The programmes did not only constructed the ecosan technologies, but also trained the farming communities on the use of ecosans in Rwanda (Mukasine, 2015), which also has been identified in the literature as an important intervention toward the efficient and safe use of ecosan (Dickin et al., 2018). Nyanza district has particularly benefited from development programs like the Isuku Iwacu project implemented by SNV (Karanja, 2019)

and the Gikundiro program implemented by FXB (FXB, 2021), among others.

Unfortunately, after the introduction of the waste-to-resource approach and the related initiatives, there have been limited resources available on the status of this initiative and adoption rate of the ecosan among the rural farming communities. One of the fewer studies that have been conducted is a study of Banamwana et al. (2020) investigated the application of human excreta in Burera district in Rwanda. The study concluded that only 3% of the ecosan users apply human excreta as fertilizer on their farms in Burera district. Also, the study suggested there is a need to upscale ecosan technology, and the need for more research on the factors that influence the ecosan technology adoption in Rwanda. As Kabera (2020) asserts, a limited number of studies have been published, with limited literature review, conducted by students who have focused on Kigali City, leaving rural districts fully unexplored. The Global Green Growth Institute (2019) reports that the lack of research makes it difficult to comment on the beneficiaries' awareness of the management of human waste excreta from the ecological latrines and their importance in improving agriculture.

Human waste excreta are acknowledged to provide new solutions to the future fertilizer challenges (Kelova et al., 2021). However, there are also other sources of nutrients such as the utilization of solid waste as input for organic fertilizers, which can be identified as an CE practice at farm level. A recent study of Nijman-Ross et al. (2023) analyzed 275 articles to identify the circular economy research gaps for Africa, concluding that there is a direct need to investigate the status quo of farmers applying CE practices and determinants of adopting organic farming practices. This means that there is not only need to study the adoption of human waste fertilizers, but also other CE practices within the local farming communities. Therefore, this study concluded that there is a need to investigate the level of awareness and perceptions of the farming community toward the adoption of the ecosan as an fertilizer, but also to assess the existing CE practices with an focus on waste into farming inputs (fertilizers) to provide insights on the status quo of fertilizer use in Rwanda.

In the context of this study, this research has the objective to investigate the state of the recirculation of nutrients as agricultural inputs back into the food system in Nyanza district in Rwanda. The study assessed the current state of the application and farmers' awareness, adoption and readiness for circular farming practices. To evaluate the application of the circular economy practices in the agricultural sector in Rwanda, this study has a special focus on turning waste into organic and human waste fertilizers back into the food system, which can be linked to the third key element of the circular economy for food as defined by Oosting et al. (2021).

In order to answer the research objective, this study has investigated three research questions:

1. Which circular economy practices are in place in the solid waste value chain in Nyanza district?
2. What is the level of adoption of ecological latrines and the management of the derived human excreta among local farming communities in Nyanza District?
3. What are the current farmers' perceptions on the use of human excreta as an fertilizer among the local farming communities in Nyanza District?

2. Methodology

2.1. Research design

The study collected both quantitative and qualitative data from select farmers and waste management actors. While quantitative data was collected by structured interviews from select farmers in both Muyira and Busasamana sectors, qualitative data was collected through a semi structured interview with select waste management actors operating in both locations. This mixed data approach was chosen to exploit the limitations of one approach (BetterEvaluation, 2022), in particular, to address participants' perceived lack of policy knowledge in order to use qualitative work to identify issues or gain insights into variables not obtained by a quantitative survey.

2.2. Study area

In response to the lack of resources on circular economy identified by the Global Green Growth Institute (2019) in secondary and rural cities, this study drowned interest in Nyanza district, one of the rural cities that experienced some circular economy projects implemented by the government of Rwanda and it is stakeholders such as SNV. The pollution targets of this study were the farmers living in the study area, represented by the heads of households. Nyanza District is inhabited by 320,000 citizens, spread across 10 districts whose bulk of the economy is based on agriculture (Nyanza District, 2017). Two sectors of Nyanza district were purposely selected for the study, a rural sector and an urban sector, respectively, Muyira and Busasamana, in order to comparatively analyze the results. With limited statistics in the agricultural yields, Muyira was selected for being predominantly rural, while Busasamana sector is predominantly urban, a hope for different perceptions for the comparative view purpose.

2.3. Sampling design

In light of the recent statistics by the Rwanda Agricultural Board (2018), considering an average household size of 5 in Nyanza district, the population of the two sectors was estimated to be approximately 64,000 citizens, that is 12,800 households. To ensure an even distribution of respondents from both rural and urban settings, a cluster sampling technique was adopted to divide the population into two clusters (sectors) and, thereafter, individual households were sampled from within each cluster. A systematic sampling technique was then used to select households for inclusion in the study, within each sector. As Cridland (2022) explains, most statisticians agree that a good maximum sample size is usually 10% for a population no larger than 10,000. With this in mind, given the consideration of 6,400 households from each of the two sectors concerned, a random sample size of 10% was drawn from each sector, as inspired by Cridland (2022), bringing the sample size to 1,280 households. The households were selected using a simple random sampling where each household had an equal chance of being selected.

2.4. Data collection

Data was collected using structured interviews to collect quantitative data from members of selected households, on key variables such as socio-economic and demographic characteristics, social perception and circular agricultural opportunities available. Key Informants Interviews (KII) were purposely held with other people in charge of agriculture, waste management and sanitation as well as schools using ecosan. An ecosan is a system that is developed to recover nutrients found in human excreta for safe agricultural re-use (Esrey, 2001; Andersson et al., 2016). A pilot study was conducted with 10% of respondents with similar characteristics to the population studied, in order to test the reliability and validity of the questionnaires (Middleton, 2019). The outcome and opinions expressed by the respondents during the pre-tests were analyzed and used to improve the interview guide before the start of the actual data collection.

2.5. Data analysis

The analysis of data began with pre-processing of the data collected through modifications to detect errors and omissions and to make corrections as far as possible. This involved careful analysis of completed interview guides to ensure that the data collected was accurate and consistent with other information collected. The quantitative data collected with interview guides was coded by the researcher to protect the identity of individuals. Once the coding is complete, the data has been classified based on common characteristics and attributes. The raw data was then assembled and compiled into statistical tables for further analysis using the Statistical Package for Social Sciences (SPSS). This facilitated the summation of elements and the detection of errors and omissions. Descriptive statistics, mainly percentages were used to analyze the data. Finally, all the data was stored on electronic copies and printed in tabular form.

2.6. Ethics

This study was assessed and cleared for ethical compliance by African Leadership University and authorized by Nyanza District prior to any interaction with participants. The researcher also raised awareness of the community about the study through community meetings for an informed decision to participate in the study. All other American Psychological Association (APA) ethical principles have been implemented as originally assessed and approved by the cited authorities.

3. Results

This chapter presents the results of data collected from selected participants from both the Muyira and Busasamana sectors of the Nyanza district with the objective to evaluate the application of circular economy principles in the agricultural sector in Rwanda. The study sampled 1,280 farming households operating in Muyira and Busasamana sectors. Out of 1,280 participants, 1,244 participants representing 97.2% of the sample size, voluntarily completed the survey, which has been claimed by Fincham (2008) as above the acceptable response rate.

The data were interpreted according to the research questions. In this section, the study presents the findings for each research question.

3.1. Composition of respondents by age, gender and household size

The data shows that the average age of farmers, in both urban and rural sectors, is 46 years old. However, in the Muyira (rural) sector, young people tend to engage in agriculture more than their counterparts in the urban Busasamana sector, as evidenced by the respective 26 and 13% engagement rates of farmers aged below 35. In terms of gender, the results do not show a clear difference, but rural agriculture tends to have more women engaged (51.3%) in our study areas than urban women engaged in agriculture (49.7%).

3.2. Composition of respondents by education level

The data collected shows that the majority of participating farmers have attended primary (45% in Muyira vs. 18.7% in Busasamana) and secondary (38.9% in Muyira vs. 19.9% Busasamana) education. While only 0.9% of participating rural Muyira farmers have attended post-secondary education, this percentage was 17.7 in the Busasamana sector. Similarly, there was an observable difference in the participants' courses in non-formal and vocational training, as evidenced by 6.5% against 20.7 and 8.7% against 22.9%, respectively, in the sectors of Muyira and Busasamana.

3.3. Value chain of solid waste management

3.3.1. Waste mostly produced at the household level

The results of the data collected in the rural sector of Muyira and the urban sector of Busasamana indicate food and yard waste as dominant waste streams generated at the household level. While food-related waste is most prevalent in both locations, with 99.5 and 58.0% responses respectively in Busasamana and Muyira, participants from Busasamana consistently reported no yard waste compared to their counterparts from Muyira who generate 46% of yard waste.

3.3.2. Waste sorting at the household level

In general, the results indicate that the surveyed rural and urban farming households do not sort waste from organic to non-organic, with 97.8% in the Busasamana sector and 98.9% negative responses in the Muyira sector. Only a small percentage of participants confirmed the sorting of household waste, i.e. 2.2% in the Busasamana sector and 1.1% of positive responses in the Muyira

sector, leaving no clear difference in the practice of waste sorting in the rural and urban areas.

However, the majority of respondents were found to be willing to sort waste if given information and guidance. About 96.9% of the surveyed households in Busasamana and 99.50% in Muyira agreed that they would be willing to sort waste if the respondents received information and guidance.

3.3.3. Quantity of waste generated at home

In both sectors, the farmers surveyed indicated that the households generate between one and two sacks of waste per week at home, with 80.3% of the interviewed households in Busasamana and 97.5% in Muyira sector. The results also show that about 16% of respondents in Busasamana estimate to generate 3–5 sacks per week against 2.5% of respondents in Muyira. Additionally, 3.5% of farmers surveyed in Busasamana estimated a collection of more than 10 sacks per week. While some factors that may increase waste generation at the household level were observed, such as domestic livestock, large household size and large-scale agriculture, rural participants had also difficulty estimating.

3.3.4. Waste dumping at the household level

The results of the data collected in both sectors indicate that most of the waste is dumped in the domestic rubbish pits, with 88% of the respondents in Busasamana and about 78% in the Muyira sector. In addition, about 4% of the households in Busasamana and 16% of the households in Muyira discharge their waste into their agricultural fields. While 3.3% of Busasamana respondents use waste collection and transportation services to dump their waste, this does not apply to their counterparts in the Muyira sector due to a lack of service providers. Similarly, 4.8% of the urban Busasamana respondents indicated the use of a publicly managed refuse area that was also not available for rural respondents in the Muyira sector. However, a considerable 6.2% of the Muyira sector respondents burn their household waste, an option which is not available to their counterparts in Busasamana.

3.3.5. Providers of waste management services

The data collected shows the presence of public waste management services in the urban sector of Busasamana and it is absence in the rural sector of Muyira, as evidenced by 90% of the respondents in Busasamana and 99.8% of respondents in Muyira. However, a sizeable proportion of respondents in Busasamana highlighted the presence of private service providers (3.5%) and community volunteers (1.2%), which are not available in rural areas of the Muyira sector. Qualitative data collected from relevant waste management stakeholders confirmed the absence of a waste management collection and transport provider and landfill in the Muyira sector, the two facilities available in Busasamana. Waste haulage services and the landfill are run by a community group under contract with the government. It was found that the waste is sorted at the landfill before being composted and sold to interested farmers as organic fertilizer, generally on a quarterly basis.

3.4. Ecological latrines and the management of the derived by-products

3.4.1. Types of toilets found in the household yard

The study showed that pit latrines are the most used type of toilet, by 98% of respondents in Busasamana and 100% in Muyira. Only 1.8% of flush latrines were observed in Busasamana, with none in the Muyira sector. No other type of latrine was identified in the farmers' households surveyed. However, the researchers visited three local public schools in each sector and found the presence of ecosan. The ecosan is well maintained by the hygiene and sanitation committee as well as an environmental club. According to the head teachers, they meet weekly to discuss hygiene issues, including use of latrines.

3.4.2. Participants knowledge of the benefit of Ecosan

Farmers in Busasamana (urban) were found to have a limited understanding of the benefits of ecological latrines. On a scale of 5 (zero, novice, basic, intermediate and advanced), a total of 99.3% participants in Busasamana reported that they do not have knowledge (zero) on the benefits of ecological latrines, compared to 0.2% of Muyira participants who ranked their knowledge at zero. Furthermore, 0.5% of the farmers in Busasamana compared to 23.5% of farmers in Muyira reported having a novice knowledge of ecological latrines. Similarly, none in Busasamana reported having a basic knowledge of the benefits of ecological latrines, compared to 76.2% of farmers in Muyira who reported having a basic knowledge of ecological latrines.

3.4.3. Participants' use of Ecosan technology

The study revealed that the majority of farmers in the surveyed locations generally do not use ecosan technology, as evidenced by 99.8% negative responses in Muyira and 98.2% in Busasamana. Only a small percentage of 1.3% of farmers in Busasamana use ecosan technology against 0.2% of farmers in Muyira.

This could be because 25% of farmers in Busasamana have received ecosan technology from NGOs while their counterparts in Muyira have not. Although the majority of farmers in both households construct ecosan technology by themselves, all farmers in Busasamana and Muyira have not received ecosan technology from the government, this could show that government sanitation facilities have penetrated in Nyanza district to a very low extent.

All participants (100%) from Muyira vs. 75% of their counterparts from Busasamana, who use Ecosan said they had built it by themselves. The remaining 25% of the farmers in Busasamana reported to have received the ecosan from Non-Governmental Organizations (NGOs). Surprisingly, none of the respondents stressed that they received ecosan from the government.

3.4.4. Participants' experience with toilet dislodging

Generally speaking, it was found that most of the farmers from both study locations have a habit of dislodging their toilets with a total percentage of 67% against 33% who did not know how to

dislodge the toilets. The results showed that farmers in Muyira have more experience in dislodging toilets than their counterparts in Busasamana, as evidenced by 99.8% of respondents in Muyira compared to 31.4% in Busasamana. This could be attributed to the fact that farmers in Busasamana could be willing to use other dislodging facilities. Pursuant to this, it was earlier seen that the farmers in Muyira understood the benefit of ecological latrines more than those in Busasamana which could also give reason to more farmers in Muyira to have experience in toilet dislodging.

3.4.5. Types of by-products being used by participants

Participants in Busasamana and Muyira sectors showed experience in applying both urine and feces on their farms (99.47 and 100 % in Busasamana and Muyira. respectively). However, it was revealed that among the participants who dislodge their toilets, 99.84% of rural farmers in Muyira use the by-products as fertilizer in agriculture against 5.32% of farmers in Busasamana. The latter mostly dislodge toilets for disposal, 94.68% except for 0.53% who use human excreta for biogas, an option not available to their Muyira counterparts. Also, a low percentage of farmers surveyed in both localities have ever sold toilet by-products, 1.06 and 0.93% in Busasamana and Muyira.

3.4.6. Constraints in the use of latrine by-products

The collected data illustrates that farmers in Muyira (rural) are only limited by discomfort related to the use of latrine by-products (100%), while those in Busasamana (urban) face limitations related to dislodging and storage cost (61.37%), discomfort (30.27%), limited technical ability (6.86%), limited knowledge (0.84%), and discouraging culture (0.67%).

3.5. Farmers' perceptions on the use of human excreta

3.5.1. Participants' use of fertilizers

In general, farmers in both locations showed that they mainly use circulating fertilizers, i.e., animal manure and household waste. However, there was an observable difference in the use of these products since farmers in Busasamana mainly use animal manure (85%) compared to 24.5% of farmers in Muyira. The latter has the highest use of domestic waste as fertilizer at 75.4% against 15% of their counterparts in Busasamana. It was also noticed that farmers in both locations do not primarily use commercial fertilizers.

Rural farmers in Muyira far outpace their urban farmer counterparts in Busasamana in the use of human excreta, with an adoption rate of 99.2% against 3.5%. However, it was found that most farmers in Busasamana (78%) who do not use human excreta are willing to use it while about 18% can consider using it.

3.5.2. Perception on food grown with human excreta

The study found that about 93 and 99.8% of the farmers surveyed in Busasamana and Muyira have no objections to eating food grown with human fertilizers. Only a small percentage of farmers in the two localities, about 2.2 and 0.2% in Busasamana and Muyira, are strictly against eating food grown with human fertilizers. Additionally, about 5% of respondents in Busasamana (urban) were skeptical of consuming food grown with human waste excreta.

3.5.3. Participants suggestions for engaging farming to use human excreta

When given the opportunity to suggest ways to fully involve farmers in adopting the use of human excreta as a potential circular fertilizer in agriculture, farmers primarily suggested educational workshops. While the responses varied, Busasamana and Muyira could point to education workshops at about 89 and 99%, respectively, and campaigns at community meetings, 7 and 1%. Only Busasamana farmers could mention the demonstration gardens (3%) while a few respondents could offer their reservations.

4. Discussion

4.1. Value chain of solid waste management

4.1.1. Type of waste mostly produced at the household level

The presence of food waste in both places suggest postharvest food losses from primary processing such as clearing, drying, sieving and grinding. While the presence of yard wastes in Muyira invokes presence of organic debris, which is often mixed with deadstock, proper on-farm waste management methods are suggested. Waste sorting.

Overall, the results indicate that rural and urban farming households surveyed do not sort waste from organic to non-organic, with 97.8 and 98.9% negative responses, respectively, from Busasamana and Muyira. Although this constitutes a limitation to the reuse of household waste, it may also signal a lack or limited coverage or the ineffectiveness of the WASH management interventions proposed so far. This is evidenced by 96.9 and 99.5% of participants, respectively, from Busasamana and Muyira, who confirmed their willingness to sort waste if they received information and advice.

4.1.2. Quantity of waste produced at household level

The results indicated that, in general, farmers in Busasamana and Muyira generate 1–2 sacks of waste per week, as evidenced by 80.3 and 97.5%, respectively. However, it was observed that another considerable number of farmers in Busasamana could generate 3–5 sacks (16.2%) and even more than 10 sacks (3.5%), compared to their counterparts in Muyira who, respectively, produce 2.5 and 0% in that regard. While it was observed that some factors that may increase waste generation at the household level, such as domestic livestock, large household size and large-scale agriculture; rural participants had also difficulty in estimating.

4.1.3. Waste dumping at household level

Generally, both Busasamana and Muyira's surveyed farmers dump their household waste into the domestic rubbish pits. This may be described as the cheapest dumping methods, allowing the reuse of domestic wastes after it has been composed. However, the qualitative data collected from community health workers indicated that rubbish pits have been initiated by the government where every household was asked to have at least one rubbish pit to dump home waste. While the 3.8 and 15.9% of Busasamana and Muyira households, respectively, who dispose of their waste in the fields can be interpreted as a lack of knowledge, negligence or inability to dig their own rubbish pits, the researchers observed that the difference thereof can also be explained by the fact that rural farmers live close to their farmlands while urban farmers may travel a few meters from their homes to reach their farmlands. Similarly, the absence of a burning option in the Busasamana sector can be explained by the agglomeration of their habitats in urban areas compared to the rural areas of Muyira. However, the availability of climate change actors can also be of significant importance.

4.1.4. Providers of waste management services

The presence of private service providers in the Busasamana may reflect residents' willingness to pay for or service affordability to urban residents, while the engagement of community volunteers may signal the presence of WASH actors, a suspected reason for not burning waste in urban areas.

The data showed that waste is collected at different time intervals in Busasamana, mainly every two weeks as evidenced by 61% respondents, compared to those who mentioned every week (19%) and every month (15.2%). Qualitative information collected from users of waste collection and transport services indicated Frw 3,000/month as the service price. Although it may be difficult to judge the affordability of this service, regular waste collection is one explanation for the lack of yard waste in farmers' homes in Busasamana.

4.2. Ecological latrines and the management of the derived by-products

4.2.1. Types of toilets found in the household yard

The predominance of pit latrines in both locations could be because pit latrines are the traditional toilets that most farmers may be familiar with and therefore easier and cheaper to construct than other types of toilets. Additionally, the common claim that flush toilets are more likely seen in urban areas than in rural areas was reflected in the survey in that 1.8% respondents in Busasamana (urban) used flush toilets compared to their counterparts in Muyira (rural) who did not have any.

4.2.2. Participants' knowledge of the benefit of ecological latrines

The study findings indicated that Muyira (rural) farmers are more knowledgeable about the benefit of ecological latrines than their counterparts from Busasamana (urban) sector. This could be due to the fact that most agricultural projects focus on rural areas rather than urban settings. Therefore, farmers in rural areas have been sensitized on the use of human excreta in agriculture as a beneficial and cost-effective means compared to expensive artificial fertilizers. However, this analysis assumes that farmers in urban areas are more willing to purchase and use artificial fertilizers.

4.2.3. Farmers' use of Ecosan technology

While generally the surveyed farmers from Busasamana and Muyira sectors do not use ecosan technology, a small number of farmers represented by 1.3 and 0.2% respectively, do use it. The difference can therefore be explained by the fact that 25% of farmers in Busasamana use ecosan technology received from NGOs while their counterparts in Muyira did not. No member of the surveyed population reported of having received ecosan technology from the government. It was revealed that the majority of farming households in both locations constructed ecosan technology by themselves, i.e., 75 and 100%, respectively, in Busasamana and Muyira.

4.2.4. Farmers' experience with toilet dislodging

The data revealed that rural farmers in Muyira are more accustomed to toilet dislodging than their urban counterparts in Busasamana. This brings a suspicion that urban farmers do not use human excreta in their farming activities. This could also be linked to the finding that farmers in Muyira (rural) understood the benefit of ecological latrines more than those in Busasamana which could also give reason to more farmers in Muyira to have experience in toilet dislodging.

4.2.5. Types of by-products being used by participants

Based on the findings that farmers in Muyira use and are more willing to use human excreta as fertilizer in agriculture, one would argue that farmers in Muyira (rural) have a better perspective of the circulation of by-products, i.e., human excrement. However, the fact that majority of respondents (98.94% in Busasamana and 99.53% in Muyira) have never sold the by-products predicts that farmers in Busasamana do not have storage facilities, hence dislodging toilets for evacuation, while Muyira-based farmers store excreta on farmland near their homes. This can be supplemented with qualitative data from the Muyira sector agronomist who confirmed that despite farmers' willingness to use human excreta, excreta are not available in sufficient quantities for agriculture.

4.2.6. Constraints in the use of latrine by-products

Findings that farmers in Muyira (rural) mostly face discomfort (100%) compared to their counterparts in Busasamana who cited dislodging and storage cost (61.37%) and discomfort (30.27%) as the main limitations to the use of toilet by-products, it can be confirmed that farmer in rural Muyira store by-products in nearby farm (hence discomfort due to the smell) while the townspeople tend to end up evacuating them after dislodging them. Additionally, in line with Gwara et al. (2022)'s findings that the main barrier

of using latrine by-products was the health risk associated with bad odor, various potential diseases, and visual repulsiveness, it can be agreed that most farmers are limited by the discomfort that comes with using latrine by-products. Pursuant to Banamwana et al. (2020) who reported that the touching of human excreta was still seen as a taboo, the untouchable "amazirantoki" in some communities, it is impressive that only 0.67% of participants in Busasamana were discouraged by culture in adopting the use of latrine by-products. This might be attributed to the awareness efforts of both the government and it is civil society partners.

4.3. Farmers' perceptions of the use of human excreta

4.3.1. Participants' use of fertilizers

The study revealed that animal manure (in Busasamana) and household waste (in Muyira) are the most used type of fertilizers, as evidenced by 84.95 and 75.39%, respectively. Surprisingly, it was also noticed that farmers in both places do not primarily depend on commercial fertilizers, perhaps due to the high costs of commercial fertilizers, which makes them more favorable to large-scale farmers (Rwanda Environmental Management Authority, 2016). However, just as it was seen earlier that the farmers of Muyira use human excreta as fertilizer (99.23%), it can now be seen that human excreta is not the most used fertilizer, a confirmation of its low supply. This shows that farmers are willing to use human excreta as a cheaper fertilizer, despite insufficient production. Similarly, 77.99% of Busasamana farmers who do not use human excreta are willing to use it while 18.2% would consider using it. This is also consistent with the previous finding that most farmers in Busasamana (urban) do not have the dislodging and storage facilities, mainly due to settlement agglomeration, hence their habit of dislodging latrines for evacuation.

4.3.2. Perception on food grown with human excreta

Since the majority of farmers in the Muyira sector have experience in using human excreta as fertilizer, the finding that 99.8% of farmers have a good perception of consuming food grown with human feces is not surprising. On the other hand, one may wonder why 92.98% of farmers in Busasamana have a good perception on consuming food grown with human fertilizers, despite their low adoption rate of 3.51%. However, the finding that 77.99% of farmers in Busasamana who do not use human excreta are willing to use it and the previous proposition about the low availability of human excreta due to difficulties in dislodging and storing them in the urban areas provide an explanation. In addition, the poor understanding of the process of decomposition and absorption of fertilizers, and the benefits of ecological agriculture for some farmers, as well as other factors such as the absence of specific legislation for recycled food products can be a barrier to the acceptance of food grown with human excreta (Palencia et al., 2023), which could be the case for the few rejections.

4.3.3. Participants suggestions for engaging farming to use human excreta

The belief of farmers that educational workshops would be effective in increasing adoption of the use of human excreta as a potential circular fertilizer is an interesting view. While community meetings discuss a variety of agenda items, workshops are best for in-depth, focused coverage of a specific issue. This aligns with Morgans (2021) who suggested farmer workshops rather than regular meetings to emphasize the valuable addition of facilitation. Given that 77.99% of the farmers surveyed in Busasamana are ready to adopt the use of human excreta, one sees a thirst to know more about the what and the how, as much as this can be linked to the outcome.

5. Conclusion and recommendations

This study has the objective to analyze the evaluation of waste into value at the household level among farmers' households in Nyanza district. From the research findings, it can be suggested that solid waste management is still at a rudimentary stage of development in Nyanza district, which is the same as other secondary cities in Rwanda. This situation requires greater involvement of all system actors to ensure the success of any waste management initiative. The lack of a common vision and awareness of the circular economy necessitates relevant policy and guidelines to drive the programming and execution of waste management and circular economy programs implemented by stakeholders.

Second, the study aimed to assess the adoption of ecological latrines and the status of the use of derived human excreta in agriculture. The population of farmers surveyed revealed a very low penetration of the use of ecological latrines, except in public schools where the government and it is stakeholders have concentrated their efforts. While the local population sticks to conventional pit toilets, considered a sustainable option for rural families but potentially contaminant (easily spreading diseases and leach into groundwater), the process of encouraging the acceptance of green latrines should start with helping families understand the concept behind it. The observed lack of knowledge and experience with ecosan is testimony to this. Success will also depend on building the capacity of users and their building contractors since the construction and use of Ecosan toilets are very different from conventional pit toilets. Just as public schools are closely supervised and have structures to monitor sanitation facilities, post-construction monitoring, within at least a year, will be very crucial to ensure families are on top of the process regarding the use of ecosan. For example, families need to know when and how to close one chamber to use the second or when and how to harvest by-products, because any mistake will cause the whole system to fail. Additionally, sustained information and occasional live demonstrations will be needed to eliminate social biases and build confidence.

Finally, farmers' perceptions of the use of human excreta were assessed against the socio-economic characteristics of excreta reuse for agricultural purposes. With the exception of farmers in Busasamana who have little experience in using human excreta but want to explore this practice, the majority (99%) of farmers based in Muyira have already tapped into this area and are willing

to use excreta as fertilizer and consume crops fertilized with excreta. Based on the lack of enough supply of human excreta in rural Muyira and the difficulties in storing excreta observed in urban Busasamana and the importance of agriculture for the community, it is important that sanitations programs also consider alternatives to ecological sanitation systems such as the use of (sanitized) excreta in agriculture to improve crop yields at a minimum cost. In order to enrich the knowledge of farmers on the proper handling and use of excreta, especially avoiding health risks, there is an immediate need for an open discussion on the benefits, risks of the technicality necessary. Further research is recommended on the factors that influence farmers' decision to reuse excreta for agricultural purposes and on the perception of health risk.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by African Leadership University, Circular Economy Program. The patients/participants provided their written informed consent to participate in this study.

Author contributions

SS conceived the work and the main concept of the article, supervised, analyzed the results of data collected from 1,244 farming households, wrote the first draft of the manuscript, and coordinated the incorporation of the editors' feedback. LK reviewed the initial concept, built the database of the literature, and contributed to the design of the survey tools. DU contributed to the design of the survey tools and supported the data collection. EN-R reviewed the full manuscript, supported with both structuring, and content editing as well as addressing the journal reviewers' feedback. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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