Ex-ante demand assessment of human excreta recovery and reuse in agriculture

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Agricultural Economics, School of Agricultural, Earth and Environmental Sciences, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by the Bill and Melinda Gates Foundation.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

As the candidate's supervisors, we agree to the submission of this thesis:

Signed [redacted]

Date: 10 January 2022

Professor E.W. Zegeye (Supervisor)

Signed [redacted]

Professor A.O. Odindo (Co-supervisor)

Date: 10 January 2022

DECLARATION 1: PLAGIARISM

I, Simon Gwara, declare that:

(i) The research reported in this thesis, except where otherwise indicated or acknowledged, is my original work;

(ii) This thesis has not been submitted in full or in part for any degree or examination to any other university;

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) Their words have been re-written but the general information attributed to them has been referenced;

b) Where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) Where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) This thesis is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

[redacted]

Signed: Simon Gwara

Date: 10 January 2022

DECLARATION 2: PUBLICATIONS

The following publications (submitted and under review) form the research presented in this thesis.

Chapter 2

- **Gwara S,** Wale E, Odindo A, Buckley C 2021. Attitudes and Perceptions on the Agricultural Use of Human Excreta and Human Excreta Derived Materials: A Scoping Review. *Agriculture* 2021, 11(2), 153; https://doi.org/10.3390/agriculture11020153

Chapter 3

- **Gwara S,** Wale E, Odindo A, Buckley C 2020. Why do We Know So Much and Yet So Little? A Scoping Review of Willingness to Pay for Human Excreta Derived Material in Agriculture. *Sustainability* 2020, 12(16), 6490; https://doi.org/10.3390/su12166490

Chapter 4

- **Gwara S,** Wale E, Odindo A 2022. Behavioural intentions of rural farmers to recycle human excreta in agriculture? Implications for research, policy, and development practice. Nature Scientific Reports (2022) 12: https://doi.org/10.1038/s41598-022-09917-z.

Chapter 5

- **Gwara S,** Wale E, Odindo A (2022) Psychometric analysis of the ecological dispositions of rural farming communities in South Africa: Implications for human excreta reuse in agriculture. PLOS Sustainability and Transformation 1(6): https://doi.org/10.1371/journal.pstr.0000019

Chapter 6

- **Gwara S,** Wale E, Lundhede T, Jourdain D, Odindo A 2021. Demand assessment and willingness to pay for human excreta derived co-compost. Empirical evidence from rural South Africa. (Under Review Journal of Cleaner Production)

[redacted]

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Signed: Simon Gwara

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ABSTRACT

The global demand for food is soaring following the increasing population, rapid urbanization, and economic growth in the developing countries. The dependence on extractive agricultural intensification systems that depend mostly on the use of external inputs to increase productivity to support food demand are largely responsible for environmental pollution. The excessive use of synthetic fertilizers in the developed and some Asian countries continues to push the planetary boundaries, contributing to climate change and environmental pollution. In sub-Saharan Africa, where the use of chemical fertilizers is low, farmers face low productivity as a result of persistent mining of soil nutrients via food without returning them to replenish the soil. The depletion of soil nutrients affects the resilience and sustainability of food systems against climatic shocks. Meeting the sustainable development goals, therefore, requires a paradigm shift in thinking towards more sustainable and responsible production and consumption systems. Resource recovery and reuse of the agricultural nutrients from waste streams could synergistically benefit the waste management, sanitation, agricultural sector, and even the health sector. Co-composting of faecal matter with organic waste could help to retain the mined nutrients and to restore soil health. The co-composting value chain is especially useful in rural and urban areas where it contributes to sanitation goals (emptying pits), waste management objectives (use of organic waste), food security (improved soil health), environmental protection (sustainable waste disposal), and human health (cleaner environment).

In rural South Africa, farmers face challenges of sanitation where approximately three million ventilated improved pit latrines constructed by the government in response to the millennium development goals for universal sanitation in the last 15 years are currently filled-up. Most of the local authorities neither have a policy, plan, nor budget for faecal sludge management (FSM). The rugged terrains in most environments limit the possibility of the central sewer connections. The common practice in these communities is that households must build new facilities on their own, leading to the use of inferior makeshift pits, which do not meet the basic sanitation ascribed in the sustainable development goals (SDG). The SDG goal number 6 aim to ensure the universal availability and sustainable management of water and sanitation (UN, 2015). The rural households continue to step down the sanitation ladder, losing their dignity in the process, while being exposed to known health risks. The principles of restoration (restoring land to original use), restoring people's dignity, and restoring people's environmental rights for all are enshrined in Section 24 of the South African Constitution (The Constitution of the Republic of South Africa | South African Government, 2017).

The current practices result in persistent pollution of air, underground water sources and the environment in general. In instances where emptying is possible, there are considerable environmental impacts and space constraints associated with the dumping of waste in hazardous landfills. The farmers also face considerable soil nutrient depletion, and low fertilizers application rates, that fail to meet the soil nutrient depletion rates or crop requirements. As a result, farmers continue to face productivity loss, food insecurity and poverty. A circular bioeconomy approach could offer a solution to the sanitation problems, environmental pollution, and soil nutrient depletion, while creating new value and business. The literature shows that the poor understanding of end-product markets is the main reason for the failure of such recovery and reuse innovations. This study aimed to address three empirical knowledge gaps, identified mainly from the two scoping reviews.

The first gap identified was the absence of a rigorous ex ante demand assessment of the resource recovery and reuse initiatives. The second gap identified was a dearth of knowledge on how farmers in the rural areas relate to their environment. The third gap identified was the paucity of published empirical work on estimating the market demand for human excreta. Following the identified knowledge gaps, the overall goal of this study was to perform an ex ante demand assessment of human excreta reuse in agriculture using cross sectional data collected from 341 farmers in the rural areas of KwaZulu-Natal, South Africa. The data were elicited from the sampled farmers in Vulindlela Traditional Authority using a validated and reliable structured questionnaire. A cloud-based mobile software was used to reduce data collection costs, and encoding errors associated with the traditional paper-based data collection tools.

The first empirical objective adopted the social psychology theory of planned behavior and an attitudinal dimension conceptual framework to predict the behavioral intentions of rural farmers in South Africa. The predictors of the behavioral intentions were questions related to attitudes, subjective norms, and perceived behavioral control. The results show that there is high demand for human excreta in rural agricultural systems with about 77% of the rural farmer expressing willingness to recycle human excreta. The hierarchical regression results show the influence of awareness, religiosity, age, education, and income on the social acceptance. Negative perceived behavioral control indicate the influence of perceived health risks, and low self-evaluation on the capability to recycle human excreta in agriculture. The second empirical objective was to understand the segregated environmental attitudes of rural farmers and the implications for human excreta reuse in agriculture. The study adopted the new or revised 15-item ecological paradigm scale, which is a measure of the endorsement of a pro-ecological worldview. The Cronbach Alpha factoring (above 0.74) indicated high internal consistency and reliability of questions. The descriptive results also show that rural farmers are moderately environmentally conscious, and that cooking, and crop type influenced the intention to use human excreta. Proenvironmental farmers perceived low health risk and believed that they were more capable of using human excreta. Placing a central importance on environmental sustainability could be a powerful marketing strategy, especially given the increasing global concern on responsible production and consumption.

The third and last empirical objective was to assess the market feasibility for different attributes of human excreta-derived co-compost required to provide the product to farmers in its acceptable and marketable form and quality. The willingness to pay study adopted a choice experiment approach, which combines the random utility theory, consumer theory, experimental design theory, and econometric analysis. The co-compost attributes include pelletization, fortification, packaging (and labelling), and certification. The descriptive results show that farmers agree that the attributes presented before them were among the most important driving forces for purchasing co-compost. The results from the conditional logit model, random parameters mixed logit model, and the latent class model show that farmers are willing to pay for the different attributes of co-compost. The random parameters mixed logit model results showed a relatively high willingness to pay estimate of R1.70/kg of fortified co-compost, while the second preferred attribute was certification, with a willing to pay estimate of R1.40/kg for certified co-compost. Third in magnitude of preference was pelletization, where farmers showed willingness to pay an implicit price of R0.45/kg of pelletized co-compost. The latent class model results show that rural farmers were willing to pay estimates of R0.13 for packaged, R0.23 for pelletized, R1.50 for fortified, and R1.14 for a certified kilogram of co-compost. The findings indicate farmer preference for certified co-compost, which confirm the perceived health risk from the first two studies. Farmer preferences for fortified co-compost indicate that mineral fertilizers and organic fertilizers could be complementary, with the inorganic component offering immediate plant nutrients while the latter could restore organic carbon and soil health. Farmer willingness to pay for pelletized compost suggests the importance of introducing innovative product design on capturing value, while netting the benefits of reduced transport costs (low bulk density).

The study also sheds light on the importance of adopting the transdisciplinary innovation approaches in creating resilient and sustainable food systems using the circular bioeconomy approach. Policymakers could integrate the circular bioeconomy ideas, based on indigenous technical knowledge systems and circular bioeconomy concepts to add value to the development strategies and frameworks while shifting the existing paradigms. Policy shifts could include viability gap funding, which involve short-term public-private partnerships or cash flow financing to support revenue flows of sustainable circular bioeconomy innovations that may perform positively after accounting for externalities. Future studies could use the willingness to pay estimates to perform ex ante economic and environmental sustainability evaluations such as cost benefit analysis and life cycle assessment, while incorporating externalities associated with the bioeconomy initiatives. Using the evidence from this study to perform rigorous market feasibility studies could be another important future research direction.

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Lastly but not least, my colleagues, friends, and family members for their encouragement and support throughout the journey

DEDICATION

This work is dedicated to my late sister.

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CHAPTER 1: INTRODUCTION

This chapter provides a background to the problem under study, including the knowledge gaps identified from the review of literature and the motivation of the *ex ante* demand assessment of human excreta reuse in agriculture in rural South Africa. The objectives of the study and the structure of the thesis are also outlined.

1.1. Rationale for the research: nature and scope

The world is faced with the high food demand arising from rapidly growing population, whose largest proportion (especially in Africa and Asia) continues to come from migration to urban areas in search of a better life (Austin and van Vuuren, 2002). Rising incomes associated with economic growth causes nutrition transition or shift in the preferences of an affluent population towards more refined foods (Drewnowski and Popkin, 2009; Kimmel et al., 2019; Moomaw et al., 2012; Nnyepi et al., 2015; Walls et al., 2018). Rapid urbanization increases the burden on the already constrained public utilities, such as decent housing, clean water and sanitation, and waste management in urban areas (UNFPA, 2014). The result is the proliferation of informal settlements or urban slums that are characterised by underserved housing structures, water services, waste management systems, and sanitation facilities (Panchang and Vijay Panchang, 2019). Urbanization is one of the main causes of the mining of soil nutrient (Ball et al., 2018).

The mining of soil nutrients contained in foods creates nutrient sinks in urban environments, in terms of food waste and human excreta across the nutrient flows (Moomaw et al., 2012). The decline in soil fertility in sub-Saharan Africa is a threat to food security (Vanlauwe et al., 2014a, 2011). Annual nutrient mining rates in Africa ranges from 9-88 kg NPK/ha (Henao and Baanante, 2006; Jones et al., 2013a). The use of chemical fertilizers is often considered the only viable option to supply plant nutrients (Vanlauwe et al., 2014c). On the other hand, the average annual fertilizer application rates (at lowest 8kg/ha) in sub Saharan Africa are far below the nutrient depletion rates or the plant requirements for crop production (Mwangi, 1996). The use of chemical fertilizers also causes serious externalities (Han et al., 2015; Lin et al., 2019; Savci, 2012). The current agricultural intensification systems, based on the use of external inputs and the extract-use-dispose linear nutrient flows, and the use of external inputs, cannot meet the high food demand without putting pressure on the environment (Foley, 2005; Tilman et al., 2011).

South Africa's urban population is expected to rise above 71% by 2030 and up to 80% by 2050 (Mlambo, 2018). Rural communities currently face the challenge of emptying the full ventilated improved pit latrines previously constructed by the government in response to the millennium development goals (Harrison and Wilson, 2012). The responsible public utilities fail to meet the waste management and sanitation backlogs due to overstretched budgets and mismanagement of public funds (Ndaw, 2016). The rugged terrains in most rural areas and informal settlements limit the possibility of the central sewer connections (Roefs et al., 2017). The farmers with full pits often resort to inferior sanitation, such as makeshift toilets and open defecation, risking exposure to known health risks and loss of dignity (Lüthi et al., 2011). Where emptying is possible, there are considerable environmental impacts and space constraints associated with the dumping of waste in hazardous and normal landfills (Still et al., 2010). The farmers also face soil nutrient depletion, and low fertilizers application rates, trapping them in poverty and persistent food insecurity as noted in the previous section.

To address the challenges and meet the sustainable development goals (SDGs), for instance, to end hunger (SDG 2), and open defecation (SDG 6), requires shifting the existing paradigms to integrate the circular bioeconomy approaches. The sustainable development goals (SDG) 6, for instance, aim at providing adequate sanitation and ending open defecation in an equitable manner by 2030 (United Nations Development Program, 2015). The estimated annual capital costs for meeting SDG 6.2 stands at $19.5 billion for basic sanitation and $49 billion for safe faecal management (Hutton and Varughese, 2016). Creating an economy that minimises waste while creating multiple value propositions may provide a solution for resource scarcity while promoting sustainable economic growth (Ellen MacArthur Foundation, 2015). A circular bioeconomy may help to build resilient and sustainable food systems while protecting the soil, human and environmental health (Giampietro, 2019; Kardung et al., 2021; Leong et al., 2021; Stegmann et al., 2020).

The co-composting of faecal matter with organic waste is one way in which waste can be recovered and recycled for agricultural use to bring back mined nutrients and organic carbon required to restore soil health. Many studies so far demonstrate the benefits of co-compost application on soil health (Jien and Wang, 2013; Mohanty and Boehm, 2015; Paetsch et al., 2018; Wang et al., 2019; Yao et al., 2010; Zhong et al., 2020). Compost application could augment the agronomic efficiency of fertilizers (Sommer et al., 2014; Vanlauwe et al., 2014a, 2011). The co-composting value chain contributes to rural sanitation (emptying pits), waste management (use of organic waste), food security (improved soil health), environmental protection (sustainable waste disposal), and human health (reduced environmental pollution and improved sanitation).

Research in the recovery and reuse of human excreta has largely focused on the technological processes, and pathways for full recovery of agricultural nutrients, and the reduction of contaminants (Cofie and Adamtey, 2009; Egle et al., 2016, 2015; Etter et al., 2015; Harder et al., 2019; Senecal et al., 2018; Simha and Ganesapillai, 2017; Udert et al., 2016). The technical feasibility of promising innovations does not necessarily translate to their wide-scale commercialization. The failure of the recovery and reuse innovations to recover costs is mainly attributed to the poor understanding of the recovered product markets (Drechsel et al., 2018; Gebrezgabher et al., 2015; Mario et al., 2018; Otoo et al., 2018; Rao et al., 2016). For example, the failure of most composting technologies is mainly due to low product demand (Pandyaswargo and Premakumara, 2014; Rouse et al., 2008).

This study was based on three knowledge gaps identified mainly from the two peer-reviewed scoping reviews presented in chapter 2 and 3. Other minor contributions were methodological, or process improvements identified through snowballing of the knowledge stock and critical thinking. The first gap identified was the paucity of rigorous ex ante demand assessment of the resource recovery and reuse initiatives. The research discourse has mainly focused on the recovery pathways, and technology processes. The findings from the few published articles on social acceptance show both missing or inconclusive influence of demographic, cultural, sociological, and economic farmer characteristics on social acceptance. It was impossible to draw meaningful conclusions from the small sample of published work. There is also paucity of knowledge on the effect of treatment, culinary preparations, and crop type on behavioral intentions. The inconclusive results may indicate methodological variations, contextual disparities, as well as differences in conceptual and theoretical underpinnings. Understanding the influence of the farmer characteristics on behavioral intentions is important for the mainstreaming of dissemination strategies.

The second main gap identified was a dearth of knowledge on how rural farmers relate to their agricultural environment. The established link between anthropogenic activities and environmental problems fortifies the imperative need for understanding public perceptions or opinions towards the environment. The findings could help policymakers in formulating effective policies that promote proenvironmental behaviors with public support or to assume didactic roles in case environmental attitudes do not align with proenvironmental policies. The third gap was the paucity of published empirical work on estimating the market demand for human excreta. Understanding the preference of farmers to the various attributes of human excreta may provide important information for the evaluation of sustainable business models, especially evaluating whether providing the compost to farmers in its safe, socially acceptable, and marketable form could achieve cost recovery.

1.2.Aim and objectives

Following the identified knowledge gaps, the overall goal of this study was to perform an ex-ante demand assessment of human excreta reuse in agriculture. The specific empirical objectives include:

1.2.1. To predict ex ante, the influence of sociological, cultural, demographic and socioeconomic farmer characteristics on their behavioral intentions to use human excreta in food systems.

1.2.2. To understand the ecological worldviews of rural farming communities and implications for human excreta recycling in agriculture.

1.2.3. To assess the farmer preferences and willingness to pay for the different production, market, and quality attributes of co-compost.

1.3. Outline of the thesis

The thesis consists of seven chapters. Apart from Chapters 1 and 7, the remaining five chapters (Chapter 2 to 6) are structured as either published peer-reviewed papers or completed manuscripts pending the peer review process. Each of the manuscripts is prepared based on the standard structure for peer reviewed journal articles. References are provided at the end of each chapter for integrity and completeness. In the context of the UKZN DR9c thesis format, the manuscript or peer reviewed paper could not provide the detailed exploration of the survey data collection process and analysis. For this reason, the detailed survey description and analysis tables are provided as supplementary information in the **APPENDIX A**: SUPPLIMENTARY INFORMATION. All the tables, figures, supplementary information, and questionnaire information are cross-referenced in-text, for accessibility and completeness. The published chapters are slightly edited to maintain the completeness and integrity of the dissertation, but efforts were made to present them as much as possible in their published state unless where changes were deemed to improve the dissertation. The chapters are, therefore, arranged as follows:

Chapter 1 provides the background to the problem, the problem statement and the knowledge and the contributions of the study, and the main objectives of the study including this thesis structure.

Chapter 2 provides a scoping review of the current stock of peer reviewed literature on the attitudes and perceptions towards human excreta recycling in agriculture. (Gwara et al., 2021). The review helped to identify knowledge gaps for **Chapters 4** and **5**.

Chapter 3 synthesizes the current stock of knowledge on the preferences and willingness to pay for human excreta in agriculture (Gwara et al., 2020). This scoping review article provided the entry point for **Chapter 6**.

Chapter 4 provides the influence of sociological, cultural, demographic, and socioeconomic farmer characteristics on their behavioral intention to recycle human excreta, namely attitudes, subjective norms, and perceived behavioral control.

Chapter 5 unpacks how the rural farmers relate with their environment using the well validated and reliable new ecological paradigm approach.

Chapter 6 endeavors to assess the farmer preferences using choice modelling approach and random utility theory to apply econometric techniques and model willingness to pay for fortified, pelletized, packaged (and labelled), and certified co-compost.

Chapter 7 provides a synthesis of the study to include, synthesis of the study result, general conclusions, recommendations for policymaking, development practice and some insights for future research directions.

Appendix A contains all the supplementary information related to the survey. **Appendix B** contains the Humanities and Social Sciences Research Ethics Committee (HSSREC) ethics approval. **Appendix C** appends the electronic version of the questionnaire.

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CHAPTER 2: ATTITUDES AND PERCEPTIONS ON THE AGRICULTURAL USE OF HUMAN EXCRETA AND HUMAN EXCRETA DERIVED MATERIALS: A SCOPING REVIEW

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Abstract

This study explicates the scope of published literature on the influence of attitudes and perceptions on the intention to use human excreta and human excreta derived materials in agriculture. Using a scoping review methodology, search results from Scopus and Web of Science were screened and synthesized using DistillerSR web-based application. Out of the 1192 studies identified, 22 published articles met the inclusion criteria. Additional studies were identified by keyword enrichment, hand-searching, and snowballing in other electronic data bases. The benefit perception of the soil health, income, and yield was the main driver for positive attitudes. Perceived health risk and socio-cultural factors were reported as the main barriers to the use of human excreta derived materials in agriculture. Limited information, availability, collection, transport, and storage were the other reported perceived barriers. The influence of socioeconomic and demographic factors on farmers' attitudes and perceptions was inconclusive and potentially attributed to contextual and methodological differences. Social and behavior change communication through community mass campaigns and targeting interventions segregated by socioeconomic and demographic contexts is recommended for development interventions. Future empirical studies could focus on the influence of crop types, treatment processes, food preparation and processing on attitudes and perceptions.

Keywords: *recovery and reuse; human excreta; attitude and perception; risk perception; benefit perception; health risk; circular economy*

2.1. Introduction

A circular approach to agriculture through the recovery and reuse of waste materials is important for sustainable agricultural development. Rapid population growth, urbanization, and nutrient mining coupled with the need to feed the rising global population have placed the recovery of mineral elements from human excreta and human excreta derived materials (HEDM) and their use in agriculture high on the global agenda (Harder et al., 2019). The global population dynamic reached an important landmark in 2007 when the proportion of urban population reached 50%, with an estimated increase of up to 60% by 2030 (UNFPA, 2014). The United Nations Settlement Program estimated that this urban population figure would double by 2050 (United Nations, 2017). The urbanization trend is most rapid in developing countries causing informal settlements to fill up the rural-urban continuum where basic amenities, such as clean water and sanitation services, are non-existent and expensive to deliver (Kobel and Del Mistro, 2015). The impacts of urbanization on sanitation also places a huge burden on public utilities whose budgets are overstretched and inadequate to maintain and provide basic sanitation systems in urban areas (McGinnis et al., 2017). Informal settlements and peri-urban areas often resort to unplanned waste management and disposal practices, such as open defecation (Panchang and Vijay Panchang, 2019), causing environmental challenges and various sanitation-related risks (Winter et al., 2019). Even in built environments, where sanitation is functional, the nature of sanitation is often not hygienically safe (Jenkins et al., 2015).

Urbanization is one of the main causes of nutrient mining (Ball et al., 2018), making it difficult to achieve sustainable global agricultural food production (Jones et al., 2013b). Rapid urbanization and rising incomes in cities increase demand and consumption of highly processed nutrient-dense diets; a phenomenon referred to as 'nutrition transition' in the nutrition parlance (Moomaw et al., 2012). The nutrition transition intensifies the mining of nutrients from rural and peri-urban agricultural lands to urban centers where plant nutrients transported and consumed as food, are mined, excreted, and flushed down the end-of-pipe centralized sewer systems. The mining of nutrients disturbs the natural ecological cycle and nutrient balances. Approximately 60% to 70% of the soil nutrients mined from the farms are excreted in the environment as waste (Jönsson and Vinnerås, 2004). Returning the nutrients to the soil would restore the ecological balance and soil health (Kudeyarova and Bashkin, 1984). Wolgast (Wolgast, 1992) estimated annual per capita nutrient production to be equivalent to 7.5 kg of NPK and micronutrients from about 520 kg of human excreta which could organically produce

250 kg of grain, enough to feed one adult person per year (Agyekum et al., 2014; Khalid, 2018; Malkki, 1997). Nutrient mining may also result in long-term productivity failure and serious health consequences related to micronutrient deficiency in developing countries (Jones et al., 2013b). The stripping of mineral elements from the soil poses a serious threat to food production, especially in the face of climate change, where soil nutrient loss leads to reduced water productivity (Moomaw et al., 2012).

Conventional high input-high output agricultural intensification, on the other hand, leads to the extraction of soil nutrients, soil degradation, and environmental pollution, through the use of chemical fertilizers (Sasmal and Weikard, 2013). Soils with low organic matter also have a high capacity to fix phosphorus through absorption and precipitation, which reduces the efficiency of chemical fertilizers (Asomaning, 2020). Empirical evidence shows that between 5% and 30% of the assimilable quantity of the total P applied using chemical fertilizers can be used by plants (Andreoli et al., 2007). The global reserves for rock phosphate are also approaching their maximum production rate (peak phosphorus), making phosphorus recovery critical. In Europe, phosphate is one of the critical raw materials (Hudcová et al., 2019), which is exacerbated by its availability in geopolitically sensitive areas (Berta Moya et al., 2019). The use of human excreta in agriculture can supplement, complement, or substitute chemical fertilizers while replenishing soil health. Long-term trials with sewage sludge show high bioavailability of P-supplying chemical fertilizers to plants (Glæsner et al., 2019; Lemming et al., 2019). In contrast, biosolids are slow-release fertilizers that ensure a steady supply of P over a long time (Andreoli et al., 2007) with an additional positive effect of reducing greenhouse gas emissions when compared to inorganic fertilizers (Rahman et al., 2019).

Conventional agricultural intensification also leads to soil erosion and degradation (van den Born et al., 2000), salinization, depletion of soil nutrients, and groundwater pollution (Sasmal and Weikard, 2013). Empirical findings from long-term trials of over 13 years in India show average paddy yield decline of about 18% associated with increase in chemical fertilizer application of about 37% over the same period (Sasmal, 1992). Good agricultural practices (such as conservation farming and application of organic matter) can help restore soil health (Sasmal and Weikard, 2013). Developing countries, especially in the sub-Saharan Africa continue to face degraded soils and very low fertilizer use (Druilhe and Barreiro-Hurlé, 2012). (Sheahan and Barrett, 2017) in their six-country study show average fertilizer application rates of 26 kg per hectare justifying the need for alternative sources of fertilizers. Sustainable Development Goal (SDG) number 6 emphasizes clean water and sanitation, Goal 12 focuses on responsible production and consumption in a way that minimizes waste (UN, 2015). Recovery of agricultural nutrients from human excreta could, therefore, help to achieve the SDGs and ensure sustainability. Achieving these goals requires a paradigm shift in the way human waste is processed, perceived, managed, and used. Multidisciplinary approaches, such as ecological sanitation, may offer a new way of redefining human excreta as wealth rather than waste (Simha and Ganesapillai, 2017). Such approaches may usher in a new way of sanitation provision and waste management to communities that would otherwise not receive centralized sanitation due to unsuitable terrains and overstretched municipal budgets (Roefs et al., 2017).

The history of the recovery and reuse of human excreta dates back to the early 9th century (Ebrey et al., 2006). In Asia and South America, human excreta was ferried from populated urban areas to farmers until the second half of the 19th century (King, 1972). The transportation of human excreta to farms led to a huge improvement in sanitation and agricultural production in populated towns (Brown, 2003). Bracken et al., (2007a) suggested several reasons for the neglect of the approach. These include perceptions of health risk (miasma theory), rapid urbanization, bulkiness in transporting, shift towards centralized sewage, and the advent of artificial fertilizers (Bracken et al., 2007b). Drangert (1998) used the phrase 'urine blindness' to describe the negative attitudes towards human urine as an agricultural fertilizer. Esrey et al., (1998) devised the term 'fecophobia' to describe the socio-cultural fear of the feces among the Muslim community. The concept of fecophobia is related to the concept of dirt as 'matter out of place' (Douglas, 1966). Perception, therefore, matters as what can be considered a valuable resource by one community may be considered waste by another. It also matters because one's action is driven by perception.

The review of technologies used to recover HEDM is available in the literature in terms of the recovery pathways and processes (Egle et al., 2016, 2015; Harder et al., 2019) and regulations (Hukari et al., 2016; Berta Moya et al., 2019). We provide a brief discussion of the findings of these and other studies in the discussion section. The general conclusion from these studies demonstrates the gap and the importance of understanding perceptions and social acceptance of HEDM as a potential barrier for wide-scale commercialization (Harder et al., 2019; Wielemaker et al., 2018). Cost-benefit analysis can be useful in evaluating the economic, environmental, and health implications of recycling waste back to wealth using various recovery pathways (Radin et al., 2019). The market demand analysis of the attributes of the end products using the discrete choice experiment can provide information for the commercialization of HEDM (Agyekum et al., 2014; Danso et al., 2017). The research in understanding the ‘demand segment’ of the recovery and reuse of HEDM in agriculture, however, remains an understudied and nascent area to this day (Danso et al., 2002a; Gwara et al., 2020).

Against this backdrop, this scoping review is the first attempt to synthesize published research on attitudes and perceptions towards the use of human excreta and HEDM in agriculture. In doing so, this review does not only enrich the work by Roma et al., (2013a), who used the receptivity framework to discuss the use of urine as a fertilizer, but, it also updates the works of Ganesapillai et al., (2016) and Lienert and Larsen, (2010) who reviewed the acceptance of ‘urine separation’ and ‘ecological sanitation’ approaches towards HEDM recovery. This review complements existing research by extending the scope of their work to include past and current research evidence, while giving a specific focus on the attitudes and perceptions on the use of all human excreta and HEDM in agriculture. The phrase ‘human excreta and HEDM’ was deliberately used to include studies that investigate attitudes and perceptions on agricultural use of material derived from human excreta (Andreev, 2017). The ‘human excreta’ in this review is limited to urine and fecal matter that could be recovered and used for agricultural purposes. This review also included studies that investigated the use of urine and fecal matter directly without processing or treatment. The findings of this review may help to channel information required by decision makers in understanding the ‘demand segment’ or social acceptance of circular nutrient economy initiatives.

The World Health Organisation WHO, (2008) has developed a methodology for identifying knowledge gaps and contextual behavioral patterns to inform more targeted interventions. While human excreta may present potential benefits to agricultural productivity, governments in developing countries continue to spend foreign currency importing inorganic fertilizer. The adoption of chemical fertilizers (through agricultural intensification as discussed above) remains low due to poorly developed input, credit, and output markets. Consolidating anecdotal evidence from different studies to evaluate the state of knowledge on the ‘demand segment’ of the human excreta recovery pathway in agriculture could inform evidence-based decision making in program interventions and save foreign currency currently lost through chemical fertilizer imports and subsidies. While most empirical studies are contextual, conducted, and relevant in specific locations, this scoping review implements the preferred reporting system for meta-analysis and systematic reviews (PRISMA) methodology to consolidate and identify trends and patterns in the results. The importance of this study is not only limited to contributing evidence-based decision making, but also to informing future empirical studies by identifying methodological gaps. The next section provides the theoretical perspectives which were used in this study to scope the literature.

2.2. Some theoretical imperatives

The theoretical foundations of the importance of attitudes and perceptions in predicting human behavior are rooted in the fields of social cognitive science and social psychology. The theory of planned behavior is the commonly used theory to predict human behavior (Gorton and Barjolle, 2014). Ajzen, (1991) posited that in addition to attitudes towards behavior, subjective norms and perceived behavioral control or self-efficacy could accurately predict human behavior. Self-efficacy refers to how well one perceives he/she can execute the attitude object, technology or behavior under investigation, subject to skills, resources, opportunities, etc. (Matsumori et al., 2019). Bredahl et al., (1998) in their theory, posited that in modeling behavioral intention, it is essential to extend the TPB to include perceived difficulty which includes the ease of using a technology and level of competence required and is linked to self-efficacy. The theory has been expanded to include the perceived risks and benefits. In this study, risk perception is defined as the subjective judgments of individuals about the probability of occurrence of negative outcomes from adopting a technology. The perceived risks can negatively influence attitudes, whereas perceived benefits have a positive impact on attitudes, that is, benefit perception is cognitively compensated by the perceived risk (Bredahl et al., 1998). Farmers will be willing to try the use of HEDM if the perceived benefits of increase in productivity can cognitively compensate the perceived risks associated with the technology.

Research in social psychology has also evolved from the dominant social paradigm to incorporate environmental concern that would help explain human-environment interactions using the New Ecological Paradigm (NEP) scale. The NEP has been incorporated into the social-psychological theories of attitude-behavior interactions (Stern et al., 1995). The dominant social paradigm which preceded the NEP posits that resources are unlimited, and humans are superior to all other species (Dunlap et al., 2000). The NEP challenged these principles by incorporating a measure of the nature of society-environment interactions and the reality of limits to growth while integrating environmental attitudes, values, beliefs, and worldviews (Dunlap et al., 2000). Various modifications have been made to the NEP to capture validity, psychometric soundness, and cultural differences (Hernes and Metzger, 2017; Ogunbode, 2013; Simha et al., 2018a). This review is, therefore, guided by these theoretical underpinnings to understand the role of attitudes and perceptions on social acceptance of using HEDM in agriculture.

2.3. Review Methodology

This study employed a rigorous, iterative and comprehensive literature review methodology for conducting a scoping review as posited by Arksey and O'Malley, (2007) and as applied, for instance, by Lam et al.,(2015a) and Corrin and Papadopoulos, (2017). The methodology allows for transparency and reproducibility; it does not restrict search criteria or terms but instead offers a flexible, iterative, and reflexive search criterion to allow for a comprehensive review process (Arksey and O'Malley, 2007; Colquhoun et al., 2014; Levac et al., 2010; Pham et al., 2014). A scoping review uses a structured methodology to answer research questions, identify research gaps and support evidence-based policy making by characterizing, screening, and summarising research evidence (Peters et al., 2015). The scoping review methodology used in this study is transparent, reproducible, and eliminates the typical risk of cherry-picking research articles often associated with other review methods (Rudnicka and Owen, 2012; White and Waddington, 2012). In doing so, it identifies gaps in the literature to inform future research (Arksey and O'Malley, 2007).

The objective of the scoping review methodology is to provide a preliminary assessment of the size and scope of the body of knowledge available on the subject matter (Grant and Booth, 2009). The outcomes of this study will, therefore, provides an imperative starting point for future empirical research and best practices for on-the-ground development initiatives in the recovery and reuse of human excreta and HEDM for agricultural use (Munn et al., 2018). It is crucial at this point to draw a clear distinction between the scoping review methodology and other types of reviews. Different review types may focus on current matters (state of the art) on the subject or may aim to develop conceptual models without any degree of structural analysis (Grant and Booth, 2009). Scoping reviews only aim to map and investigate the nature and extent of emerging research evidence by quantifying and characterizing literature through the use of study designs, among other essential study features (Levac et al., 2010; Munn et al., 2018; Peters et al., 2015). Scoping reviews provide only a general overview of the available research evidence without providing a synthesized answer to a specific research question (Sucharew, 2019). Below we discuss the five stages used in undertaking this scoping review.

2.3.1. Research questions

Scoping reviews share several characteristics with systematic reviews (Grant and Booth, 2009). In specifying the research question or objective, Moher et al. (Moher et al., 2015) suggested that one has to address the research objective with reference to participants, interventions, comparisons, study designs, and outcomes. In this study we adopted the method as follows;

participants (users of human excreta and HEDM in agriculture), interventions (human excreta reuse in agriculture), comparators (conventional chemical fertilizers or other organic manure), study design (quantitative, qualitative and mixed methods) and outcomes (perceptions and attitudes towards human excreta and HEDM). Other studies apply the setting, perspective, intervention, comparison, evaluation (SPICE) and the sample, phenomenon of interest, design, evaluation, research type (SPIDER) methodologies. Given these options, the method by Moher et al. (Moher et al., 2015)is the most commonly used in the survey literature (Eriksen and Frandsen, 2018; Methley et al., 2014). The decision to focus on attitudes and perceptions of the end-users of human excreta was arrived at after considering the importance of resource recovery and reuse and its link to sanitation provision in most underserviced communities, where dry sanitation is the only form of sanitation. Major research questions addressed in this study included what are the major analytical tools employed by the previous studies on willingness to pay? What were the main attributes for increasing market appeal of compost? What were the major outcomes of the previous studies?

2.3.2. Identification of relevant studies, data sources, and search strategy

The authors performed an initial search of pertinent literature using electronic databases with Title-Abstract-Keyword search in Scopus and Topic search in all the bibliometric databases in Web of Science, namely, WoS Core Collection, KCI Korean Journal Database, MEDLINE, Russian Science Citation Index, and SciELO Citation Index. The two databases were preferred because Web of Science is the oldest tool for citations analysis until the year 2004 when Scopus and Google Scholar were created with the later having data quality issues (Mongeon and Paul-Hus, 2016). The errors and limitations of Google Scholar are a result of its automated document indexing (Martín-Martín et al., 2018). This review restricted the Scopus and WoS searches to peer-reviewed English language articles published between 1945 and 15 February 2019. The following restriction on the time of publication enables this review to focus on all studies conducted on attitudes and perceptions towards recovery and the use of human excreta and HEDM in agriculture.

The restriction on published research articles in peer reviewed journals and exclusion of books, grey literature, dissertations and conference contributions allowed for methodological and quality assessment of the research evidence (Adams et al., 2017). While grey literature may cover niche topics usually not covered by traditional literature, including it in this study would bring in incompleteness, inaccuracies and self-publication bias as they often do not go through stringent peer-review publication processes (Benzies et al., 2006). Grey literature may not be indexed by traditional bibliometric databases which may limit efficiency and reproducibility of scoping reviews.

Exhaustive and comprehensive keywords, synonyms and Boolean operators were used in the search criterion to perform the search (**Table** 2.1). This was conducted in an iterative manner to ensure that all the articles on the subject matter are extracted from the bibliometric databases. This study borrowed some keywords from related reviews, such as Lam et al., (2015a) and Corrin and Papadopoulos, (2017). The snowballing technique was also applied to ensure that the key words identified by the researcher from the retrieved articles were used to enrich the search strategy and make it more comprehensive. This is the iterative and important part of the search where the search syntax will continue to be modified, taking cognizant of the Boolean operators. The authors used additional references suggested by some reviewers and hand-searched other articles through backward snowballing from the reference lists of related reviews and included articles (Badampudi et al., 2015; Sucharew, 2019; Wohlin, 2014). The snowballing technique was also applied to hand-search relevant articles in other electronic databases including Google Scholar, factoring the variability of databases in indexing, abstracting and breadth of information (Arksey and O'Malley, 2007; Gwara et al., 2020).

The results retained from each search of the electronic databases are exported to EndNote software or other referencing software for cleaning and preparation for importation. In EndNote, the duplicate removal can be performed, followed by saving the references in an EndNote 'Compressed Library' format (.enlx). The data can then be exported into a web-based informetric software application.

Table 2.1 Search query

Database	Search Strategy	Search Results
Scopus	TITLE-ABS-KEY ("human waste" OR "faecal sludge" OR "human manure" OR "solid waste" OR "humanure" OR faec* OR fec* OR "human excreta and human excreta derived material") AND (attitude* OR perception* OR "health risk*" OR "Perceived benefit*" OR "Perceived risk*") AND (agriculture* OR farm* OR crop*)	795 document results
Web Science	TOPIC: ("human waste" OR "faecal sludge" OR "human manure" OR "solid waste" OR "humanure" OR faec* OR offec* OR "human excreta") AND (attitude* OR perception* OR "health risk*" OR "Perceived benefit*" OR "Perceived risk*") AND (agriculture* OR farm* OR crop*)	690 document results

The Boolean operator * refers to the shortest possible keyword retrieved by the search syntax
Source: Author's insights from the literature

2.3.3. Study selection

The DistillerSR Evidence Partners Incorporated, a web-based informetrics software application, was used to sort references including removal of duplicates. Other available software includes the Cochrane's Covidence (Moffa et al., 2019). DistillerSR software allows for screening and extraction of articles based on the title, abstract, full text, and study characteristics, such as study design, sample size, research methods, and outcomes. The DistillerSR user interface includes the review, reports, reference, workflow, users, and project tabs. It is in the projects and in 'File Manager' where you import the enlx format reference file from EndNote. The projects tab in DistillerSR allows the reviewer to import the references into a project. Just as a double check, the duplicate detection function was used to further recheck and quarantine duplicate references. The function gives options of extreme precision option. The review tab allows for title screening, abstract and full text screening of each article retrieved using the search criterion described above. The review tab contains the data extraction which is linked to the study characteristics as defined in the workflow. In the workflow, the built-in forms can be edited to suit the researcher's data extraction method.

For this study, the title screening form, abstract screen form and the study characteristics forms were used. The title and the abstract screening forms only used one question (Is this reference potentially relevant to our study?) with Yes/No/Can't tell, as the potential responses to use for screening purposes as described below. The data extraction form was edited to include study characteristics to include radio- and check box-type questions such as study design, type of HEDM, study population, if the study investigated crop type-processing-cooking, validity checks, sample size, and the data analysis methods, with the responses being defined by the reviewer as explained in relevant sections below.

2.3.4. Relevance screening and eligibility criteria

The study employed a multi-stage screening process based on the title, abstract, and full text of selected articles. Initial screening was performed based on the relevance of the titles of the articles. The second screening used the abstract to further screen the articles included for relevance. The selected relevant articles were then screened based on the full article review, where articles were further screened in or out based on the inclusion criteria (**Table** 2.2). The strength of DistillerSR is that it gives the opportunity to have more than one reviewer in the project to co-screen and there is a clever algorithm that deals with conflict between researchers. Each included article goes through the data extraction process, mining each information required to complete the data extraction form. After completing this rigorous extraction process, the results of the survey-type questions are ready for downloading and reporting. The results can be downloaded from the statistics-extraction-study characteristics in the reports tab and presented in a user-friendly scheme in MS Excel or MS Word format.

Table 2.2. Inclusion and exclusion criteria during article screening

Article inclusion Criteria
✓ The study investigated and reported the attitudes and perceptions of human excreta and/or HEDM for use in agriculture
✓ The study examined the factors affecting attitudes and perception of human excreta and HEDM use in agriculture
✓ The study was published in English
✓ The study was published in a peer-reviewed journal
✓ The study contains original results
✓ The study contains sufficient information to assess the validity of empirical methodology

Source: Author's insights from the literature

2.3.5. Charting the data/data extraction

Arksey and O'Malley (Arksey and O'Malley, 2007) opine that simply producing a summary of each included study may make it difficult for readers to make decisions based on the short profile of each study. This review applied a descriptive-analytical method by extracting data based on a common analytical approach within the framework of the traditional narrative review. The framework includes the name of author, publication year, location, study design, type of HEDM assessed, factors influencing attitudes and perceptions, and key results on perceptions and attitudes towards HEDM. While a standard scoping study does not allow for quality assurance (Arksey and O'Malley, 2007), this study synthesized and triangulated the study designs, research methods, and findings of the articles reviewed. Thus, the fact that researchers may arrive at different conclusions due to different study designs, methods of data analysis, and context can be mitigated using this reporting framework.

2.3.6. Synthesizing and reporting

This last stage of the scoping review framework helps to collate, summarise and report the results to identify key research findings and knowledge gaps while allowing the reader to understand the potential bias used in coming up with the recommendations (Arksey and O'Malley, 2007). Grouping results by geographic location, type of intervention, sample size, participants, research methods, and major outcomes helps to identify contrasting and similar findings while offering a consistent approach in reporting the results of the review. The review discussed the results based on the outcomes of the study to include the scope and maturity level of technologies used to recover human excreta derived material, the global and regional legal context and case studies on factors impacting wide scale commercialization.

2.4. Results

2.4.1. Search results, article screening, and inclusion

Following the search criterion, a total of 795 articles were identified in Scopus and about 690 articles in Web of Science to make a total of 1485 publications. Duplication removal function in EndNote was used to remove a total of 223 duplications before exporting a total of 1262 articles to the DistillerSR web-based application. The duplicate detection function in DistillerSR quarantined an additional 70 duplicates. Finally, we used the title and abstract screening on 1192 unique articles, which excluded 1147 as irrelevant and failing to meet the title inclusion criteria. A total of 45 articles were then eligible for abstract and full-text screening. Additional 25 articles did not meet the full text eligibility or inclusion criteria (**Table** 2.2 and **Figure** 2.1). A total of 20 articles met the full text inclusion criteria and an additional two articles were included from hand-searching using the snowballing technique.

2.4.2. Characteristics of articles included

All studies identified, except for one, were conducted in developing countries (**Figure** 2.2). This result may indicate the increasing need for developing countries to manage waste and provide basic sanitation strategies to meet the sustainable development goals by 2030 (UN, 2015). The results also show an upward trend in the number of publications over the years from 2000 to 2018, which implies that understanding attitudes and perceptions on the use of HEDM in agriculture is indeed gaining impetus as a research agenda (**Figure** 2.3). There was at least one peer-reviewed publication per year on the attitudes and perceptions of end-users of HEDM in agriculture from the year 2013 to 2018. The growing trend may also indicate the increase in the importance of circular nutrient economy initiatives in research and development practice.

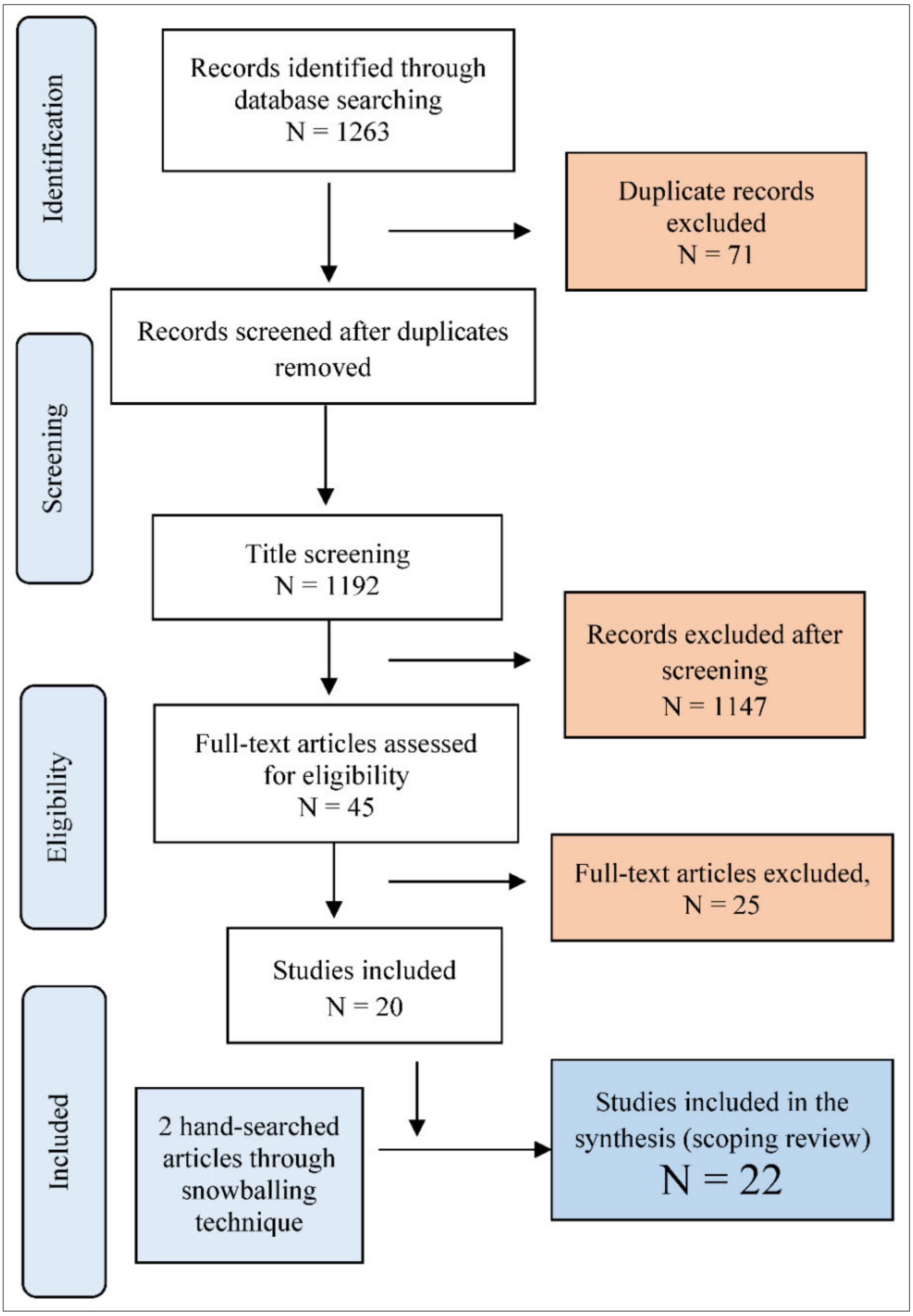

Figure 2.1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow chart diagram.

Source: Author's synthesis of the literature

Analysis of results based on the type of HEDM reported in the study showed that 13 articles did not specify the HEDM type nor technology process used to recover the HEDM (**Figure** 2.4). The second most common type of human excreta was human urine (*n* = 5), followed by wastewater (*n* = 3), composted feces (*n* = 2) and lastly feces (*n* = 1). Some studies reported more than one type of human excreta, for instance, urine and human feces, without describing the recovery process of the end-product. None of the included studies evaluate the impact of the different treatment alternatives on the attitudes and perceptions of farmers. Although the perceptions (of farmers and consumers) could be expected to vary for the different types of HEDM treatment, proving or disproving this, remains an important area for further research in the future as explained in the discussion of results.

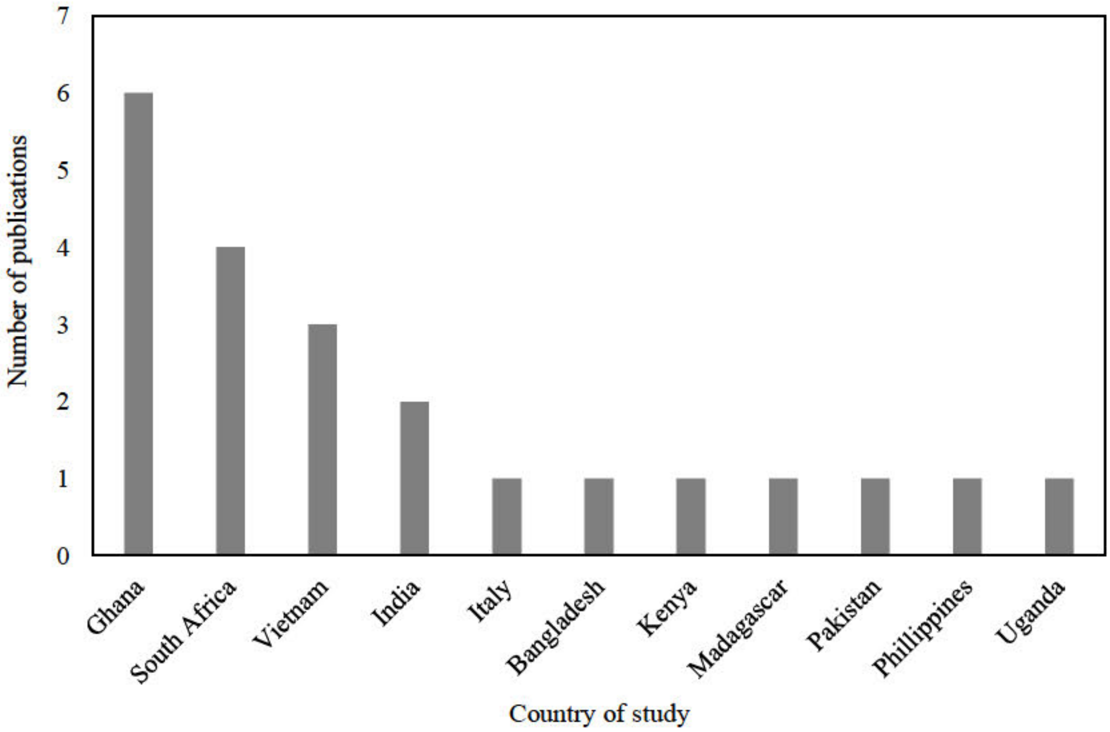

Figure 2.2. Number of publications by country of study

Source: Author's synthesis of the literature

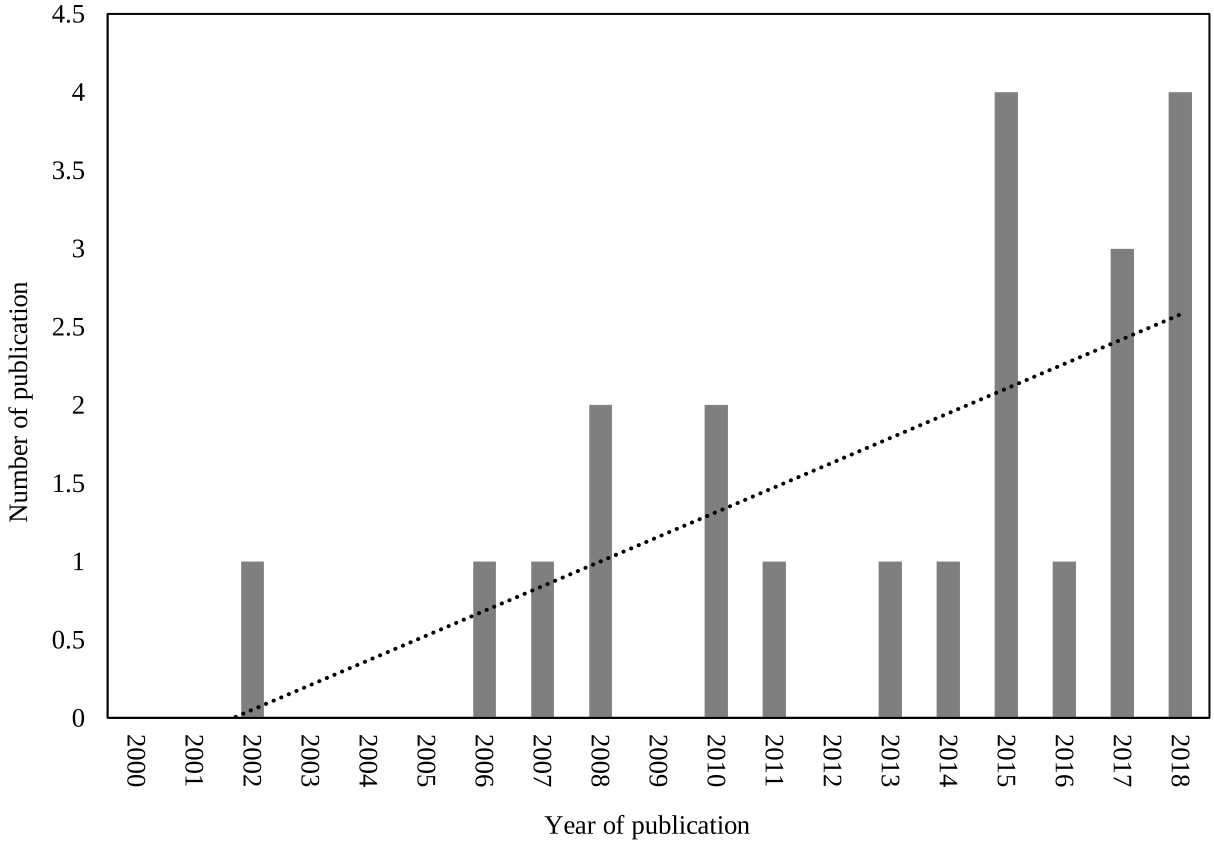

Figure 2.3. Number of publications by year

Source: Author's synthesis of the literature

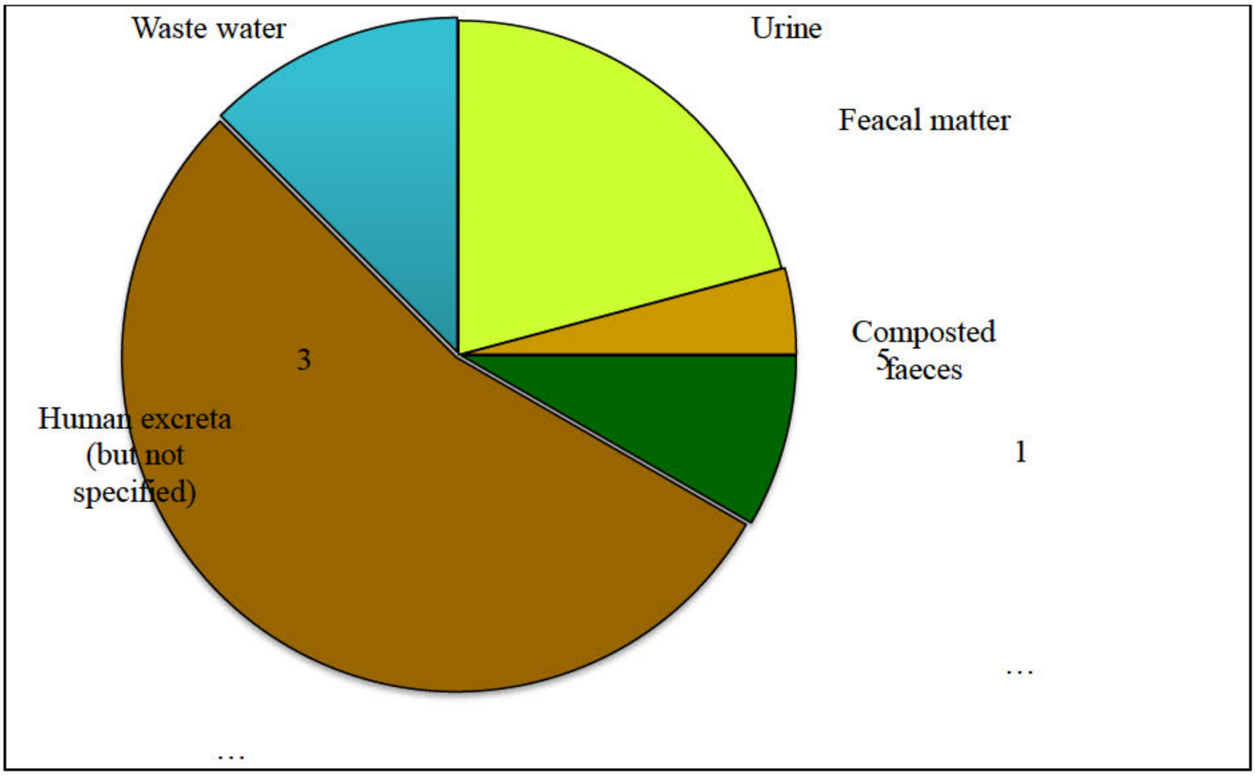

Figure 2.4. Number of publications by type of human excreta and HEDM reported

Source: Author's synthesis of the literature

The included studies were also analyzed to understand the nature of the study participants. The results show that a total of twelve studies reported the study participants to be farmers. However, some of these studies specified these farmers or included other types of participant consumers (**Figure** 2.5). The second most common type of participants included rural farming community, while seven studies defined the study participants as peri-urban farmers. Only two studies specified university students as participants, while two articles investigated the attitudes and perceptions of consumers. The nature of the study participants may help to accurately target interventions based on the contextual results.

It is also important to note that most included studies (n = 16) investigated the attitudes and perceptions of farmers on human excreta and HEDM use for different crop types (**Table** 2.3). Other included articles distinguished between comestible and inedible crops (n = 5), cooked and uncooked (n = 1), while a total of five articles did not separate or specify the attributes of the crop fertilized or investigated. Attitudes and perceptions may vary depending on whether the crop is consumed, as this has implications on the contamination pathway and pathogen load in terms of microbial risk assessment. Ten out of 22 included studies did not indicate the influence of crop type or purpose on attitudes and perceptions of farmers. The remaining 12 articles found that the reluctance of farmers to use human excreta and HEDM to grow comestible crops was due to perceived health risks (Andersson, 2015; Ignacio et al., 2018; Mariwah and Drangert, 2011; Mugivhisa and Olowoyo, 2015; Nimoh et al., 2014; Simha et al., 2018a). Three studies found the reason for poor acceptance of the use of HEDM on edible crops to result from perceived rejections by consumers when marketing (Buit and Jansen, 2016; Mariwah and Drangert, 2011; Mojid et al., 2010). One study found potential direct exposure to HEDM for leafy vegetables to be another reason for poor acceptance of HEDM use on edible crops (Khalid, 2018).

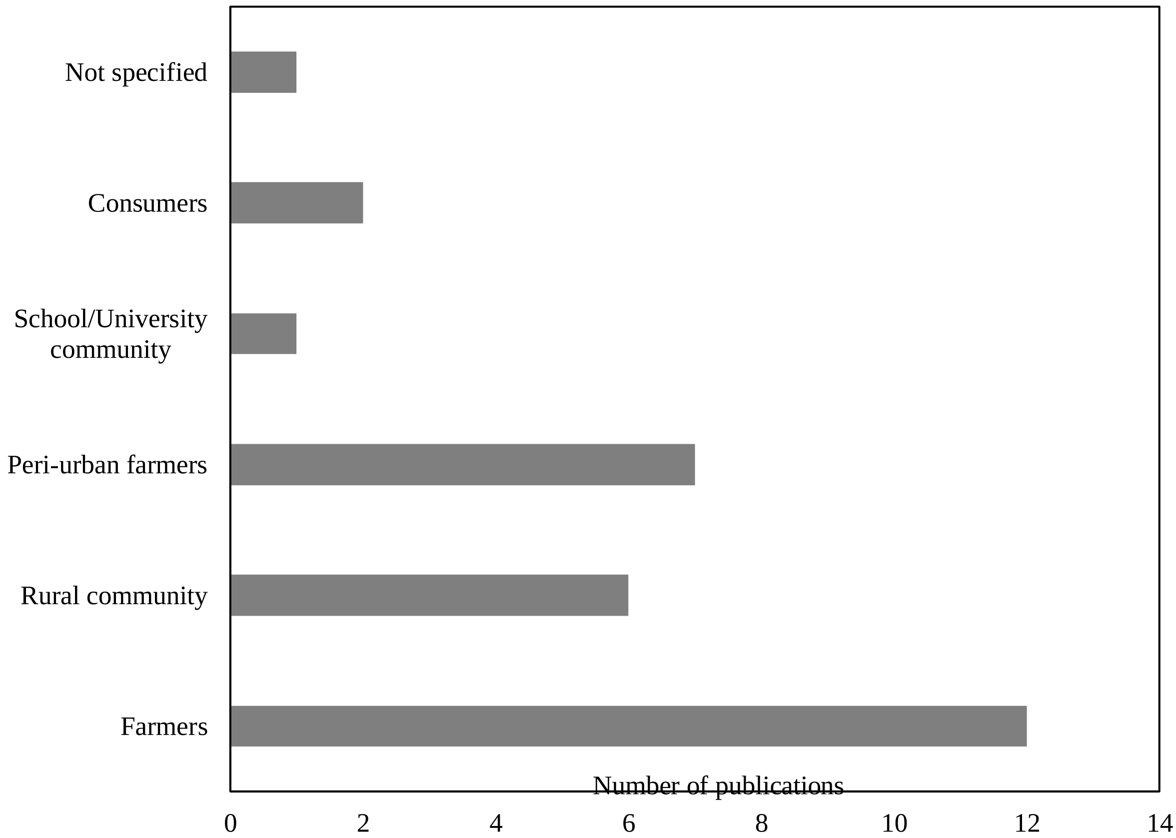

Figure 2.5. Number of publications by type of study participants

Source: Author's synthesis of the literature

In terms of study design, the review grouped the included articles into those that used cross-sectional data, focus group discussions, key informant interviews, and mixed methods (**Table** 2.4**).** Mixed methods in this review included a mix of focus group discussions, cross-sectional data, and key informant interviews. The results show that 11 out of 22 articles used cross-sectional data and some personal interviews, while eight studies used mixed methods, and only one study used focus group and key informant interviews. This study also analyzed the sample sizes reported as well as the methods used to analyze the data. The results show that the sample sizes were spanning from a minimum sample size of 60 and a maximum sample size of 480 participants for the cross-sectional studies, making a mean sample size of 214 participants. The studies that used mixed methods had a sample size spanning from a minimum of 35 to a maximum of 700, giving a mean sample size of 245 participants. Only one of the included studies did not specify the number of participants. None of the studies reported the sample size calculation method and the rationale behind using the adopted sample sizes.

The study also grouped the data analysis methods into descriptive statistics, inferential statistics, and econometric modeling. Descriptive statistics was defined in this study to include narrative reporting of qualitative data and measures of central tendency and position, such as means, the median, and graphical representation for quantitative data. Inferential statistical methods include analytical methods such as exploratory factor analysis, Chi-square or Fisher's exact tests, t-tests and analysis of variance, and other non-parametric statistics. Econometric modeling was defined to include confirmatory factor analysis, structural equation modeling, and regression analysis (Zheng and Pavlou, 2010). The results show that most studies used descriptive statistics (n = 21), followed by inferential statistics (n = 8) and econometric modeling (n = 3).

Table 2.3. Influence of crop type and purpose on attitudes and perceptions.

Author (Year)	Whether the Study Investigated (and If So) the Effect of Crop Type on the Attitudes and Perceptions towards HEDM
(Khalid, 2018)	• Participants used HEDM on cereal and did not wish to use it on leafy vegetables because they perceived different exposure pathways because of the edible parts of the later to HEDM
(B Moya et al., 2019)	• The study did not investigate whether there will be a change in attitudes and perception because of the difference in crop types
(Mugivhisa et al., 2017)	• Same as Moya et al. (Berta Moya et al., 2019)
(Buit and Jansen, 2016)	• 25% of the farmers find HEDM acceptable for food crops compared to non-food crops • 20% considered the use of HEDM to be less suitable for food crops because of the feeling of disgust • 50% viewed acceptance to be influenced by other factors than crop type such as consumer reluctance to buy the crops fertilized with HEDM
(Mugivhisa and Olowoyo, 2015)	• 83% would not eat spinach grown from human urine • 81% would not eat maize grown from urine • The reluctance to eat crops fertilized with HEDM was due to the perceived health risk
(Appiah-Effah et al., 2015)	• Same as Moya et al. (Berta Moya et al., 2019)
(Lagerkvist et al., 2015)	• Same as Moya et al. (Berta Moya et al., 2019)
(Okem et al., 2013)	• Same as Moya et al. (Berta Moya et al., 2019)
(Mariwah and Drangert, 2011)	• 36% would not use HEDM on their crops even if the HEDM were treated • 54% would never use HEDM on their crops • 42% agree that crops fertilized with HEDM are suitable for consumption • 28% would eat such crops • Health risk and unpleasant smell as well as poor acceptance of HEDM fertilized crops
(Cofie et al., 2010)	• Same as Moya et al. (Berta Moya et al., 2019)
(Mojid et al., 2010)	• Some farmers preferred to fertilize leafy vegetables with HEDM as it provided good vegetative growth for leaves • Others preferred to use on rice only because their land was only suitable for rice • Perceived health risks and marketability of vegetables prevented farmers from wanting to use HEDM on leafy vegetables
(Duncker et al., 2007)	• Same as Moya et al. (Berta Moya et al., 2019)
(Jensen et al., 2008)	• Only the main crop rice had HEDM applied to the field because of the limited availability
(Knudsen et al., 2008)	• Same as Moya et al. (Berta Moya et al., 2019)
(Phuc et al., 2006)	• Same as Moya et al. (Berta Moya et al., 2019)
(Danso et al., 2002a)	• Same as Moya et al. (Berta Moya et al., 2019)
(Ignacio et al., 2018)	• 56% and 76% thought urine and fecal matter respectively can be sanitized into fertilizer

	• 83% and 78% thought urine and fecal matter should not be used for edible crops and would never buy or eat crop produced using HEDM
	• The change in perception was due to perceived health risk
(Simha et al., 2017)	• Participants thought HEDM should not be used for comestible crops
	• Perceived change in taste of food crops
(Andersson, 2015)	• Some farmers perceived great taste on edible crops
	• The change in perception was due to perceived health risk for crops eaten raw and unpeeled, especially the HIV virus.
(Nimoh et al., 2014)	• 63% of participants would use human excreta on their crops
	• 58% thought crops fertilized with HEDM can be eaten
	• 12% would never eat crops grown with HEDM
	• Perceived health risks were the main reason for influencing negative attitudes
(Simha et al., 2018a)	• 55% thought of urine as fertilizer
	• 44% would eat crops grown from urine fertilizer
	• The change in perception was due to perceived health risk

Source: Author’s synthesis of the literature

2.4.3. General perceptions and attitudes

Most of the findings demonstrated positive attitudes and perceptions towards the use of human excreta and HEDM in agriculture. Most farmers expressed willingness to use human excreta and HEDM for different reasons. Two of the studies reported that artificial fertilizers are more expensive than human excreta (Khalid, 2018; Mojid et al., 2010), suggesting a perceived economic benefit in using human excreta. Other perceived benefits were reported in six out of the 22 studies which reported that soil health improvement was the common driver of positive attitude towards the use of human excreta and HEDM in agriculture (Duncker and Matsebe, 2008; Ignacio et al., 2018; Jensen et al., 2008; Mojid et al., 2010; Saliba et al., 2018; Simha et al., 2017). In six out of the 22 studies, farmers were more willing to use human excreta in agricultural production if treated or sanitized as the use of fresh excreta was associated with bad smell, visual repulsiveness and various kinds of potential diseases (Buit and Jansen, 2016; Cofie et al., 2010; Khalid, 2018; Mariwah and Drangert, 2011; Mojid et al., 2010; B Moya et al., 2019). This type of negative risk perception could be mitigated using different treatment technologies, pelletizing, packaging and certification to make the products safe and visually appealing. One paper demonstrated that farmers were particularly keen to visually inspect the unprocessed human excreta before use (B Moya et al., 2019), reinforcing the importance of product attributes on willingness to accept.

Perceived benefits were associated with the soil nutritive value of human excreta and cost-saving (Khalid, 2018; Simha et al., 2017). The use of human urine as a fertilizer was perceived to reduce economic risk and associated with perceived benefits, such as low cost and improved yield, household income, and food security (Andersson, 2015). One study found that the use of excreta in agricultural production contributed to more than three times the income of non-users (Cofie et al., 2010). Some farmers thought that the use of human excreta and wastewater could be associated with a reduction in production costs (Chapeyama et al., 2018; Tran-Thi et al., 2017). Positive attitude to human excreta use in agriculture was also associated with being a nature-loving person compared to self-comfort (Khalid, 2018). Contradictory results showed no significant difference between attitude towards the environment as measured by the new ecological paradigm scale and the use of human excreta in agriculture (Simha et al., 2018a). The effects of ecological disposition on social acceptance requires further empirical work to understand whether environmental literacy has impact on social acceptance.

2.4.4. Perceived barriers to the adoption of human excreta and HEDM in agriculture

The perceived barriers were mainly related to health risks associated with human excreta and HEDM use in agriculture. A total of twelve studies concluded that health risks perception is the main barrier to the use of excreta-based fertilizers (Duncker and Matsebe, 2008; Jensen et al., 2008; Knudsen et al., 2008; Mojid et al., 2010; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Phuc et al., 2006; Saliba et al., 2018). Two studies showed that health risk perception was not the barrier to the use of human excreta and HEDM in agriculture, especially when the excreta is treated (Appiah-Effah et al., 2015; Buit and Jansen, 2016). The health concerns included fear of awful smell, handling, skin infections, and many other occupational hazards (Memon et al., 2016). Most farmers believed that training on the handling and sanitizing or treatment of human excreta is necessary to reduce health risks (Samuel, 2016).

Other perceived barriers included socio-cultural factors, religion, norms, pecuniary factors, and taboos in six studies (Andersson, 2015; Buit and Jansen, 2016; Khalid, 2018; Lagerkvist et al., 2015; Mariwah and Drangert, 2011; Elisa Roma et al., 2013a). Visual contact with human excreta was considered a reminder of one's internal badness and a taboo (Buit and Jansen, 2016). Cultural beliefs and religiosity were not perceived as barriers to human excreta and HEDM use in agriculture in two studies (Appiah-Effah et al., 2015; Cofie et al., 2010). A total of three studies found that limited availability, collection, transport, storage, and lack of knowledge on the application of human excreta as potential barriers to the use of human excreta (Andersson, 2015; Cofie et al., 2010; Lagerkvist et al., 2015), suggesting technology and self-efficacy constraints. These studies recommended that making sure that human excreta and HEDM is available in sufficient quantities and recommended quality would improve the use of these products.

Other studies found that precautionary measures and education on safe handling to potentially reduce health risk and improve attitudes as well as farmer confidence on human excreta and HEDM (Lagerkvist et al., 2015). Providing training could increase awareness of the precautionary handling of food, which may change negative attitudes on crops grown for consumption (Mojid et al., 2010). Making information available to farmers was thought to improve their knowledge of the risks and benefits of excreta use in agriculture (Nimoh et al., 2014). The idea of switching to a new farming practice implied taking the risk associated with adopting a new and unknown farming practice (B Moya et al., 2019). In another study, about 50% of the participants were willing to use human excreta, and training and information on HEDM use in agriculture were provided (Mugivhisa et al., 2017).

In six studies, the majority of the participants were not aware of the fertilizer value of human excreta and HEDM in agriculture, and this acted as a barrier to their use (Appiah-Effah et al., 2015; Ignacio et al., 2018; Knudsen et al., 2008; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Saliba et al., 2018). Coinvestigation by engaging the community, for instance, on pathogen determination through action research allows for co-production and co-development of ideas required for enhancing social acceptance of HEDM. The co-development of knowledge with the community could be achieved through community campaigns, on-farm demonstrations, field days, and lead farmers among other inclusive and participatory approaches. Including farmers in transdisciplinary innovation platforms, for instance, can accelerate social acceptance by creating space for social learning.

2.4.5. Socioeconomic and demographic factors

Various socioeconomic factors influence the attitudes towards the use of human excreta and HEDM in agriculture. The social economic predictors include age, experience, education, farm size, income, agronomic benefits, and gender of the participants. Experience, income, farm size, and agronomic benefits significantly influence the use of human excreta in agriculture (Cofie et al., 2010). In Ghana, positive perceptions were significantly related to experience (Danso et al., 2002b). A more recent study in India reported contradictory results where experience had no significant effect on social acceptance (Simha et al., 2018a). Age is another factor influencing attitudes towards excreta use. One included study in South Africa concluded that younger farmers were more willing to use human excreta compared to older farmers (Mugivhisa and Olowoyo, 2015). In another study in India, the results showed contradictory results, where older farmers expressed a more positive attitude compared to younger farmers (Simha et al., 2017). The last two examples may be related to different contextual differences (India versus South Africa) or differences in study characteristics as illustrated in **Table** 2.4.

Attitudes towards human excreta and HEDM use can also be related to the level of education of the study participants (Hosseinnezhad, 2017). Two studies reported the positive influence of education on attitudes (Mariwah and Drangert, 2011; Mugivhisa et al., 2017). Educated farmers had higher mean attitude scores (2.66) compared to those with no formal education (1.44) (Mariwah and Drangert, 2011). Farmers with tertiary education rated human excreta higher than animal manure when compared to those with no education (Phuc et al., 2006). Lastly, in terms of gender, female and male respondents did not show a significant difference in their ranking of animal and human excreta (Mugivhisa et al., 2017). In another study in South Africa, female farmers had a more negative attitude than male farmers (Mariwah and Drangert, 2011), although in another study in South Africa, male farmers were found to be less willing to eat food fertilized with human excreta when compared to female farmers (Duncker and Matsebe, 2008). In a more recent study in India, female farmers were found to be more positive than male farmers (Simha et al., 2017). The inconclusive nature of gender, age, experience among other social economic predictors can indicate the importance of contextual and methodological differences on the study results.

Table 2.4. Characteristics and key findings of the studies included in the scoping review.

First Author Surname (Year)	Country of Study	Target Group	Study Design	Sample Size	Human Excreta Product		Main Findings and Conclusions
(Khalid, 2018)	Pakistan	Farmers	Mixed methods	50	Greywater, feces, Urine Wastewater Fresh excreta	Treated	• Religion and socio-cultural factors affect the use of human excreta in agriculture. • Human excreta used on annual crops like wheat, maize, and barley but not for vegetable farming because of direct consumption. • Human excreta use related to being close to nature and environment. • Artificial fertilizers considered expensive and affected the taste of the end product negatively. • Fresh excreta more repulsive, smelly and contains pathogens and disease-carrying agents.
(B Moya et al., 2019)	Madagascar	Rural farmers	Cross-sectional study	81	Human excreta (but not specified)		• Changing current farming practice to include human excreta use may imply risk-taking. • About 88% willing to use human excreta fertilizers after visual inspection. • Approximately 16% not willing to use the human excreta and human excreta derived fertilizers. • About 59% prefer vermicomposting over the compost
(Mugivhisa et al., 2017)	South Africa	Farmers	Cross-sectional study	60	Dry sewage, human feces, and human urine		• Human excreta were unacceptable because of smell, unhygienic and fear of pathogens and diseases. • Female farmers ranked the source of fertilizers as: animal droppings > animal urine > human feces > sewage > human urine. • Male farmers ranked the source of fertilizers as: chicken droppings > cow dung > animal urine > sewage > human urine > human feces. • Those with no education ranked chicken droppings (93%) > cow dung (84%) > animal urine (66%) and human urine (27%). • Those with tertiary education rated sewage and human feces positively.

						• Approximately 50% willing to change to organic farming provided education and information is available.
(Buit and Jansen, 2016)	Ghana	Peri-urban farmers and consumers	Mixed methods	35	Human excreta (fresh feces vs. dried feces)	• Although farmers had negative perceptions of fresh human feces, dried or treated feces, they are still acceptable. • Human excreta reflect personal moral badness—a reminder of one's badness. • Dried or treated feces perceived as more neutral. • Dried or treated feces reduce contagion and link to the socioeconomic status of the owner. • Perception of health risks not the major issue of concern for treated fecal fertilizers. • Changing physical appearance and smell may increase acceptance, even among 'faecophobic' farmers.
(Mugivhisa and Olowoyo, 2015)	South Africa	School/University community	Cross-sectional study	225	Urine	• About 87% unaware of the uses of human urine as a fertilizer. • Approximately 83% would not eat spinach while 81% would not eat maize fertilized with urine. • Roughly 38% eat vegetables fertilized with animal urine compared to human urine. • Respondents attached negative attitudes to human urine fertilized crops mainly for health reasons. • Younger students were willing to change their attitudes if there is guaranteed safety of using urine.
(Appiah-Effah et al., 2015)	Ghana	Peri-urban farmers	Cross-sectional study	150	Composted feces	• Around 34% aware of fecal sludge as fertilizer, but only 4% use it on their farms. • Perception of excreta as waste was the main reason for the negative attitude towards fecal sludge compost, but the cultural beliefs not a barrier to the use of fecal sludge.
(Lagerkvist et al., 2015)	Kenya	Peri-urban farmers	Cross-sectional study	125	Human excreta (but not specified)	• Cultural factors and non-pecuniary aspects related to the use of human feces as fertilizer. • Information and training is essential to increase confidence about the use of composted human feces.

(Okem et al., 2013)	South Africa	Peri-urban farmers/rural community	Cross-sectional study	473	Urine	• Approximately 5% of farmers using urine in agriculture attributed to limited awareness. • About 10% were aware of urine as a fertilizer. • The potential barriers to urine included health risks, smell, and the opinions of peers. • Participatory trials and promotional campaigns crucial to improve farmers' awareness and acceptance.
(Mariwah and Drangert, 2011)	Ghana	Farmers	Mixed methods	150	Human excreta (but not specified)	• Study results show a generally negative attitude towards fresh excreta. • Roughly 84% considered human excreta as waste not suitable for use • Around 97% perceived health risks in handling human excreta • Roughly 72% thought excreta should not be handled in any way • Female farmers were more negative with mean attitude scores of 1.52 compared to male farmers (1.82). • Educated farmers had a positive attitude with mean attitude scores of 2.66 (no formal education = 1.44). • Religion showed significant difference among religious groups with Muslim and Christians more conservative than traditional religion. • Open discussions with residence were suggested as preconditions for acceptance.
(Cofie et al., 2010)	Ghana	Farmers	Cross-sectional study	60	Human excreta (but not specified)	• No cultural and religious barriers to excreta use in agriculture. • 70% used unsterilized excreta. • Excreta users had three times the net income of non-users. • Treated excreta was attested not to contaminate crops. • Experience, farm size, income, health risk, and agronomic benefits significantly affect excreta use. • Excreta availability in recommended quantity and quality and precautionary education reported improving perception.

(Mojid et al., 2010)	Bangladesh	Peri-urban farmers	Cross-sectional study	416	Wastewater	• Most farmers realized the benefits of wastewater to plants. • Farmers lack knowledge of optimum fertilizer adjustments and doses. • Freshwater was associated with high pumping costs and use of chemical fertilizers compared to wastewater. • Peri-urban and sugar mill farmers perceived odd smell, skin infection and other occupational hazards. • Farmers felt a strong need to treat wastewater before use. • Training on precautionary information and food safety considered necessary for acceptance.
(Duncker et al., 2007)	South Africa	Rural community	Focus group discussion	Not reported	Human urine and feces	• Rural people were aware of the nutritional value of human feces but not urine. • Few farmers were willing to use faces on their garden crops. • The study suggested the importance of changing attitudes on excreta use. • Health perceptions and attitudes are more important than beliefs. • Male farmers were less willing to eat food from excreta compared to female farmers.
(Jensen et al., 2008)	Vietnam	Farmers	Mixed methods	417	Human urine and feces	• Approximately 90% of participants used excreta as fertilizer. • About 94% composted the excreta before use. • Farmers expressed concern over health risks with human excreta. • Various diseases were associated with bad smell (miasma theory). • There is a need for revision of guidelines on ways of reducing the time needed to sanitize excreta through composting.
(Knudsen et al., 2008)	Vietnam	Farmers	Mixed methods	68	Wastewater and human excreta	• Health risk perceptions with excreta use thought to be inevitable.

						• Hygiene and health concerns were considered women's issues. • Excreta from family and peers was considered more acceptable than from distant people or unknown sources. • Health promotional campaigns considered essential to increase safety acceptance and awareness.
(Phuc et al., 2006)	Vietnam	Rural farmers	Mixed methods	75	Human excreta (but not specified)	• Around 85% used composted waste in agriculture. • About 28% composted waste 3 to 6 months while 18% composted human excreta for more than six months. • 66% of farmers spread wastes with bare hands as it was considered convenient. • Highly educated farmers used gloves compared to those with low education. • Sustainable interventions to reduce the health effects of using human excreta recommended.
(Danso et al., 2002a)	Ghana	Peri-urban farmers	Mixed methods	700	Composted feces	• Majority of farmers had positive perceptions and expressed willingness to use and pay for excreta. • Positive perceptions were related to prior experience. • Farmers recommended field trials and education on the use of the product. • Farmer groups, landscape designers and real estate developers are a potential market for human excreta.
(Saliba et al., 2018)	Italy	Farmers and consumers	Cross-sectional study	480	Wastewater	• There was a high acceptance of the use of wastewater by farmers (59%) and consumers (87%). • Farmers are willing to exploit the benefits of excreta. • Negative attitude resulted from perceived health risks. • Invest in infrastructure and wastewater management and informing the public on potential benefits of excreta use.
(Ignacio et al., 2018)	Philippines	Rural farmers	Cross-sectional study	167	Human excreta (but not specified)	• Approximately 50% of the farmers were aware of the fertilizer value of human excreta. • About 25% prefer to utilize human excreta for food production. • Knowledgeable farmers were willing and displayed a more positive attitude towards excreta use.

(Simha et al., 2017)	India	Farmers	Cross-sectional study	120	Human excreta (but not specified)	• Around 59% expressed a positive attitude towards the use of urine and 46% of human feces. • Prefered that the neighbors could use their, but not urine to their friends, family, and colleagues. • Farmers appreciate soil quality improvement and cost savings. • The burning of crops, fear of being mocked, and uncertainty over consumer demand drove negative attitudes. • Female farmers were more positive than male farmers. • Older farmers had a more positive attitude while incomes, social class, and experience showed no significant difference among farmers. • Trust between the source of information and users of human excreta was essential in designing and planning implementation programs.
(Andersson, 2015)	Uganda	Rural farmers	Mixed methods	140	Urine	• Urine fertilizer was a low-cost and low-risk product that contributed to high yield, income, and food security. • Social norms and cultural perceptions are not absolute barriers to the adoption of human excreta. • Availability, collection, transportation, storage and lack of application knowledge were potential barriers. • The study found that bad smell, fear of diseases, witchcraft, social exclusion, norms, taboos, and uncertainty about long-term effects of human excreta on the soil drove negative attitudes • Group action by farmers to negotiate norms and taboos and develop new procedures and practices may increase the acceptance.
(Nimoh et al., 2014)	Ghana	Peri-urban farmers	Mixed methods	400	Human excreta (but not specified)	• The majority disagreed with the notion of excreta as waste and therefore were willing to use it in agriculture. • The majority agreed that excreta use had health risks. • Information and discussions on risks and benefits to improve farmers' knowledge.

(Simha et al., 2018a)	India	University community	Cross-sectional (web-based)	1252	Human urine	• Positive attitude observed towards human excreta—68% mentioned that human urine should be recycled. • Approximately 55% considered human urine as valuable fertilizer, but 44% could eat food fertilized with human excreta. • About 65% perceived some health risk, while 80% believed excreta could be sanitized to reduce risk. • Consumer environmental attitudes did not influence attitude towards urine use.

Source: Author's synthesis of the literature

2.5. Discussion

The synthesis conducted in this study demonstrates evidence of perceived health risk as the potential barrier to the acceptance of human excreta and HEDM in agriculture. The available research evidence of occupational health risks associated with the use of human excreta includes diarrhea, parasitic, skin, and bacterial infection, as well as epilepsy, making the use of untreated human excreta and wastewater potentially harmful to farmers (Lam et al., 2015a). The WHO sanitation safety planning manual for safe use of excreta provides steps towards achieving health objectives in line with the WHO guidelines (World Health Organization, 2015). The manual includes comprehensive exposure-group assessments for the sanitation service chain to include maintenance, cleaning, operations or emptying workers, farmers and consumers of the end products (World Health Organization, 2015).

The manual also includes risk identification training to include hazard types, exposure routes, risk control and mitigation measures through interactive training (Winkler et al., 2017). The pilot-testing of the sanitation safety planning manual in Portugal, India, Philippines, Peru, Viet Nam and Uganda concluded that health risk reduction could be an easy task even in low-income settings (Winkler et al., 2017). The piloting exercise identified practical measures to manage risks of improper human excreta handling when used as agricultural fertilizer, namely, restriction on the use of wastewater treatment sludges on food crops, processing or cooking food before consumption, handwashing hygiene, and promotion of the use of protective clothing during application (Winkler et al., 2017). There is growing evidence that pharmaceutical and personal care products can be taken up from soil nutrient solutions by plants, although evidence of accumulation under realistic field concentrations remains inadequate (Bartrons and Peñuelas, 2017; Carter et al., 2014; X. Wu et al., 2015). The evidence that some pharmaceutical and personal care products have high bioaccumulation factors present in roots hints caution in the use of HEDM in tuber crops (Holling et al., 2012), although the WHO safety plan provides some guidelines on crop selection.

On the other hand, scientific research on the best-bet recovery technologies that works in specific contexts remains an ongoing discussion, especially potential of full nutrient recovery and contaminants elimination, namely, pathogens, organic pollutants and heavy metals. Technology readiness level (TRL) analysis shows that the most mature technologies are crystallization/precipitation of dissolved P from sludge digester supernatant (DHV Crystalactor®, AirPrex® and Ostara®) and wet chemical or acid extraction of P from monoincineration ash (RecoPhos®) (Egle et al., 2016; Harder et al., 2019). Source separating sanitation technologies such as the urine diversion and dehydration toilets, may reduce pathogen load, heavy metals, and organic pollutants in the feedstock and final product (Abarghaz et al., 2012; Kumwenda et al., 2017; Mohammad et al., 2014; E. Roma et al., 2013; Udert et al., 2016, 2015). For instance, full-scale struvite and ammonium sulfate production from urine (SaNiPhos®) in the Netherlands, is sourced from source separating technologies (Egle et al., 2015; Wielemaker et al., 2018). Urine storage and co-composting are also among technologies which have the highest readiness level of 9 (Zhou et al., 2019). The use of locally available materials (such as coconut shells (Ganesapillai et al., 2015), pine bark, zeolite, and wood chips) as sorbents could help remove micro pollutants while facilitating extraction of N-rich urea from solutions by absorption processes (Hina et al., 2015). More recently, Simha et al., (2018b) and Senecal et al., (2018) demonstrated the effect of alkaline treatment in reducing pathogen load and volume of urine (reduce transport costs) while recovering more than 6% of the nitrogen from the urine.

The inconclusive effect of socio-cultural factors (such as cultural norms, religion, beliefs, and taboos) and socioeconomic and demographic factors on perceptions could be due to the contextual differences of the studies. Other contextual factors could include the role of the head of the household, age, study design, which could skew the outcomes. While in India, age and gender had a positive effect on attitudes and perceptions with older farmers being more positive, in South Africa, younger farmers were more positive towards HEDM. The results, however, indicated the importance of education in influencing positive attitudes and perceptions. Promoting trainings initiatives through field campaigns may facilitate scaling of innovations of development projects (Kiptot et al., 2016; Lukuyu et al., 2012).

The desirable attributes of the final product also determine whether farmers will find it more appealing and accept it or will be disgusted and display negative attitudes. Certification, fortification, and labeling increase farmers' willingness to accept and pay for HEDM (Agyekum et al., 2014; Danso et al., 2017). Comlizer, an example of a blend of compost and inorganic fertilizers developed in Ghana, reported higher nitrogen and phosphorus uptake, soil organic matter, nutrient uptake, water use efficiency and crop yield than chemical fertilizers (Cofie and Adamtey, 2009; Vaish et al., 2019). Pelletizing compost, for instance, is important as it improves product structure and bulk density which reduce costs associated with handling, transport, and storage (Danso et al., 2017; Pampuro et al., 2018; Rahmani et al., 2004). Understanding farmers' willingness to pay for these attributes remain a nascent research area of research, although an important one for understanding financial feasibility. Complete demand assessment occurs when we can estimate willingness to use (quantity) and willingness to pay (price).

Of course, each country and region will have to create policies that are enabling and consistent with the reuse of human excreta redefining human excreta from waste to wealth, while creating incentives for sustainable business models. Wide-scale commercialization of HEDM can be hindered by prevailing challenges such as the inconsistent global regulations, market availability, availability of composting material, the logistics of collection, price of compost, and availability of advanced testing laboratories, especially in low-income countries (Berta Moya et al., 2019). The Global Good Agricultural Practice (Global GAP) manual, which is the widely adopted standard for food safety and protection of the welfare of farmworkers, was reported as a major barrier for the use of HEDM on horticultural exports in Kenya (Berta Moya et al., 2019). Therefore, creating a harmonized global regulatory and legislative environment that supports the recovery and reuse of human excreta remains an important consideration.

2.6. Future research directions

While this scoping review provided an assessment of the scope, nature, and extent of the stock of knowledge on the attitudes and perceptions of human excreta reuse in agriculture thus far, it has also identified various issues that require further investigation in the future. More empirical work is required to validate the findings of this study in different contexts, especially least developing countries where providing sanitation can easily be linked to resource recovery and reuse through ecological sanitation technologies. Further work on cost-benefit analysis of HEDM recovery pathways is required, especially incorporating the environmental and health benefits of the decentralized sustainable sanitation and nutrient recovery technologies. Empirical work on willingness to pay for HEDM is also required, especially using choice experiment models to estimate demand for various product attributes suggested in this study.

The scope of this review was limited to only peer-reviewed articles published in the English language. The existence of various languages other than English in other databases, such as Google Scholar shows possible exclusion of some relevant articles published in other languages (Mongeon and Paul-Hus, 2016). Future reviews could include more languages and grey literature. Our focus on published peer-reviewed articles can be thought of as quality assurance. To reinforce this quality assurance, we made sure that all included studies were from accredited journals. While the bibliometric databases selected may differ in terms of their archiving, abstracting, and indexing, we used the two bibliometric databases that provide the broadest coverage for the subject matter. Future reviews can build on this work to perform a wider search of online electronic bibliometric databases when performing systematic reviews and meta-analysis of attitudes and perceptions of farmers (as producers and consumers) towards excreta and HEDM use in agriculture.

All the included studies did not clarify whether the use of HEDM came from different treatment alternatives nor if the material came from stabilized waste. As explained in the discussion section, we can hypothesize that the attitudes and perceptions would differ based on different treatment alternatives used to recover the end-product as this has implications on the quality of the HEDM. Future empirical work may investigate the effect of varying product attributes and treatment alternatives on participant perceptions. None of the studies also investigated the effect of the processing or cooking food produced using HEDM on consumer perceptions, which could be an interesting area for future research.

Crops that are equally contaminated in terms of exposure pathways but are consumed cooked may present a change in perceptions of HEDM reuse when compared to crops that are consumed directly as a salad, such as cucumbers, carrots, lettuce, and spinach. Lastly, the effect of socioeconomic and demographic factors in forming attitudes and perceptions towards human excreta and HEDM requires future investigation building on the results of this study. Systematic and meta-analysis studies that allow for quantitative assessment of results from studies with similar characteristics could provide more information on the nature of the relationship between socioeconomic and demographic factors on general attitudes and risk perceptions towards human excreta and HEDM use.

2.7. Conclusion

The social acceptance of human excreta and HEDM in agriculture remains an essential step towards creating a circular nutrient economy in agricultural systems. This review endeavored to synthesize the available evidence in understanding attitudes and perceptions of human excreta and HEDM in agriculture using the best practices for conducting scoping reviews, namely, the preferred reporting items for systematic reviews and meta-analysis. Many studies found that there were positive attitudes and perceptions towards human excreta and HEDM use in agriculture, notwithstanding evidence of potential barriers. The commonly reported barrier was health risk perceptions, although there were other factors, such as socio-cultural norms, religiosity, visual repulsiveness, and socioeconomic factors. These results were not consistent in all studies as some of the studies showed insignificant effect of the predictors of attitudes and perceptions. This can be attributed to contextual and methodological differences.

Providing training through community promotional behavior-change communication, on-farm participatory demonstration trials, health campaigns, and participatory demonstration trials could help to enhance knowledge, awareness, social acceptance and therefore mitigate perceived barriers. A discussion of the findings of this study demonstrates various important factors for ensuring the wide-scale commercialization of waste recovered fertilizers. These factors include understanding of the scope of recovery technologies by combining complementary recovery pathways and processes. The review found that horticultural exporters do not currently approve crops grown using human excreta derived fertilizers for exporting to the European market based on the stipulations of the Global GAP.

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CHAPTER 3: WHY DO WE KNOW SO MUCH AND YET SO LITTLE? A SCOPING REVIEW OF WILLINGNESS TO PAY FOR HUMAN EXCRETA DERIVED MATERIAL IN AGRICULTURE

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Abstract

Challenges associated with rapid population growth, urbanization, and nutrient mining have seen increased global research and development towards 'waste to wealth' initiatives, circular economy models, and cradle-to-cradle waste management principles. Closing the nutrient loop through safe recovery and valorization of human excreta for agricultural use may provide a sustainable method of waste management and sanitation. Understanding the market demand is essential for developing viable waste management and sanitation provision business models. The pathways and processes for the safe recovery of nutrients from human excreta are well-documented. However, only anecdotal evidence is available on the willingness to pay for human excreta-derived material in agriculture. This review closes this gap by identifying and synthesizing published evidence on farmers' willingness to pay for human excreta-derived material for agricultural use. The Scopus and Web of Science search engines were used to search for the literature. The search results were screened, and the data were extracted, charted, and synthesized using the DistillerSR web-based application. The findings show that understanding willingness to pay for human excreta-derived material is still a nascent and emerging research area. Gender, education, and experience are common factors that influence the farmers' willingness to pay. The findings show that pelletization, fortification, labeling, packaging, and certification are essential attributes in product development. The wide-scale commercialization can be achieved through incorporation of context-specific socioeconomic, religious and cultural influences on the estimation of willingness to pay. Promoting flexible legislation procedures, harmonization of regional legislations, and creating incentives for sustainable waste recovery and reuse may also promote the commercialization of circular nutrient economy initiatives. More empirical studies are required to validate willingness to pay estimates, especially using the best practice for conducting choice experiments.

Keywords: *waste to wealth; circular economy; cradle to grave; choice experiment; contingent valuation; willingness to pay*

3.1. Introduction

Decentralized sanitation systems could help to achieve the United Nations Sustainable Development Goals (SDGs) through guaranteeing basic sanitation (Libralato et al., 2012). The challenges of rapid urbanization, sustainability, and persistent soil nutrient mining have seen an increased call on the global agenda to meet the sanitation needs of the poor. Agricultural intensification and expansion of cities as more native vegetation is converted for crop production call for more sustainable options for restoring soil health (Kopittke et al., 2017; Sasmal and Weikard, 2013; van den Born et al., 2000). The decline in soil physical and chemical properties to support plant growth results from agricultural intensification, especially in Sub-Saharan Africa (Tully et al., 2015). The long-term trials in India show the fall in crop yield to be associated with increased chemical fertilizer application (Sasmal, 1992). The increased research interest in circular economy research fortifies this growing attention for sustainable waste recovery and reuse (Burlakovs et al., 2017; Ellen MacArthur Foundation, 2015; Heshmati, 2017; Iacovidou et al., 2017; Kirchherr et al., 2017; Korhonen et al., 2018; Lewandowski, 2016; Saidani et al., 2019; Witjes and Lozano, 2016; Xue et al., 2010).

SDG Goal 6 emphasizes clean water and sanitation, while Goal 12 calls for responsible production and consumption in a way that minimizes waste (United Nations Commission, 2015). Providing improved sanitation technologies is directly related to SDG Goal 6, and the recovery of nutrients from waste for agricultural use links to the minimization of waste (Goal 12). The creation of sustainable and cheaper alternative fertilizer sources to close the nutrient loop could also help to improve agricultural production. Understanding the demand for nutrients recovered from human waste through the elicitation of farmers' willingness to pay (WTP) may assist in the development of inclusive business models for private sector participation and partnerships with public utilities in line with SDG Goal 17(United Nations Commission, 2015). It is through these linkages with the global agenda that most researchers and partners in the waste management and sanitation value chain have started paying attention to identifying sustainable viable and business cases and models within the resource recovery and reuse service chain (Drechsel et al., 2018; Otoo, 2018; Rao et al., 2017).

The provision of sanitation services is commonly the mandate of the public sector. The failure of local municipalities to meet sanitation requirements due to overstretched budgets, corruption, mismanagement of public funds, and poor governance of public affairs has created the need for alternative, inclusive business models within the sanitation sector. Developing inclusive business strategies within the sanitation sector is in line with the Growing Inclusive Markets initiative of the United Nations Development Program, which emphasizes a human development framework, home grown solutions, and inclusive partnerships (UNDP, 2008; United Nations Development Programme UNDP, 2013). Inclusion of the private sector enterprises should emphasize not only the financial viability of business cases but also economic and environmental viability as this is often critical for public institutions. A win-win situation could result where the private enterprises can generate profits while the public sector can meet sanitation, waste management, and cost recovery objectives without straining the waste sink services of the environment.

The United Nations Population Fund (UNFPA) estimates show that more than half of the global population live in urban areas (UNFPA, 2014).The rapid population growth and urbanization create increasing pressure on urban municipalities to meet sanitation requirements (UNFPA, 2014). The United Nations Human Settlements Programme (UN-Habitat) opines that population growth, better socioeconomic activities, socio-cultural interactions, and humanitarian activities in urban areas continue to attract migrants from the rural areas (UN-Habitat, 2018). Overpopulation and expansion of urban areas lead to the proliferation of informal settlements where basic amenities such as clean water and sanitation are non-existent and expensive to construct (Jenkins et al., 2015). Consequently, informal settlements and peri-urban dwellers often resort to unplanned waste management and disposal practices such as open defecation (Panchang and Vijay Panchang, 2019).

Urbanization and rising incomes often lead to nutrition transition. Nutrition transition is the increased demand for nutrient-dense diets and is linked to population growth, economic development, rising incomes, and urbanization, which exacerbate the mining of agricultural nutrients (Drewnowski and Popkin, 2009; Moomaw et al., 2012). Nutrition transition creates massive nutrient sinks in urban areas (Moomaw et al., 2012). The consumption of food produced in rural and peri-urban agriculture by urban consumers takes with itself nutrients from the soil. The almost constant mass balance of nutrients in the body means that virtually all nutrients are excreted as urine and fecal matter (Jönsson and Vinnerås, 2004; Maurya, 2012). An estimate of 3.4 kg of nitrogen (N), 0.5 kg of phosphorus (P), and 1.6 kg of potassium (K) are excreted as waste per person annually (Jönsson and Vinnerås, 2004). The ecological balance can be maintained if these nutrients are recovered and returned to the soil, and this is not often the case because the philosophy within which the centralized sanitation systems are constructed did not consider waste as a resource (Simha and Ganesapillai, 2017). The global trend is that only 50% of the soil nutrients mined from the soil are returned, posing some severe agricultural production bottlenecks due to soil nutrient depletion and consequently reducing water productivity (Noble, 2012).

A paradigm shift in thinking towards a circular economy may provide a new way of redefining human excreta as 'wealth' rather than 'waste' (Simha and Ganesapillai, 2017)(Simha and Ganesapillai, 2017). Globally, full resource recovery and reuse present 41 million tons of nutrients, making up 28% of the present world N, P, K utilization (Otoo et al., 2018)(Otoo et al., 2018). Furthermore, the depletion of non-renewable nutrient sources ('peak phosphorus') also contributes to this paradigm shift in thinking towards the circular economy models (Cordell and White, 2011). Long-term agronomic trials with human excreta show significant phosphorus recovery when compared to cattle manure and inorganic fertilizers (Glæsner et al., 2019; Lemming et al., 2019). The findings of agronomic trials demonstrate the effectiveness of human excreta-derived fertilizers in improving soil physiochemical properties and crop yields (Odindo et al., 2016). Human excreta-derived material (HEDM) improves soil physiochemical properties, namely, soil hydraulic conductivity, pH, electrical conductivity, and cation exchange capacity (CEC) (Simha and Ganesapillai, 2017). Recycled organic waste reduces greenhouse gas (GHG) emissions compared to inorganic fertilizers (Rahman et al., 2019).

More recently, there has been another shift in scientific research towards the development of technologies that can recover safer and acceptable excreta fertilizer for agricultural use (Simha and Ganesapillai, 2017)The pathways and processes for the safe recovery of micronutrients and macronutrients for use in agriculture have been extensively discussed in the literature focusing on the elimination of pathogens, organic pollutants, and heavy metals (Deng and Zhao, 2015; Egle et al., 2016; Pastor and Hernández, 2012). The maturity and potential for wide-scale commercialization of the recovery and reuse processes and pathways are discussed in the literature (Harder et al., 2019; Sartorius et al., 2011; Zhou et al., 2019). The wet chemical extraction of P from mono-incinerated sewage sludge ash using phosphoric acid (RecoPhos®) and P crystallization of digester supernatant (AirPrex® and Ostara®) are among the mature technologies (Egle et al., 2016; Harder et al., 2019). The use of urine harvested from source-separated sanitation technologies eliminates pathogen, heavy metal, and organic pollutant concerns in the end-product. The SaNiPhos® in the Netherlands, which uses source-separated urine to produce struvite and ammonium sulfate at full-scale commercially, is an excellent example of such mature recovery technologies (Egle et al., 2015). Storage, composting, and anaerobic digestion are among the technologies with the highest readiness level (Zhou et al., 2019). Other technologies with great potential for nutrient recovery include nitrified urine concentrate production, black soldier fly larva production, and Latrine Dehydration and Pasteurization (LaDePa) of screened ventilated improved pit latrine sludge (Etter et al., 2015; Harrison and Wilson, 2012; Septien et al., 2018).

The market or demand segment remains the most understudied, especially the pecuniary and non-pecuniary factors that affect the acceptance of the waste-derived products (Danso et al., 2006). Drechsel et al., (2018) opined that the failure of resource recovery and reuse projects to cover operational costs is related to the complexity of the technologies selected, high maintenance costs, and failure to understand the product markets. Developing viable business models for resource recovery and reuse has become imperative for policy decision making (Drechsel et al., 2018). This review provides a synopsis of the state of published knowledge in understanding the HEDM market demand and farmers' WTP. Establishing the monetary value that farmers are willing to pay for different product attributes is vital to evaluate whether the estimated price covers the cost of providing the product and its attributes (Danso et al., 2006, 2017).

A scoping review methodology offers a way of compiling and synthesizing research evidence in a systematic and reproducible manner (Arksey and O'Malley, 2007). The review provides a picture of the state of research evidence by characterizing and synthesizing the previous empirical evidence. There is a growing body of literature on understanding the attitudes and perceptions of farmers on HEDM but little on their WTP. This review is the first study to employ the scoping review method in understanding the state of knowledge and research evidence of the WTP for HEDM. Providing this research evidence may inform future research directions on knowledge gaps, study design improvements, sample sizes, attribute quality and levels, and the number of alternatives, among other design issues. Moreover, consolidating the WTP estimates from different studies may provide valuable information required by policymakers for improved decision making on the viability of waste management and sanitation provision.

3.2. Methods

A scoping review methodology proposed by (Arksey and O'Malley, 2007) (Arksey and O'Malley, 2007) provided a rigorous and comprehensive methodology for synthesizing research evidence. The methodology offers a flexible but reproducible guide on search terms that allows for a comprehensive literature review process (Arksey and O'Malley, 2007). This study follows the proposed five stages, which include: defining the research objective, search strategy, study selection, synthesizing, and reporting the findings (Arksey and O'Malley, 2007). The application of the method in other research areas includes compiling the state of research evidence in public health (Choudhry et al., 2019; Hosking and Campbell-Lendrum, 2012; Pilot et al., 2019), public health and sanitation (Lam et al., 2015b; Moffa et al., 2019), epidemiology (Chikafu and Chimbari, 2019), environmental health(Pelch et al., 2019), consumer health(Castro et al., 2018), and in the investigation of social determinants of the rural labor force (Cosgrave et al., 2019) and dental health care(Como et al., 2019).

3.2.1. Research question

This review employed the population, interventions, comparatives, outcomes, and study design (PICOS) methodology in specifying the research objective (Moher et al., 2015). The population was specified as users of HEDM in agriculture, such as rural, peri-urban, and urban farmers. The intervention was the agricultural use of the HEDM in comparison with conventional inorganic fertilizers and animal manure. The outcome was defined as the WTP for HEDM by farmers or other users. The study designs were categorized into quantitative, qualitative, and mixed methods. Specific research questions addressed in this study included what are the major analytical tools employed by the studies for assessing perceptions and attitudes? What are the factors influencing the attitudes and perceptions of farmers from the previous studies?

3.2.2. Identification of relevant studies, data sources, and search strategy

The study involved performing the primary search in all databases in Web of Science (WoS Core Collection, KCI Korean Journal Database, MEDLINE, Russian Science Citation Index, and SciELO Citation Index) and Scopus electronic databases. Web of Science was selected as it provides a greater depth of citation coverage in the areas of Sciences and Social Sciences (Castro et al., 2018). Title-Abstract-Keyword search was performed in Scopus while Topic search was employed in all databases of Web of Science. The review was limited to peer-reviewed articles published in the English language till 8 April 2019. The time limitation allowed for this review to extract all studies conducted on WTP of HEDM for agricultural use thus far. By employing several search terms, synonyms, and Boolean operators, this review provided a structured, exhaustive, and comprehensive search (**Table** 3.1). The snowballing technique was also employed to back-search and handpick references of the articles included in other electronic databases such as Google Scholar because electronic databases may vary in their abstracting, indexing, depth, and breadth of information (Arksey and O'Malley, 2007).

Table 3.1. Search queries.

Database	Search Strategy	Search Results
Scopus	TITLE-ABS-KEY (“human manure” OR “fecal sludge” OR “human waste” OR “humanure” OR “solid waste” OR fec * OR fec * OR “human excreta” OR “human excreta derived material”) AND (“Willingness to pay” OR “Contingent valuation” OR “Discrete choice Experiment” OR “Choice experiment”)	325 document results
Web of Science	TOPIC (“human manure” OR “fecal sludge” OR “human waste” OR “humanure” OR “solid waste” OR fec * OR fec * OR “human excreta” OR “human excreta derived material”) AND (“Willingness to pay” OR “Contingent valuation” OR “Discrete choice Experiment” OR “Choice experiment”)	321 document results

*Operator in the search syntax refers to Boolean for the shortest word to be retrieved from the search

Source: Author’s synthesis of the literature

3.2.3. Study selection

All peer-reviewed articles or references from WoS and Scopus were exported to the DistillerSR Evidence Partners Incorporated web-based application. The duplicate detection function in DistillerSR was used to quarantine duplicates before conducting the initial screening. The DistillerSR application allows for data extraction from included articles based on study characteristics. This application has been employed in other studies (Lam et al., 2015b; Pelch et al., 2019).

3.2.4. Screening and eligibility criteria

The study screened the remaining unique articles for relevance using title screening. Studies that passed the inclusion criteria were further screened using abstract and full-text screening. Only the articles that were relevant after the full-text screening were considered for data extraction. The references of the included articles were scanned for potential references that might not have been indexed and archived in WoS and Scopus databases. The data from these articles were also added to the included articles for data extraction. These additional studies identified through handpicking or snowball technique were searched in Google Scholar. The articles considered for inclusion were those that investigated the WTP for HEDM, which is a unique fertilizer product when compared to other organic fertilizer sources available to agricultural producers **(Table 3.2)**

Table 3.2. Article inclusion and exclusion criteria.

• **Article Exclusion Criterion**
• The study described WTP for other products but human excreta and or HEDM
• The study was published in other languages and not in the English language
• The study was not published in a peer-reviewed journal, such as articles published in predatory journals, conference proceedings, working papers, abstracts and books
• The study was a review article without original results
• The study had insufficient details to evaluate the methodology
• The full text of the article could not be retrieved for evaluation

Source: Author's synthesis of the literature

3.2.5. Data extraction

The review implemented a descriptive-analytical approach to extract information from the articles that passed the inclusion criteria following the framework of the traditional narrative review (Arksey and O'Malley, 2007; Lam et al., 2015b). The data extracted included the name of the author, publication year, location, study participants, type of HEDM investigated, study design, analytical framework, sample size, and WTP attributes and estimates reported. Systematic reviews are supposed to assess the strength of research evidence. This study, therefore, extracted variables that may offer quality assessment from the included studies. Variables such as whether the articles assessed the validity and reliability of the survey instrument, sample size calculation, the econometric model estimated, the goodness of fit tests, HEDM attributes, the mean WTP estimated, and the factors influencing farmers' WTP were also extracted for analysis.

3.2.6. Synthesizing and reporting

This review was summarized into specific themes that emerged from the included articles. The summarizing stage included supporting research evidence from grey literature, which was essential to support the claim that more work is needed in this research area in terms of understanding the consumer demand and the market value of HEDM. The additional benefit is especially in identifying future research directions and knowledge gaps, which form the rationale for conducting scoping reviews.

3.3. Results

3.3.1. Search and article screening results

A total of 647 articles were exported to the DistillerSR web-based application for screening. A total of 174 duplicate articles were quarantined using the duplicate detection function leaving 473 unique articles. A total of 344 articles were excluded using title screening. The remaining 129 articles were excluded following abstract and full-text screening. Only two articles were considered for data extraction. Three additional references were identified through handpicking and snowballing for data extraction (**Figure 3.1**).

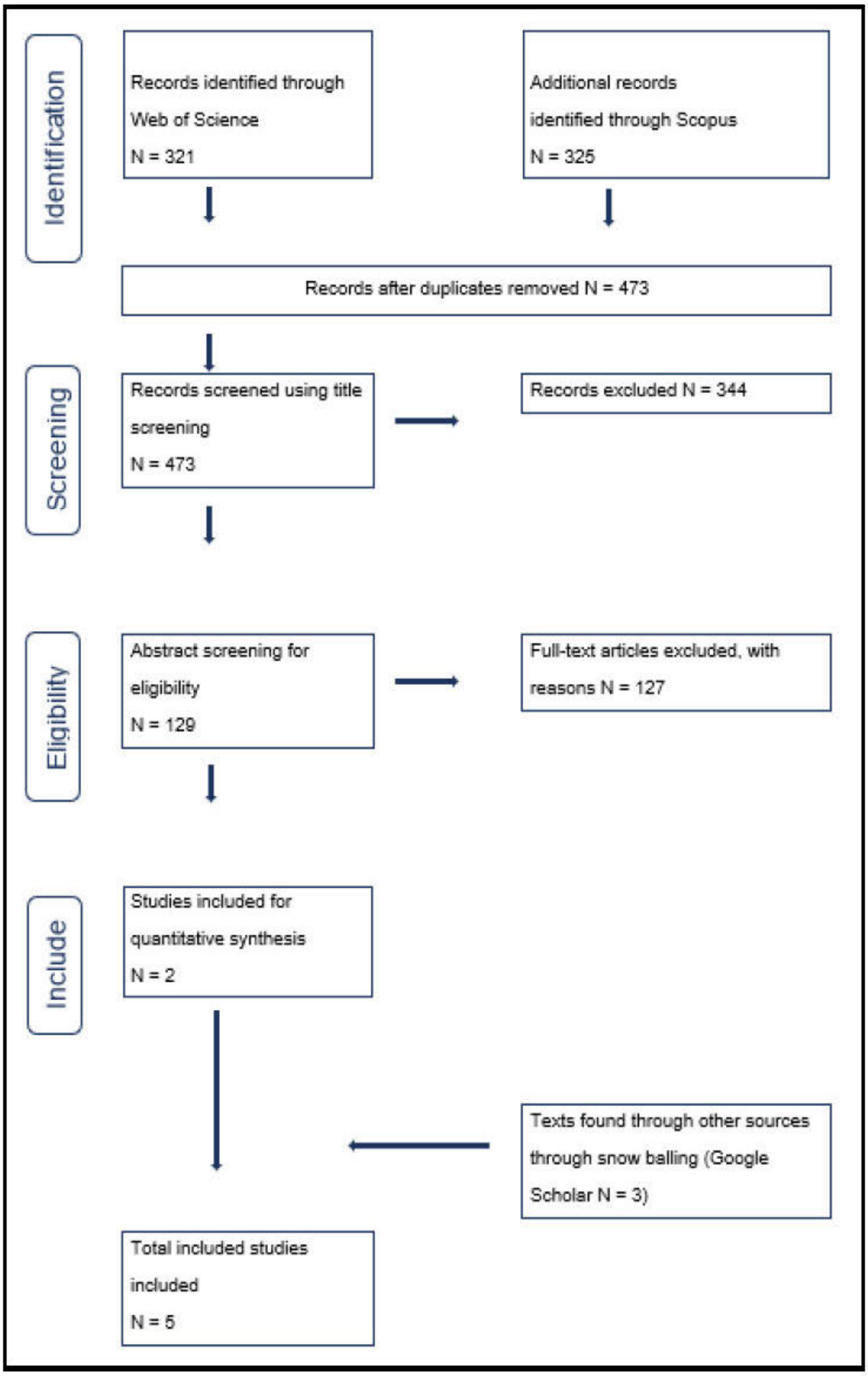

Figure 3.1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow chart

Source: Author's synthesis of the literature

3.3.2. Characteristics of the articles included

Out of the five published studies conducted on the WTP of farmers for HEDM, three were from Uganda, while the remaining two were from Ghana and Vietnam. Out of the five publications, the first publication was conducted in the year 2006, followed by another one in 2014. The remaining three studies were conducted in 2017. The participants in all the studies were farmers. The types of HEDM analyzed in the studies include fortified and pelletized municipality solid waste, which was co-composted with human excreta(Danso et al., 2017). Fortified excreta pellets involve the enrichment of composted excreta with inorganic fertilizers or struvite to enhance its value (marketability and competitive advantage) and reduce bulkiness while allowing usability for different crops (Nikiema et al., 2013). Pre-gelatinized cassava starch and clay binders may be used to reduce nitrogen loss through volatilization(Adamtey et al., 2009; Danso et al., 2017; Nikiema et al., 2013).

Another study estimated the WTP for municipal solid compost, which was co-composted with human excreta but not enriched with inorganic fertilizer(Danso et al., 2006). Other types of HEDM investigated include pelletized human excreta-derived fertilizer (Kuwornu et al., 2017)and fecal compost (Agyekum et al., 2014). Pelletization of compost enhances product structure, increases the bulk density, reduces costs associated with handling, transport, storage, and application while homogenizing and concentrating nutrients in manure(Danso et al., 2017; Pampuro et al., 2018; Rahmani et al., 2004). The fifth study investigated WTP for human excreta-derived organic biomass liquid fertilizer treated using auto-thermal thermophilic aerobic treatment (Hong et al., 2017a). The auto-thermal thermophilic aerobic treatment uses aeration flow and batch flow manipulation to regulate the solid-retention-time and digester temperature required for sludge pasteurization (Nájera et al., 2017).

This review also extracted data on the type of research design and the technique used to elicit the WTP for HEDM. The results show that all the studies included collected cross-sectional data. The methods used to elicit WTP included the contingent valuation method (CVM) (Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017)(Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017). The remaining two studies used the choice experiment (CE) method (Agyekum et al., 2014; Danso et al., 2017). The sample sizes ranged from a minimum of 200 farmers to a maximum of 700 farmers. None of the included studies gave information on the sample size determination in terms of the population heterogeneity and the power tests. Recommendations for sample size calculation consider the number of choice tasks, alternatives and the largest number of levels for main effects, and the largest product of any two attributes for interaction effects (Johnson and Orme, 2003; Orme, 1998). Researchers may also use the rule of thumb of over 100 respondents for choice experiment surveys as proposed by Pearmain et al., (1991) or use power test recommendations proposed by de Bekker-Grob et al., (2015). The survey instruments used in the included articles were checked for validity and reliability. None of the studies reported any ex-ante validity and reliability checks to the survey instruments. However, one of the studies reported piloting the survey instrument to a few unspecified numbers of farmers. Typically, formal tests are required in cross-sectional survey instruments reported, such as the Cohen's kappa index or the Cronbach's alpha test for reliability (Taherdoost, 2016).

The data analysis methods used show that all five studies used different empirical models. (**Table** 3.3 **and**

Table 3.4). A mix of models including the conditional logit (CL) model, random parameters logit (RPL) model, and latent class model (LCM) were used in estimating WTP for HEDM in Ghana (Danso et al., 2017). In another similar study that used the CE elicitation technique, the basic and hybrid CL models were used to elicit WTP for HEDM (Agyekum et al., 2014). The studies that elicit WTP using CVM used the Tobit model (Kuwornu et al., 2017), the Probit model (Danso et al., 2006), and the log-logistic model (Hong et al., 2017b). Based on these empirical models, the review further extracted data on the WTP estimates. The CVM model results showed the WTP estimates ranging from a minimum of 0.4 US cents per kilogram (kg) of organic biomass liquid fertilizer (Hong et al., 2017b) to 19 US cents per kg of pelletized human fecal matter (Kuwornu et al., 2017). The mean WTP estimate for municipal compost with human excreta was estimated to be 3 US cents per kg (Danso et al., 2006).

Table 3.3. Characteristics of articles included

Author (Year)	Country of study	Target group	Study design	Sample size	Human excreta product	Validity reported?	Reliability reported?
(Danso et al., 2017)	Uganda	Farmers	Choice Experiment	300	Fortified Pelletized Municipality Solid Waste and Human Excreta	No	No
(Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017)	Ghana	Farmers	Contingent Valuation	461	Pelletized feces	No	No
(Danso et al., 2017)	Ghana	Farmers	Contingent Valuation	700	Co-compost	No	No
(Agyekum et al., 2014)	Ghana	Farmers	Choice Experiment	200	Composted feces	No	No
(Hong et al., 2017)	Vietnam	Farmers	Contingent Valuation	530	Organic Biomass Liquid Fertilizer	No	No

Source: Author's synthesis of the literature

Table 3.4. Characteristics of articles continued.

Author (Year)	Econometric model	Log Likelihood	Attributes	Mean WTP estimate USD/kg
(Danso et al., 2017)	Conditional Logit Model	−2134.551	Fortification	0.09
	Random Parameters Logit Model	−1910.586	Pelletization	0.13
	Latent Class Model	−2245.083	Certification	0.40
(Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017)	Tobit Model	−1770.300	-	0.19 (Pelletized feces)
(Danso et al., 2017)	Probit Model	(8.9; 645.7; 745.13) †	-	0.03 ‡ **(**Co-compost)
(Agyekum et al., 2014)	Basic and Hybrid Conditional Logit Model	−305.827 -296.676	Packaging Labeling	0.01 0.01
(Hong et al., 2017)	Log-logistic Model	−293.400	-	0.004 (Organic Biomass Liquid Fertilizer)

† Pearson's goodness of fit was used for three cities. ‡ WTP value was estimated as average for the three cities for different crops.

Source: Author's synthesis of the literature

Farmers were willing to pay 1 US cent for a labeled and 1 US cent for a packaged kg of composted feces (Agyekum et al., 2014). The fortified HEDM had a marginal WTP of 9 US cents per kg below the market price as compensation for fortification, 13 US cents per kg above the market price for pelletization, and 40 US cents above the market price per kg for certification (Danso et al., 2017). The reported WTP estimates for certification were found to be 67 times above the cost of providing a certified product while being 0.57 times lower than the cost of providing a pelletized product (Danso et al., 2017).

3.3.3. Factors influencing WTP for HEDM

Various factors were discussed that influenced the WTP for HEDM in the five included studies. The variables used in different econometric models were extracted and tabulated **(**
Table 3.5**).** The results show that gender, education, and experience are the most common factors that influence farmer WTP for HEDM reported in all the five studies. The next common factors include age, household size, and income, which were reported in four studies. Awareness of the HEDM was the third most common variable in three of the studies. Farm size and perception of the use of HEDM were reported in two out of five studies. The remaining factors include product quality, religion, training, and membership of a farmer-based organization, which were reported each in one study. For the two CE studies, one used price, fortification, certification, and pelletization as the HEDM attributes (Danso et al., 2017). The other CE study used price packaging and labeling as HEDM attributes (Agyekum et al., 2014).

Table 3.5. Factors Influencing WTP for HEDM.

Danso et al., 2017	Kurwonu et al., 2017	Danso et al., 2006	Agyekum et al., 2014	(Hong et al., 2017b)7
† Price (−)	† Unit cost of current fertilizer (+)		† Price (+)	† Bid coefficient (−)
† Fortification (−)	† Household head (+)		† Packaging (+)	
† Certification (+)	Own land		Labeling	
† Pelletization (+)	No of 50 kg	† Location (+)		Farm size
† Gender (+/−)	Gender	Gender	† Gender (+)	Gender
	Age (years)	† Age (years) (+/−)	† Age (years) (−)	Age (years)
† Household size (+)	† Household size (+)	HH dependency	† Household size (+)	Household size
† Education (−)	Education	† Education (+/−)	† Education (−)	Education
† Experience (+/−)	Experience	† Experience (+)	Experience	† Experience (+)
	Farm income	† Farm income (-)	† Disposable income (+)	† Household income (+)
† Religion (+/−)	Awareness		† Awareness (+)	† Awareness (+)
Farm size	Farm size†			† Training (+)
† Product quality (+/−) perception	† Used Organic (-)	† Soil input (+/−)		
† Water holding capacity (+/−)	FBO member			
† Product reservation perception (+/−)		† Perception (+/−)		
† Product use perception (+)				

†Significant effect of WTP (+ or − sign indicates the direction of the relationship and +/− indicates negative or positive effect depending on which attribute was interacted with.
Source: Author's synthesis of the literature

The effect of the socioeconomic and demographic variables on the WTP in the CE studies differed depending on which attribute it was interacted with. For instance, a negative effect on WTP was reported when gender was interacted with pelletization and certification, but a positive and significant effect was reported when gender was interacted with fortification (Danso et al., 2017). The results may imply that women are more risk-averse and therefore prefer a certified product compared to men. Women may prefer a product that is easier to handle, as it reduces drudgery. However, men and more experienced farmers were found to prefer a more valuable fortified compost compared to women. However, education had a negative effect on all three interactions and with packaging and labeling, implying that educated farmers may find less value in all the improved compost attributes (Agyekum et al., 2014; Danso et al., 2017). Larger households were also willing to use HEDM in the two CE studies, which is very intuitive because of the availability of labor (Danso et al., 2017). Household income was reported to have a positive effect on WTP when interacted with packaging and labeling (Agyekum et al., 2014). The finding shows that low resourced farmers could still accept HEDM even if it were to be sold in bulk without packaging and labeling. However, resourced farmers would prefer a packaged and labeled compost for ease of handling. The results also show that older farmers have lower WTP than younger farmers, which is the usual case in most examples of adoption of new technologies in agriculture (Agyekum et al., 2014).

In the three studies that used the CVM method, the effects of the socioeconomic and demographic factors are straightforward as there are no interaction terms. While two studies found no effect of income on WTP (Hong et al., 2017b; Kuwornu et al., 2017), the other study reported a positive effect of income on WTP (Danso et al., 2006). The effect of education was also not significant in the two studies (Hong et al., 2017b; Kuwornu et al., 2017), but was reported to have a positive effect in Kumasi and a negative effect in Tamale in Ghana. Experience had a positive effect in the two studies(Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017), but no effect in another(Danso et al., 2006; Hong et al., 2017b; Kuwornu et al., 2017). Awareness had a positive effect on the WTP for packaging (Agyekum et al., 2014) in Tamale but no effect in Kumasi and Accra (Danso et al., 2006) and Ghana (Kuwornu et al., 2017).

3.4. Discussion

3.4.1. Why do we know so much and yet so little about the market demand for HEDM?

Incubation studies, tunnel experiments, and field trials have demonstrated positive impacts of HEDM on soil physio-chemical properties and crop productivity (Odindo et al., 2016). Specific findings from long-term agronomic trials demonstrate significant nutrient recovery, of phosphorus in particular, compared to its recovery from cattle manure and conventional fertilizers (Glæsner et al., 2019; Lemming et al., 2019). Other experiments show improvement in soil physical and chemical properties (Simha and Ganesapillai, 2017) and a considerable reduction in greenhouse gas emissions (Rahman et al., 2019). For these and many other reasons (such as rapid urbanization, population growth, and nutrient mining), there has been a recent shift in scientific research towards understanding and development of technologies to safely recover socially acceptable and stabilized material from human excreta waste streams for agricultural use (Simha and Ganesapillai, 2017). The technologies range from those developed for the safe recovery of agricultural products from human excreta: struvite precipitation and nitrified urine concentrate (Etter et al., 2015); biochar pyrolysis (Clough et al., 2013; Gurwick et al., 2013; Hallowell et al., 2017); residue derived from black soldier fly larva(Diener et al., 2014; Maleba et al., 2016; Purkayastha et al., 2017; Semiyaga et al., 2015); latrine dehydration and pasteurization (Harrison and Wilson, 2012; Septien et al., 2018); composting, co-composting and vermicomposting (Eastman et al., 2001; Kharrazi et al., 2014; Mengistu et al., 2017; Rodríguez-Canché et al., 2010; Song et al., 2014; Zhou et al., 2019).

The pathways and processes for the safe recovery of micronutrients and macronutrients for use in agriculture have been extensively discussed in the literature focusing on the elimination of organic pollutants and heavy metals (Deng and Zhao, 2015; Egle et al., 2016; Pastor and Hernández, 2012), technology maturity and potential for wide-scale commercialization (Harder et al., 2019; Berta Moya et al., 2019; B Moya et al., 2019; Sartorius et al., 2011; Zhou et al., 2019). The chemical extraction of P from incineration ash using phosphoric acid (RecoPhos®) and the P precipitation/crystallization of digester supernatant (AirPrex® and Ostara®) and co-composting are among the full-scale and mature technologies with the highest readiness level (Egle et al., 2016; Harder et al., 2019) Although composting has been identified as a low-cost technology (Monfet et al., 2018), evidence from Northern Europe shows contradicting results with farmers citing market, financial, institutional, technological, and behavioral factors as potential barriers to wide-scale acceptance of composting (Viaene et al., 2016).

The concerns about product homogeneity and quality, especially heavy metals and organic pollutants, can potentially reduce the market demand and acceptance of the products. The use of urine derived from source-separated sanitation technologies eliminates pathogen, heavy metal, and organic pollutant concerns in the end-product. The SaNiPhos® in the Netherlands, for instance, uses source-separated urine to commercially produce struvite and ammonium sulfate at full scale (Egle et al., 2015). The partnership between SaNiPhos® and the MSD pharmaceutical company, albeit at the pilot level, has seen the recovery of the hormones for use in developing fertility medicines (Nutrient Platform, 2019). The scoping review of the literature at the time of this writing shows that 22 studies have been published to understand the attitudes and perceptions of farmers on the HEDM for use in agriculture (Buit and Jansen, 2016; Ignacio et al., 2018; Khalid, 2018; B Moya et al., 2019; Mugivhisa et al., 2017; Saliba et al., 2018; Simha et al., 2018a, 2017). These studies reported health risk perception as the main barrier to the use of HEDM in agriculture (Duncker et al., 2007; Jensen et al., 2008; Knudsen et al., 2008; Mojid et al., 2010; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Saliba et al., 2018)The cost-effectiveness of HEDM for use in agriculture has also been empirically demonstrated in the literature (Chapeyama et al., 2018).

With so much known about HEDM, one wonders why there are only five published studies on estimating the market demand for human excreta in peer-reviewed journals. The ‘peak phosphorus’ phenomenon, where phosphorus is rapidly approaching global economic depletion, shows the importance of incorporating the demand for recycled fertilizer options into product development. Understanding factors that influence how much farmers are willing to pay and accurately estimating the amount they are willing to pay may provide the vital information required to put HEDM on the market. We suggest that the product heterogeneity resulting from the nascence of the commercialization of HEDM and the infancy of the regulatory environment may explain this dearth of information in scientific/academic publications. However, while the technologies to recover a more consistent product are being explored, it is imperative to explore the market demand if the green fertilizers and other HEDM are to cross the ‘innovation chasm’ or what is often stylized as ‘bridging the valley of death’ (Gulbrandsen, 2009; Malele et al., 2019). We discuss these among other issues hindering wide-scale commercialization in the following sections.

3.4.2. Product attributes

The product attributes that have been suggested in the two studies that used CE to elicit farmers’ WTP for HEDM include pelletization, fortification, labeling, packaging, and certification, which should be considered strongly in product development. Pelletization is an attribute that improves the product structure while making it easy to apply HEDM in the crop field(Danso et al., 2017). Fortification with other HEDM such as struvite, urine, and inorganic fertilizer may increase the competitiveness of the product on the market by reducing its bulkiness while adding to its value. A combination of fast- and slow-release nutrients can be added to the soil while improving the soil organic matter content. Packaging and labeling are essential for ease of handling and may provide an opportunity to specify information such as the composition of nutrients and application rates (Agyekum et al., 2014). It is highly recommended that the labeling and packaging of HEDM should follow the country-specific legislation and regulations, including global policies where export markets are the target.

The results of the five reviewed studies show that the WTP for the attributes covers the cost of production, which presents a significant opportunity for product design, placement, and marketing of HEDM. However, this depends so much on the creation of an enabling regulatory environment. A review of the legislation regulating the use of HEDM shows that the United States legislation is guided by Part 503 of the Environment Protection Agency (EPA) under Section 405 of the Clean Water Act (EPA, 1993). In Europe, the Fertilisers Regulation, Reg.

(EC) 2003/2003, and the Animal Byproducts Regulation (ABP), Reg. (EC) 1069/2009 guide the use of sludge as fertilizer (European Parliament, 2009). Additional clearance is required for use as organic fertilizer under the Organic Products Regulation, Reg. (EC) 834/2007 (European Commission, 2007), and the production, labeling, and control of organic products, Reg. (EC) 889/2008 (EU, 2008) while the Sewage Sludge Directive Dir. 86/278/EEC (National Research Council and NRC, 2002) regulates sewage sludge. Harmonization of fragmented policies to include all fertilizer categories such as HEDM for EC certification and generic rather than the piecemeal application of mutual recognition could offer an excellent enabling policy environment for commercialization and product standardization within the European market. However, current legislation on the EC status does not have provisions for waste-derived material as fertilizer source as well as heavy metal limits for HEDM (Hukari et al., 2016). Compost and other materials from waste streams do not need registration according to the European Chemicals Regulation (REACH; Reg. 1907/2006) (Hukari et al., 2016).

In South Africa, the Department of Water and Sanitation regulates treatment and application of sludge on agricultural land in consultation with various departments such as the Department of Environmental Affairs) (e.g., Act No. 39 of 2004), the Department of Agriculture, Forestry and Fisheries (DAFF) (e.g., Act No. 36 of 1947) and the Department of Health (e.g., Act No. 85 of 1993) (Agriculture, 2016). A positive environmental impact assessment (Record of Decision) from the Department of Environmental Affairs is required for the Department of Water and Sanitation to issue a license (Snyman and Herselman, 2006). In terms of Act 36 of 1947, sludge can be classified as an organic fertilizer (Snyman and Herselman, 2006). The Act 36 of 1947, however, prohibits the use of insect-processed animal protein (PAP) as animal feeds intended for commercial purposes (Agriculture, 2016). Use of PAP in aquaculture is allowed in North Korea and Europe while use in poultry is allowed in Canada and also considered as animal feed in South Korea and the United States (Joly, 2018; Sogari et al., 2019). The Global Good Agricultural Practice (GAP) also limits the commercialization of the use of human excreta on certified farms for horticultural exporters(GlobalG.A.P., 2016). The specifications of the Global GAP create a barrier for the use of HEDM among horticultural exporters in Kenya (Berta Moya et al., 2019; B Moya et al., 2019). In most countries where legislation and policies are missing, the global good agricultural practices take precedence to local legislations.

Transportation costs (Danso et al., 2017) and financial support (Mario et al., 2018) are among the other factors that can limit the commercialization and scaling-up of HEDM. Conditional cash transfers as financial incentives can potentially increase the bulking of treatment material to reduce collection logistics, although designing effective payment vehicles with minimum regressive welfare distribution is still a question for empirical and development research in recycling systems (Tilley and Günther, 2016). Using clustered or nucleated settlements and densely populated centers such as shopping centers, hospitals, and universities for on-site treatment centers can potentially cut transport costs while ensuring consistent availability of raw materials. However, this remains an area for future research. Inclusive business models such as the community-based approaches to total sanitation and community-led total sanitation may have the potential to achieve both waste management, resource recovery, and sanitation provision objectives (Caplan, 2016). Examples include the Menengai Waste Recycling Management Group, Nakuru Waste Collectors and Recyclers Management Cooperative Society in Kenya (E. Muchiri, B. Mutua, 2010; Otoo et al., 2018), the Sustainable Organic Integrated Livelihoods in Haiti, the X-Runner in Peru, and the Clean Team in Ghana and SANERGY in Kenya (Rao et al., 2017).

3.4.3. Best practice for conducting stated preference studies

The results of the studies show that there is indeed a high demand for HEDM by the farmers. However, the WTP estimates differed from one study to another, and the factors influencing WTP showed inconclusive results as they also differed from one study to another. The study results did not show consensus on the significance, direction, and magnitude of factors influencing WTP, such as socioeconomic and demographic factors. This study proposes possible explanations for this outcome. Various efforts have been made in the literature to raise the quality and promote best practices of stated preference studies (Arrow et al., 1993; Johnston et al., 2017). In more recent work, several recommendations have been proposed and grouped into several categories, namely: survey development and implementation, value elicitation, data analysis, validity assessment, and study reporting (Johnston et al., 2017). The goal of survey development and implementation is and should be to maximize the validity and reliability of parameter estimates. The pretesting of survey instruments is critical for content validity. However, the decision to choose between the attribute or non-attribute approaches depends on the type of goods or policy being evaluated (Johnston et al., 2017).

The validity and reliability of the data collection instruments were not reported in any of the studies. In conducting cross-sectional studies, it is crucial to ensure that the survey instruments are valid and reliable. Different types of validity exist in the literature (such as face, content, construct, and criterion validity) (Taherdoost, 2016). Subjecting survey instruments to pilot studies and then testing validity using either the Cohen's kappa index, Lawshe's content validity ratio, factor analysis, and expert opinions may allow for more valid survey tools (Taherdoost, 2016). Reliability, on the other hand, may also be measured using Cronbach's alpha in exploratory analysis before conducting a survey. The validity of choice experiments can be enhanced by accurate attribute framing, through the provision of information cues, varying monetary attributes, consultation with key informants, such as scientists, policymakers, and through conducting focus group discussions (Kragt and Bennetta, 2010).

The design of the choice experiment is also critical in stated preference approaches. Experimental designs need to be explicit regarding the statistical power (de Bekker-Grob et al., 2015), information order or scope effects in CV (Lew and Wallmo, 2011), attribute nonattendance (Byrd et al., 2017; Nguyen et al., 2015), omitted attributes, bid amount effects, and the effects of the selected optimization criteria (Johnston et al., 2017). Regarding statistical power, none of the included studies included a formal calculation of sample size or power test. The standard rules for sample size calculation consider the number of choice tasks, alternatives, and the largest number of levels for main effects and product of any two attributes (Johnson and Orme, 2003; Orme, 1998). Researchers may also use the rule of thumb of over 100 respondents for choice experiment surveys (Pearmain et al., 1991). The number of choice tasks can also be formally calculated as the minimum number divisible by all the attribute levels (Rose and Bliemer, 2009).

The welfare measure to use between the equivalence variation and the compensating variation is tantamount to the willingness to accept and willingness to pay for welfare changes (Bockstael and McConnell, 1980; Zhao and Kling, 2004). The selection of welfare measures should be considered taking cognizance of the underlying theoretical approach and the empirical difficulties associated with the willingness to accept or pay (Johnston et al., 2017). Other recommendations include the response options in a CV payment vehicle and how the study makes use of various design elements and auxiliary questions to increase and evaluate the validity, such as the use of cheap talk scripts and certainty scales to improve incentive compatibility and consequentiality (Johnston et al., 2017). As such, elicitation methods should minimize strategic responses and inconsistent response behaviors. Incentive compatibility theoretically pushes the respondent to truthfully reveal their preference as the dominant strategy (Lusk and Schroeder, 2004; Zawojska and Czajkowski, 2017). Design elements such as the randomization of questions order across respondents, task complexity, and sequencing effects, for instance, scope effects and use of visible choice sets, may improve the validity of the studies.

Researchers conducting choice experiments need to make assumptions about the decision makers' behavior, and as such, utility-maximizing behavior that is generated from random utility maximization models is commonly assumed to reflect this behavior (León et al., 2016). The included studies used orthogonal fractional factorial designs, which have the advantage of producing unconfounded estimates because of the enforced statistical attribute independence of the design (Lancsar and Louviere, 2006). However, in practice, socioeconomic and demographic variables may exhibit some correlation with the main effects, as seen when examining the asymptotic variance-covariance design matrix. Correlations may also occur between socioeconomic and demographic variables and attributes as they do not vary across individuals (Tang et al., 2014). There may also exist unrealistic and behaviorally implausible choice tasks, where new information may not be gained. The non-linearity of choice models and cognitive burden (task complexity) may also arise from having too many choice sets per respondent (Tang et al., 2014).

Full factorial designs used in the studies included are entirely orthogonal in both the main and higher-order interactions. Fractional factorial designs assume that the preference distribution is identically and independently distributed (IID), and that higher-order interactions are zero and that there is attribute-level balance (Lancsar and Louviere, 2008; Louviere et al., 2011). Orthogonal designs also make an additional assumption that there is no confounding, and therefore, the main effects can be determined stochastically and independently. This assumption is called the independence of irrelevant alternatives (IIA). The assumptions of orthogonality fail to fulfill this linear independence assumption for nonlinear discrete choice models. As a result, desirable design properties such as statistical efficiency, utility balance, attribute balance, task complexity, and response efficiency are sought after in trying to maximize the information gained from each choice made by the respondent. (Rose and Bliemer, 2009). Optimal designs help to achieve this by maximizing the negative inverse of the Fisher information matrix (calculated as the second derivative of the log-likelihood function) which is the covariance matrix of the parameter estimates (Tang et al., 2014).

The Fisher information is applied to experimental design because of its reciprocity with the asymptotic variance-covariance matrix. Maximizing the Fisher information (dispersion matrix) is equivalent to minimizing the variance or confounding. A statistically efficient design, therefore, produces smaller confidence ellipsoids around the parameter estimates for a given sample size. Minimizing the D-error can be achieved using several algorithms, for instance, the classical Fedorov algorithm or its modification. The information matrix, however, relies on the parameter distribution of the assumed model. Therefore, the efficiency of the model to be estimated depends on the accuracy of information priors using Bayesian efficient designs (Kessels et al., 2011, 2006). The research evidence in this area concludes that efficient design may outperform both orthogonal and D-optimal designs (Bliemer and Collins, 2016; Kessels et al., 2011; Rose and Bliemer, 2009), albeit with sensitivity to the specification of the prior distribution. The guidelines on specifying priors include literature reviews, expert judgment, context analysis, focus group discussions, and pilot surveys (Okumu and Muchapondwa, 2017; Rose and Bliemer, 2009).

None of the included studies discussed the bias that might result from choice inconsistency. The most common definition of choice consistency in the DCE literature is to make identical choices when faced with identical choice tasks (Lancsar and Louviere, 2006). Non-satiation is essential for removing circular indifference curves, which indeed may be rational for certain bundles with bliss points (Lancsar and Louviere, 2006). The satisfaction of the non-satiation or dominance axiom of revealed preference, however, is not crucial for rationality according to economic theory. Tests for non-satiation in DCEs involve investigating whether individuals chose dominated options (Lancsar and Louviere, 2006). When dealing with lexicographic preferences, non-satiation or attribute dominance, the researcher must decide on the theoretical approach on which to explain the respondent's choice rule. Lexicographic preferences satisfy the axioms of the preference-based consumer theory, namely, completeness, transitivity, strong monotonicity, and strict convexity. However, such preference patterns fail to satisfy the continuity assumption, which is essential for the existence of utility functions (Lancsar and Louviere, 2006). Researchers should, therefore, be cautious when concluding the irrationality of lexicographic choice rules as what may appear irrational using the standard preference-based approaches could be explained as rational using an alternative approach to consumer theory, such as the theories of choice under uncertainty.

(Lancsar and Louviere, 2006) also noted that the use of fractional factorial designs and linearly additive utility functions, or orthogonal main effects only designs might prevent studies from observing a full pattern of responses that would be possible with a full factorial design. This may label some decision rules as irrational when there are no enough full degrees of freedom to conclude the presence of dominance and lexicographic preferences (Lancsar and Louviere, 2006). The fact that the choice tasks are repeated in choice experiments means that respondents can learn through institutional learning or reconsider initial choices through value learning, which can magnify the scale parameters (Bateman et al., 2008; Day et al., 2012). Throwing away such observations may reduce the degrees of freedom required to accurately estimate parameters for a given sample size (Lancsar and Louviere, 2006). However, such behavior may be rational and accurately captured in the random utility error term based on random utility theory (Lancsar and Louviere, 2006; McFadden, 1998).

The studies used different elicitation methods, which may potentially lead to different conclusions. The choice of the correct elicitation method between CVM and CE has raised debate over the past few decades (Halvorsen and Soelensminde, 1998; Hynes et al., 2011; Mahieu et al., 2014; Niroomand and Jenkins, 2018). The models used in the analysis may also differ depending on the type of data and research objectives. While the CVM estimates the WTP of moving from one holistic non-marketed good to a new alternative by altering the attributes, CE approaches attach the value of individual attributes by providing different options, altering the number of attributes and levels within each bundle which is not possible in CVM (Hynes et al., 2011). Moreover, including the price attribute in different choice sets helps to estimate how much value people attach to each attribute level (Hynes et al., 2011). However, the use of CVM to elicit WTP has been found to have a practical advantage of reducing cognitive burden primarily where a large number of attributes and levels are used to achieve design efficiency, which is often the case with most CE methods (Hanley et al., 2002). The CE estimates are also sensitive to the nature of the study design, choice of attributes, number of attribute levels, and the method of representing choices to participants (Hanley et al., 2002).

A systematic review of the literature in the fields of environmental, health, and agricultural economics showed that CE methods have become more popular than CVM (Mahieu et al., 2014). Although the overall objective is the same, CE presents several advantages over CVM, which has led to its growing popularity. The first and apparent reason is that it allows for the estimation of both mean WTP and marginal WTP for different attributes (Mahieu et al., 2014). The CE methodology also reduces ethical protesting and strategic response when compared to CVM while providing information that allows for an in-depth understanding of trade-offs between attributes (Adamowicz et al., 1995; Hanley et al., 2002) While CVM is suited for the overall holistic policy or product package, the CE approach is more suited to cases where individual attributes make up the product (Hynes et al., 2011). The CVM and CE welfare estimates have been analyzed in the literature (Hanley et al., 2002; Hynes et al., 2011; Mahieu et al., 2014). The CE method has been found to perform better than CVM in terms of precision of welfare estimates as measured by error variance of parameter estimates relative to the mean (Adamowicz et al., 1995).

Lastly, the choice and specification of the empirical models also varied from one study to the other. Focusing the attention on the CE studies, the conditional logit model, random parameters model, and latent class model were used to estimate WTP for HEDM. Agyekum et al. (2014) employed the basic and hybrid conditional logit model, which does not incorporate preference and scale heterogeneity. The conditional logit model assumes that the error terms are independently and identically distributed (IID) and that preferences are homogeneous, leading to independence of irrelevant alternatives (IIA) assumption (Danso et al., 2017; Kassie et al., 2017). Under real-world situations, preferences or tastes for observed attributes do vary from farmer to farmer. Danso et al. (2017) applied the mixed logit or RPL models, which relaxes this assumption and allows for correlation induced by the scale and behavioral heterogeneity. However, the source of this heterogeneity (tastes and scale) is empirically impossible to disentangle with the RPL model (Hess and Train, 2017a). Running a restricted generalized multinomial logit (GMNL) and the RPL may allow the researchers to make a nearly weak conclusion about the structure of heterogeneity. It is, therefore, advisable to use WTP-space models when estimating welfare estimates, which provides a way of directly estimating WTP without imposing normal distribution assumptions on the price coefficient (Hess and Train, 2017).

3.4.4. Implications for policymaking and development practice

While the importance of accurately estimating WTP has been clarified in this short review, the evaluation of development initiatives in developing countries has taken a different approach. The precision of WTP estimates is demanded when performing project evaluation procedures such as cost-benefit analysis and other related welfare analysis. The standard in most project evaluation procedures in developing countries has been to avoid conducting WTP studies. The possible reasons for this practice include the monetary costs of conducting such studies and both the seemingly pedantic nature, empirical demands, and the level of expertise required to apply the best practice when conducting WTP studies, including those explained in this review. There has been a general inclination towards the benefit-transfer approach whenever attempts are made to incorporate non-market social and environmental impacts in project evaluation. The social/environmental cost-benefit analysis often used in project evaluation is sensitive to the accuracy of the WTP estimates used when calculating the gross value-added of a development initiative or project. The metrics used, namely, the net present values, benefit-cost ratios, modified internal rate of return, and the economic rate of return, are sensitive to the accuracy of the WTP estimates or other inferred alternatives from the benefit transfer approach. Regardless of whichever value is used, it is essential to consider incorporating social and environmental gains from recovery and reuse initiatives in cost-benefit analysis of development initiatives. Some circular economy initiatives may appear not feasible financially but could justify 'viability gap funding' when social and environmental benefits are incorporated in feasibility studies.

Increased resource-use efficiency can improve crop yields from the use of human excreta-derived material and water efficiency through recovery and reuse of wastewater for irrigation. Indirect socio-economic and developmental benefits include improved food security, energy security, and public health. Environmental gains may also occur from recovery and reuse of human excreta by extending the lifetime of landfills, thereby sustaining the waste-sink ecosystem services. Extending the lifespan of landfills may also save costs for the local municipalities in developing countries that currently face substantial budgetary constraints and sanitation backlogs. Other indirect benefits include reduced greenhouse gas emissions, such as methane and carbon dioxide.

Appreciating the micro-diversity, idiosyncrasies, and uniqueness of local elements by understanding the indigenous knowledge systems is imperative for adaptation (Allen, 2001). The rationale behind this thinking rests on the complexity of the rural livelihood strategies and the importance of adaptive project management. Community-based adaptation is one such integrated approach that focuses on socio-economic and political dimensions of poverty and vulnerability, including the physical dimension of climate risks (Forsyth, 2013). concept, and other cross-sectoral integrated resource management frameworks. Investing in initiatives that promote social acceptance while promoting an enabling policy environment for circular economy initiatives remains a crucial area for future research and policymaking.

3.5. Limitations and future research directions

While this study provides pertinent information on understanding the demand for HEDM by farmers, there are a few caveats that need to be mentioned. Firstly, to offer quality checks, we limited this review to only published peer-reviewed studies. Thus, some vital information found in grey literature, which includes academic theses, project reports, and conference proceedings, may have been excluded. Secondly, this review was limited to articles published in the English language and excluded other peer-reviewed articles published in other languages. Therefore, the assumption drawn from this study is that a similar publication trend exists in all the other languages. Thirdly, there were only five published articles on WTP for HEDM. A clearer picture would have been drawn if more studies had been conducted in this research area. Future research should consider results from this review as an essential point of departure for conducting further empirical studies in this area.

This study confirmed that the market demand segment of the recovery and reuse of human excreta-derived material is a nascent but important area of research. The findings of this review are not surprising, given the technocentric nature of this research area. Most circular economy research, in general, focuses on the production/supply side with little attention paid to the demand side. The lack of understanding of the consumption patterns, the social dimensions of end-users, and how they can be transformed is one of the barriers to the success of most circular economy projects (Hobson and Lynch, 2016; Mario et al., 2018; Mylan et al., 2016; Rizos et al., 2016; Wastling et al., 2018; Zurbrügg et al., 2005). The demonstration of the knowledge, attitudes, and perceptions of farmers is imperative for the social acceptance of the new fertilizer alternatives given their contextual differences. However, even more critical is establishing the monetary value that farmers attach to pertinent attributes of the human waste-derived products to evaluate whether the estimated price covers the cost of providing the product in its acceptable form.

The findings of this study also demonstrate the contextual differences in the results of the included articles, especially the effects of socio-economic, cultural, and religious factors on the value that farmers attach to the attributes of human excreta-derived products. It is, therefore, difficult to draw conclusive evidence from the included studies due to the dearth of published research in this area. Alternatively, the inconsistency in the results could be a result of the different methodological approaches implemented by the five studies, as discussed in the sections above. The different conclusions drawn from the studies included in this review may also reflect contextual differences. The latter point may justify the importance of conducting WTP studies whenever estimates are required for decision-making and evaluation procedures. Thus, reliance on the benefit-transfer approach in such instances may provide misleading results and misguided decision making. More importantly, the findings of this review demonstrate that farmers are willing to pay for the new fertilizer alternatives derived from human excreta. The differences in the WTP estimates and factors influencing WTP remain an important area for future research to validate the findings of this review. Improving the methodological approaches using best practice for conducting willingness to pay studies in future research may help to draw conclusive evidence on the WTP estimates and the factors affecting the willingness to pay for human excreta-derived material in agriculture.

3.6. Conclusions

This review synthesized knowledge on the extent of published research evidence on farmers' WTP for HEDM. The results of this study show that the area of understanding WTP for HEDM is a very nascent research area. While many studies have been conducted on HEDM, little is known about its demand and farmers' willingness to pay. More research should be conducted in this research area. While this review provided useful information on the factors influencing WTP for HEDM, several methodological issues were identified. These include failure of included studies to check data collection instruments for validity and reliability, model selection considering the scale, and taste heterogeneity, among other issues. Incorporating these issues may provide more accurate estimates while providing more consistent information on the direction and magnitude of factors influencing WTP for HEDM.

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CHAPTER 4: BEHAVIORAL INTENTIONS TO RECYCLE HUMAN EXCRETA IN AGRICULTURE: IMPLICATIONS FOR RESEARCH, POLICYMAKING, AND DEVELOPMENT PRACTICE

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Abstract

Considerable progress has been made in developing human excreta recovery pathways and processes for maximum nutrient recovery and contaminant elimination. The demand segment has often been ignored as an area for future research, especially during the technology development. The findings from the few published articles on social acceptance show missing and inconclusive influence of demographic, sociological, and economic farmer-characteristics. This study endeavours to close this gap by using the social psychological theories, technology adoption theories and the new ecological paradigm to investigate the factors that influence the behavioral intentions of rural farmers to recycle human excreta in agriculture. Study findings show that social acceptance was driven by awareness, religiosity, income, source of income, and environmental dispositions. Perceived behavioral control represents a potential barrier to human excreta reuse. The study recommends the demographic, cultural, sociological, and economic mainstreaming of dissemination strategies of circular bioeconomy approaches within the context of agricultural innovation systems.

Keywords: *Human excreta; health risk; self-efficacy; behavioral intention; segregated attitude*

4.1. Introduction

The global demand for food is soaring due to rapid population growth, urbanization, and international trade (Jenkins et al., 2015; UNFPA, 2014). The decline in soil fertility in sub-Saharan Africa is continuing to threaten household-level food security (Vanlauwe et al., 2014b, 2011). The mining of soil nutrients via food transportation from farms is worsened by rapid population, urbanization, economic development, rising incomes, and nutrition transition (Drewnowski and Popkin, 2009; Moomaw et al., 2012). Plant nutrients are involved in anabolic processes that produce organic compounds during photosynthesis and are not absorbed by a healthy human body, but excreted as, for instance, faeces and urine. The mining of nutrients from the agricultural soils via food creates nutrient sinks in urban environments (Moomaw et al., 2012). Annual nutrient mining rates in Africa ranges from 9-88 kg NPK/ha (Henao and Baanante, 2006; Jones et al., 2013a). About 60-70% of the nutrients mined from the soil as food, and through soil erosion, leaching and as human excreta goes to the environment (Jönsson and Vinnerås, 2004) and closing the nutrient loop would restore the ecological balance and soil health (Kudeyarova and Bashkin, 1984). Nutrient mining may also result in long-term productivity failure (Moomaw et al., 2012) and may pose negative health impacts related to micronutrient deficiency in developing countries (Jones et al., 2013a). The use of chemical fertilizers is often considered the only viable option to supply plant nutrients (Vanlauwe et al., 2014b, 2014c). On the other hand, the average annual fertilizer application rates (at lowest 8kg/ha) in sub-Saharan Africa are far below the nutrient depletion rates or the plant requirements for crop production(Mwangi, 1996).

The sub-Saharan Africa uses annual chemical fertilizer application rates of as low as 8kg/ha/year, far below the nutrient depletion rates or the plant requirements for crop production (Mwangi, 1996). The mean fertilizer application rate in Sub-Saharan Africa is about 8kg/ha/year and far below the 141kg/ha/year in South Asia, 154 kg/ha/year in the Europe, 175 kg/ha/year in South America, and 302 kg/ha/year in East Asia (Bonilla Cedrez et al., 2020). The excessive use of chemical fertilizers poses negative environmental impacts on aquatic systems and soil health (Han et al., 2015; Lin et al., 2019; Savci, 2012), as well as to human health (Nicolopoulou-Stamati et al., 2016; Sharma and Singhvi, 2017). Globally, sustainable food production under the high-input agricultural intensification systems, which mainly depends on intensive use of synthetic fertilizers is considered impossible without causing significant negative environmental impacts (Foley, 2005; Tilman et al., 2011). Ecological intensification, therefore, has a great potential to achieve sustainable food production without using external inputs (Kleijn et al., 2019a). The use of sustainable agricultural systems to restore soil health augments agricultural productivity, reduces greenhouse emissions, and build the soil's resilience to shocks (Corning et al., 2016).

In rural South Africa, farmers face challenges of sanitation where approximately three million ventilated improved pit latrines constructed by the government in response to the millennium development goals for universal sanitation in the last 15 years are currently filled-up. Most of the local authorities neither have a policy, plan, nor budget for Faecal Sludge Management (FSM) for instance, emptying, transportation and disposal of faecal sludge (Still et al., 2010). The common practice is the building of inferior makeshift pits (rather than emptying and reuse) which expose farmers to known health risks. In instances where emptying is possible, there are considerable environmental impacts and space constraints associated with the dumping of waste in hazardous landfills. Deep row entrenchment often considered a simpler and immediate solution to faecal sludge disposal from on-site sanitation systems (Still et al., 2010). More research is needed to understand the mineralization (ammonification and nitrification) processes in deep row entrenchment. For instance, examining the extent to which the conditions at depth would allow for nitrification of ammonium to inorganic compounds for absorption. Hazardous landfills and deep trenches should be far from residents to reduce air pollution, but close enough to the waste source to reduce transportation costs (Nikiema et al., 2020), with the trade-off being met with high landfill costs and stringent environmental regulations.

Technologies designed to safely recover agricultural nutrients from human faeces include biochar pyrolysis (Clough et al., 2013; Gurwick et al., 2013), black soldier fly (Diener et al., 2014; Purkayastha et al., 2017), Latrine biosolids Dehydration and Pasteurization (LaDePa) (Septien et al., 2018), and co-composting and vermicomposting (Lin et al., 2019; Song et al., 2014). Acid extraction of phosphorus from incineration ash (RecoPhos®), phosphorus crystallization of digester supernatant (AirPrex® and Ostara®) and composting have the highest technology readiness levels (Egle et al., 2016; Harder et al., 2019) Co-composting is, however, preferred as a low-cost technology (Monfet et al., 2018), and due to its link with the "circular sanitation economy in agriculture" (Toilet Board Coalition, 2017). The composting thermophilic biological degradation process can inactivate helminth eggs to the World Health Organisation's recommended levels for safe agricultural use (Khadra et al., 2019; Koné et al., 2007). Considerable studies have demonstrated the benefits of co-compost application on land in terms of improved soil water-holding capacity, nutrient retention, and soil structure (Mohanty and Boehm, 2015; Paetsch et al., 2018; Wang et al., 2019; Zhong et al., 2020).

Compost application complements and supplements the use of chemicals fertilizers by augmenting their agronomic efficiency (Sommer et al., 2014; Vanlauwe et al., 2014c, 2011).

The co-composting value chain, however, continues to face potential barriers related to lack of wide-scale acceptance of the end product by customers (Viaene et al., 2016). A synthesis of nutrient management systems attributes the low demand for fertilizers to low benefit perception, lack of awareness, high input prices, poor credit markets, low farmer-return on investment or agronomic response (Bonilla Cedrez et al., 2020; Sommer et al., 2013). Similarly, the failure of the recovery and reuse innovations to recuperate the costs is attributed to the poor understanding of the product markets (Drechsel et al., 2018; Mario et al., 2018; Rao et al., 2016). The failure of composting innovations is mainly attributed to the low product demand (Pandyaswargo and Premakumara, 2014; Rouse et al., 2008). The limited marketability and the bulkiness of compost are among other reasons for the low demand, making it costly to transport over long distances (Rouse et al., 2008). Although the technologies for recovering human excreta for agricultural use exist, scaling up such innovations would mainly depend on public acceptance of the end products (Segrè Cohen et al., 2020). Initiatives to address the poor demand include the fortification (agronomic response), pelletization/pelleting (visual appeal, handling, and bulk density), packaging (application instructions and nutrients content) and certification (risk perception). The current study, therefore, investigated the factors that influence the social acceptance of human excreta derived fertilizers in South Africa and the potential for wide-scale commercialization in rural communities. Investigating the factors influencing the market demand for compost could help to mitigate the stated failure of the recovery and reuse innovations through better understanding of the product market.

The current study is based on research gaps identified in a scoping review undertaken using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA). The objective of the study was to scope and synthesise the stock of published research on the social acceptance of human excreta reuse in agriculture. The findings demonstrate the paucity of published scientific knowledge on social acceptance of human excreta, and the inconclusive influence of demographic, sociological, and economic farmer characteristics on social acceptance(Gwara et al., 2021). It was impossible to draw meaningful conclusions from the small sample of published work. The review retrieved 22 published articles on the behavioral intentions to use human excreta. Fourteen peer-reviewed studies did not specify the recovery technology, while the remaining studies (*n* = 5) investigated human urine wastewater (*n* = 3), and composted faeces (*n* = 2). Research on the social acceptance of faecal sludge is, therefore, nascent and more studies are required to help inform profit-based business cases, research and development practice, and policymaking. The study findings could inform customer prospecting and segmentation, mainstreaming of policies and awareness campaigns, as well as targeting of innovative farmers to champion on-farm demonstration trials in development practice.

4.2. Research methods

4.2.1. Study area and design

A total of 341 farmers were interviewed in the Vulindlela Traditional Authority of South Africa, after obtaining a Humanities and Social Sciences Research Ethics Committee (HSSREC/00001499/2020) ethical approval and verbal consent from the Ethics Unit of the university's Research Office **(Appendix C)**. The participants were provided with details of the study purpose, survey time, confidentiality, and the freedom to withdraw from the study at any time. An informed verbal consent was obtained from the participants before beginning the survey and the details of the informed consent are provided in the survey instrument, which is available at https://enketo.ona.io/x/#EkSVyazm. All the methods used in this study were performed in accordance with the guidelines and regulations of the Humanities and Social Sciences Research Ethics Committee. Power analysis was performed using at alpha = 0.05 and number of predictors of =7, to detect a medium Cohen's *d* effect size = 0.15, and the total sample size was calculated to be 153 with an actual power of 0.95. The G*Power software (Kang, 2021)was used to determine the sample size and power calculations because of it is an open source software that is easy to use (Cohen, 2013, 1992; Daly and Cohen, 1978). The sample size was however increased to the total sample size of 341 farmers, to accommodate two other studies that used the same survey instrument to collect information on ecological attitudes and willingness to pay using discrete choice experiments. The study adopted a cross-sectional study design which obtains information from all the respondents at a specific point in time. The detailed description of the study area, design, training, and budget is provided in the supplementary information **Appendix A**APPENDIX A: SUPPLIMENTARY INFORMATION.

The survey data collection tool was developed using an XLS form, which was then converted to an XLM format for use in Open Data Kit mobile-based software solution. The instrument is available in ONA cloud server https://enketo.ona.io/x/#EkSVyazm. Online mobile-based survey tools allow for assigning of constraints and restrictions which helps to avert data collection and encoding errors, while increasing the data accuracy and reliability. The data is also available in an analysis-ready format that is compatible with the readily available software. The data collection tool was also tested online for content validity with academics, research, and development practitioners with operating within the food system and circular sanitation economy in agriculture projects. The detailed description of the nature of the survey questions is provided **Appendix D.** The study used a multi-stage sampling procedure, to select two wards (ward 8 and 9) based on the maximum distance from the main city. A sampling interval was calculated to systematically select household units, where the main decision maker in the household was identified for interviewing. The non-response rate was negligible as absentee or inaccessible respondents were replaced by the closest house then resample from the newly selected household. The survey did not record any protesters nor failed to collect data because of the farmer's refusal to participate in the survey. More details of the sampling strategy and the survey process are provided **Appendix A3**.

4.2.2. Attitudinal dimension scores

All the data was managed and analysed using the IBM SPSS Statistics software package. The behavioral intentions of farmers to use human excreta was elicited using questions with the binary responses coded as 2 'yes' and 1 'no', such that the probability of the response was given as $1 \leq \boldsymbol{\mu} \leq 2$ (Lamichhane and Babcock, 2013; Simha et al., 2018a). The computation of the mean score ($1 \leq \boldsymbol{\mu} \leq 2$), was such that a mean score of 1.5 was considered neutral and a mean score greater than 1.5 indicate positive attitude, while below 1.5 suggests negative attitude. Some previous studies evaluated attitudes on a question-by-question basis (Simha et al., 2018a), and such methods are perfect for a more targeted understanding of specific questions of interest. However, it may be necessary to have several questions measuring a single construct to avert biases associated with single question responses. The responses were decomposed into a unidimensional construct to reduce the complexity of evaluating segregated attitudes on a question-by-question basis. This allows for mean comparison tests used to investigate the influence of different farmer-specific characteristics such as t-tests, ANOVA, and hierarchical regression, which depend primarily on the dependent variable's continuity in scale.

The *individual attitude score* was calculated by computing the mean scores of six attitudinal question items, namely; i) willingness to use co-compost ii) willingness to use human urine, iii) if the respondent thought human excreta should be disposed and never used, iv) if the farmer would buy food produced using human excreta, v) if the farmer would eat food produced using co-compost, and vi) if the farmer would consume food produced using human urine. The attitude score was then segregated to reflect the production and consumption demand elements. The *production attitude* score was computed by taking the mean score of three out of the six attitudinal questions above, that are akin to production, namely: i) willingness to use co-compost as a fertilizer ii) willingness to use human urine, iii) if the farmer thought human excreta should be disposed and never used. The *consumption attitude score* was computed by taking the mean score of the three questions that relate to the willingness to consume and buy food produced using human excreta, namely: i) willingness to buy food produced using co-compost (cost-risk element), ii) if the farmer was willing to eat food produced using co-compost, and iii) willingness to consume food produced using human urine. The *perceived behavioral control score* was computed by taking the mean score of the four attitudinal question items that relate to self-efficacy and risk-benefit perception of using human excreta, namely: i) if the farmer 'thought' that he/she had enough skills to use human excreta in farming, ii) the effect of treatment on perceived health risk, iii) whether the farmer thought that treated human excreta contains pathogens or microorganisms that can cause diseases, and iv) whether the farmer thinks that pharmaceuticals/medicines can be found in crops grown with human excreta derived fertilizers. The attitudinal construct captures self-efficacy and perceived health risks.

Research in cognitive neuroscience demonstrates the existence of convergent human behavior (Bikhchandani et al., 1998) and the co-influence of individual attitudes by the behavior of others (Frith and Frith, 2006). The social cognitive theory posits that social learning occurs by modelling the behavior of other people or social conditioning from direct relational experience (Bandura, 1971). The *subjective norms score* was therefore computed by taking the mean score of the four question items that evaluate the influence of the behavior of others, namely: i) do you think other people in general would use human excreta in their fields to fertilize crops? ii) do you think other people in the market would buy food produced using co-compost as fertiliser? iii) do you think your family members would eat food that was fertilised with human excreta? iv) do you think your neighbours, friends, relatives or other people would eat food that was fertilised with human excreta? The *combined attitude score* was then calculated by taking the mean score of all the computed constructs, namely, attitude score, perceived behavioral control and subjective norms.

4.2.3. Environmental worldviews using the New Environmental Paradigm

The New (or Revised) Environmental Paradigm (NEP) responses were coded as 5-point Likert scale type questions, with 1 indicating strong disagreement while 5 represents strong agreement with the statement (Dunlap et al., 2000). The seven even-numbered NEP statements where disagreement with the statements reflects a proenvironmental worldview were reverse coded following (Simha et al., 2018a). The overall NEP rating ($1 \leq \boldsymbol{\mu} \leq 5$) indicated the mean scores of all responses (Ogunbode, 2013), with 3 being neutral, 1 being extreme environmentally unfriendly, and 5 representing extreme proenvironmental or eco-friendly worldviews (Van Petegem and Blieck, 2006). The current study used the Cronbach's Alpha (α) to test for the responses of the participants for internal consistency and reliability to the NEP statements. Although there are no absolute cut-off points for internal consistency, most research points to a minimum acceptable value of 0.70 (Robinson, 2010; Taherdoost, 2016). Other cut-off points that have been suggested in the literature for reliability analysis, include low reliability (<0.50), moderate reliability, ($0.50 \leq \alpha \leq 0.70$), high reliability ($0.70 \leq \alpha \leq 0.90$), and excellent reliability (>0.90) (Hinton and McMurray, 2017; Taherdoost, 2016).

4.2.4. The direction and magnitude of the influence of demographic, socioeconomic and environmental factors on behavioral intentions

The objective of this study is to estimate the influence ex-ante the sociological, demographic, and socio-economic factors that influence and characterises the behavioral intention of farmers to use human excreta in agriculture. A family of hierarchical regression models were estimated using the 'naïve approach', where the dependent variables include a) the individual attitude score, b) the production attitude score, c) the consumption attitude score, d) the perceived behavioral control, e) the subjective norms, and f) the combined attitude score. The hierarchical regression approach is commonly used in the disciplines of psychology, sociology, and education to evaluate the incremental validity of the variables of interest, based on theory, past research, and the depth of understanding of the research problem (Lewis, 2007). The hierarchical regression approach is also the most used analytical approach for understanding the theory of planned behavior (Cheung et al., 1999). The predictive modelling approach is applicable in social science research, where independent variables are likely to be correlated and because of its superiority to the stepwise regression in terms of degrees of freedom, pre-specification effect, replicability, and sampling error (Lewis, 2007). Classical diagnostic tests did not show any violation of the classical regression assumptions. The income variable, which is normally used as a dependent variable is some cases was checked for endogeneity using the control function approach or the exclusion restriction method (Petrin and Train, 2010). The method tests the suspected endogenous variable for potential influence on the dependent variable then uses this exclusion restriction to control for endogeneity in a two-step approach.

Although research organisations, governments, and development practitioners promote agricultural technologies, their adoption remains low. A meta-regression analysis of the adoption of agricultural technologies showed that, on average, education, family size, access to credit, land tenure and size, extension, and membership to farmer organizations have positive influence on the adoption of agricultural technologies (Ruzzante et al., 2021). Agricultural technology adoption theory combines decision theory and diffusion of innovations theory to understand the factors that influence farmers to adopt new technologies, leading to three paradigms: the perceptions, innovation-diffusion and the economic paradigms (Ruzzante et al., 2021). Diffusion is a social process of the spread of new innovations in the society over time (Kreps, 2017). Identifying the factors that influence decision or intention to adopt an innovation in the target population maximizes the diffusion efficiency initially focussing on innovators to champion on-farm pilot demonstration trials, while enhancing the design and implementation of awareness campaigns and dissemination plans (Kreps, 2017). Identification of the farmer characteristics may help to circumvent potential barriers before introducing the innovation into the community. The innovation-diffusion paradigm posits that information is the key driver of the diffusion of innovation and groups the adopters into innovators, early adopters, and laggards based on the observable demographic and socioeconomic attributes (Rogers, 2003). The economic constraints or utility-based paradigm and the adopter-perception paradigm posits that perceived attributes of innovations and innovators (farmer-characteristics) influence the perception (knowledge, attitudes and perceptions) that drives that diffusion process (Adesina, 1993). The conceptual and theoretical diagram describes how the agricultural technology adoption theory, and the scoping review of literature informed the identification of the factors influencing farmers' behavioral intentions to recycle human excreta. The theory of planned behavior was used to identify the outcome variables, namely, attitudes, perceived behavioral norms and perceived behavioral control **(Figure. 4.1).**

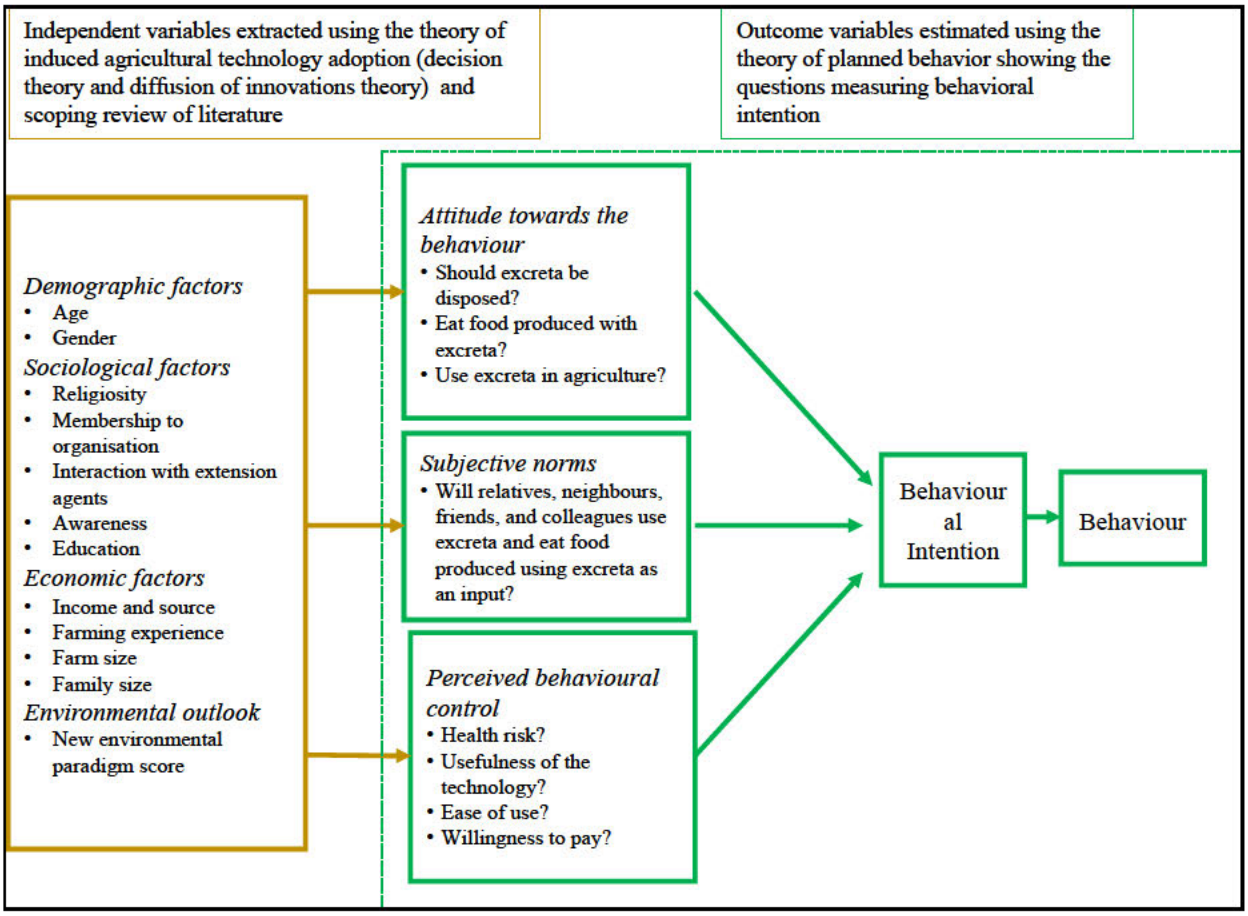

Figure 4.2. A Diagram of factors that influence behavioral intention to recycle human excreta in agriculture: a conceptual framework

4.3. Results

4.3.1. General characteristics of the interviewed farmers in Vulindlela rural traditional community

Reporting the demographic and socioeconomic characteristics of the study participants helps to understand the segregated attitudes of the farmers for customer segmentation. Approximately 68.2% of the 341 interviewed farmers were female, while 31.4% were male (**Table A.5**). The average age of the interviewed farmers, who were essentially household heads as described in the methods section, was 54 (14.2) years. The average and median (mean=median) years of education were approximately 8.0 (4.1) years (i.e., first year of secondary education), while the average farming experience in the area was 23.2 (3.3) years. The average number of household members in the traditional community was 6.3 members (**Table A.6**). Most of the farmers were married making up 43.7% of the households. The rest of the farmers were either single (32.0%), widowed (22.3%), or divorced (2.1%). In terms of religiosity, Christianity was the most popular religion making up 50.1% of the respondents, followed by polytheism (23.4%), traditionalism (12.6%), Shembe or Nazareth Baptist Church (7.9%), with atheists and agnostics making up the remaining 5%.

The study results show that 34.6% of households earn less than R12 000 per annum, 31.4% earn between R12 000 and R60 000, 18.2% between R60 000 and R100 000, while the remaining 15% earn greater than R150 000 per year (average exchange rate 1USD ≈ R15). Most of the income came from social grants (child support and old age), making up 60.7% of the households. The other sources of income were formal salary work (10.9%), casual labour (7.6%), remittances (6.2%), wage work (4.4%), sale of farm produce (3.8%), formal business (3.7%), informal economy (2.6%), and gifts (0.6%). Most of the farmers had smaller plots, with 77.4% of the participants owning less than a hectare of farming land. Although, all land belongs to the King, ownership in this study was based on the ‘permission to occupy’ type of lease, which guarantees the right to use the land. The tenure system does not give freedom to alienate, limiting the use of the land as collateral when performing economic and financial transactions. This type of lease may also limit investment in long-term benefits to the soil. The rest of the farmers were such that 19.6% owned between one and two hectares, while 3% owned more than two hectares. About 8.5% of the farmers belonged to some farming association, while 93% had never interacted with extension officers (**Table A.6**).

4.3.2. General attitudes of farmers towards human excreta use in agriculture

The general attitude score was positive (1.62), indicating that farmers were willing to use human excreta-based fertilizers (

Table 4.1). The estimated production attitude score was positive (1.59), while the consumption attitude score shows even more optimistic attitudes (1.66). The subjective norms were not as deterring as indicated by the generally positive (1.59) that others would comply with using, eating, and buying crops produced with human excreta. Perceived behavioral control presented potential barriers (1.43), indicating that farmers perceived lack of capability and some health risks in using human excreta in agriculture.

Table 4.1. Descriptive statistics of the attitudinal dimensions

Attitudinal dimensions	Number of respondents	Mean scores	Standard Deviation	Minimum	Maximum
Perceived behavioral control	341	1.43	0.23	1.00	2.00
Subjective norms	341	1.59	0.39	1.00	2.00
Overall attitude score	341	1.62	0.35	1.00	2.00
Production attitude score	341	1.59	0.36	1.00	2.00
Marketing attitude score	340	1.66	0.41	1.00	2.00
Combined attitude score	341	1.51	0.23	1.00	2.00

The farmers' attitudes were mostly positive that treating human excreta would reduce risk with an average attitude score of 1.83. Farmers exhibited negative attitudes on questions relating to perceived behavioral control, including skills or self-efficacy, pathogen, and pharmaceutical risks, all of which had mean attitude scores below 1.50 (**Table A.20**). On average, farmers were highly positive on the use of human excreta-based co-compost (1.77). A mean score of 1.77 could also be interpreted as indicating that approximately 77% of the farmers agreed to recycling human excreta. Surprisingly, farmers were generally negative on using urine to fertilize their crops, with a mean attitude score of 1.48.

The mean market-related attitude scores indicated that farmers have a positive attitude on buying co-compost, and (1.73), buying food produced with urine (1.57). The analysis of subjective norms also indicates positive attitudes with farmers expecting that other people in general, would use human excreta (1.63), buy food produced using co-compost as fertiliser (1.71), and that other people would eat food fertilised with human excreta (1.59). In terms of whether human excreta should be disposed of, farmers were moderately positive, with mean attitudes score of 1.51 (**Table A.20)**. Farmers expressed their doubt that other family members would eat food produced using human excreta with a sample mean attitude score of 1.42. The effect of crop type on willingness to accept human excreta was investigated in this study. Approximately 103 farmers (31%) of the sample farmers thought that the crop type fertilized with human excreta influenced their perceptions on the use of human excreta. Of the 103 farmers about 85% were willing to eat human excreta fertilised product if the fertilized crop was maize (**Table A.11**). A moderate 52% would eat vegetables, while only 41% were willing to eat root or tuber crops fertilized with human excreta.

4.3.3. The direction and magnitude of the influence of demographic, socioeconomic and environmental factors on attitudes

The hierarchical regression models estimated using the 'naïve approach' confirmed the importance of awareness in influencing social acceptance of human excreta. The results showed that awareness was the only independent variable that affects all dimensions of attitudes (**Figure 4.2**). A unit increase in attitudinal scores explains the degree to which attitudes shift into positive (or negative) attitude by a unit change in the independent variable. For a positive shift in awareness, the average increase in all the mean attitudinal scores ranged between a moderate 0.06 units for perceived behavioral norms and as high as 0.24 (0.03) units for consumption-market related attitudes (Error! Reference source not found.). Religiosity was the second most variable regressor across the five attitudinal scores, namely, the production attitude score, the consumption-market related attitude score, the perceived behavioral control, and the subjective norms all increasing by orders of magnitudes of 0.13 at the least, and 0.22 units at most, for a unit change from Christianity to other religions.

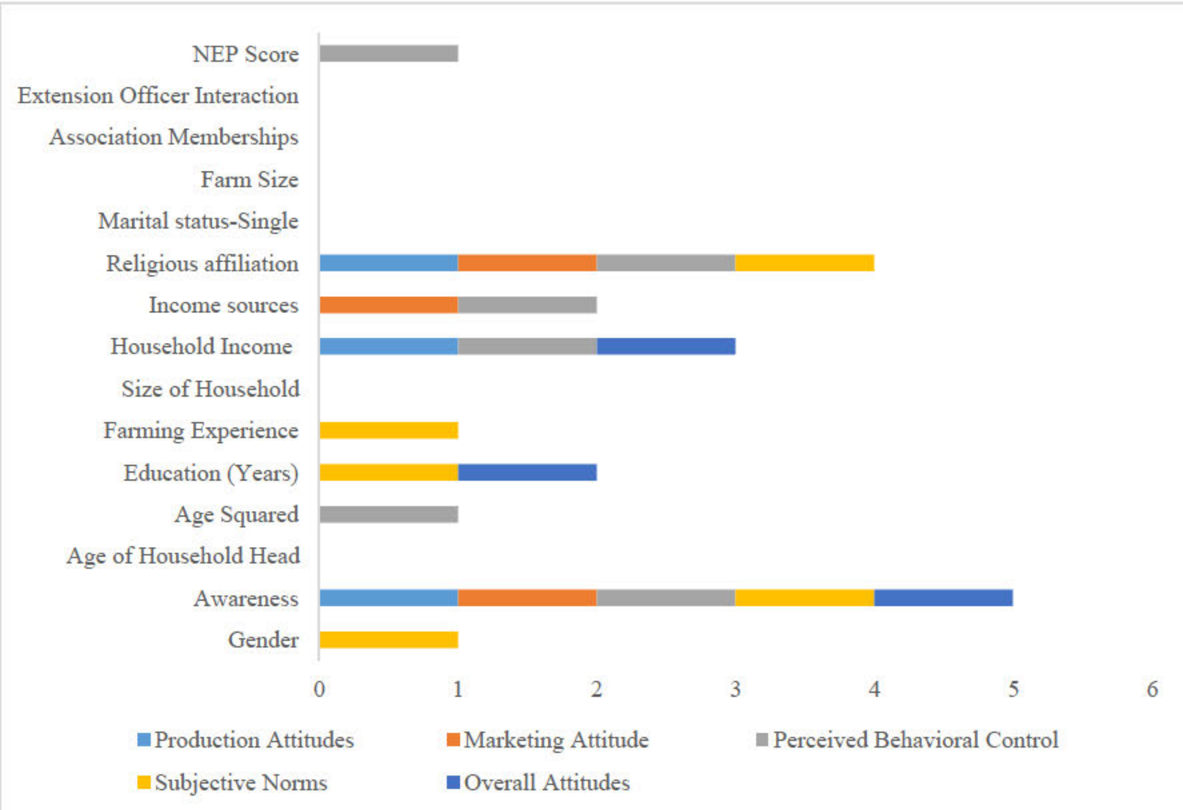

Figure 4.2. Segregated attitudes: the sensitivity of different attitudinal constructs to farmer characteristics

The third most sensitive variable was income. A change in the income from the lower to the middle-income group had a 0.15 increase in production attitudes. However, if income was to increase beyond the middle-income group to greater than R150 000 per year, farmers' attitudes were reduced by 0.19 units and 0.15 units for subjective norms and overall attitudes, respectively. A ten-year increase in education improves subjective norms by 0.20 score points and the overall attitude score by 0.10 units, confirming education's importance in changing subjective norms and overall attitudes. A 10-year increase in farming experience results in a 0.04-unit change in subjective norms score. Changing the income source from agricultural sales to remittances and social grants reduced perceived behavioral control by 0.13 and 0.16, respectively. Relying on agriculture to eke a living increased social acceptance. Being male also had a positive impact on subjective norms by 0.11 units. In terms of the environmental outlook, a positive unit increase in the NEP score had a 0.07 unit increase in the subjective norms. The results suggest that being proecological increases the social acceptance.

Table 4.2. Segregated attitudes using the naïve regression approach

Dependent Variables	Production Attitudes		Marketing Attitude		Perceived Behavioral Control		Subjective Norms		Overall Attitude Score	
Independent Variables	Coefficient	Std error	Coefficient	Std error	Coefficient	Std error	Coefficient	Std error	Coefficient	Std error
Gender	-0.015	(0.04)	0.041	(0.05)	-0.020	(0.03)	0.109**	(0.05)	0.045	(0.03)
Awareness	0.234***	(0.04)	0.241***	(0.05)	0.060**	(0.03)	0.148***	(0.05)	0.104***	(0.03)
Age of Household Head	-0.002	(0.01)	0.005	(0.01)	-0.010	(0.01)	0.012	(0.01)	0.001	(0.01)
Age Squared	0.000	(0.00)	-0.000	(0.00)	0.000*	(0.00)	-0.000	(0.00)	-0.000	(0.00)
Education (Years)	0.011	(0.01)	0.008	(0.01)	0.003	(0.00)	0.018**	(0.01)	0.010**	(0.00)
Farming Experience	0.002	(0.00)	-0.002	(0.00)	-0.001	(0.00)	0.004*	(0.00)	0.001	(0.00)
Size of Household	0.000	(0.01)	0.005	(0.01)	-0.001	(0.00)	-0.000	(0.01)	-0.001	(0.00)
Household Income less than R12 000										
R12 000≤ Y< R30 000	0.043	(0.05)	-0.083	(0.06)	-0.010	(0.04)	-0.003	(0.06)	-0.007	(0.04)
R30 000≤ Y<R60 000	0.070	(0.08)	-0.088	(0.09)	-0.019	(0.05)	-0.031	(0.09)	-0.025	(0.05)
R60 000≤ Y<R100 000	0.145*	(0.07)	0.026	(0.09)	-0.039	(0.05)	-0.104	(0.08)	-0.071	(0.05)
R100 000≤ Y<R150 000	-0.011	(0.08)	-0.128	(0.09)	-0.068	(0.05)	-0.066	(0.09)	-0.067	(0.05)
Greater than R150 000	-0.074	(0.12)	-0.120	(0.14)	-0.193**	(0.08)	-0.099	(0.14)	-0.146*	(0.08)
Income sources-Farm or agricultural sales										
Formal salary work	0.063	(0.11)	0.235*	(0.13)	-0.103	(0.08)	0.059	(0.12)	-0.022	(0.07)
Informal economy	-0.004	(0.11)	0.081	(0.13)	-0.092	(0.07)	-0.053	(0.12)	-0.072	(0.07)
Remittances/gifts	0.094	(0.12)	0.232	(0.15)	-0.155*	(0.08)	0.108	(0.14)	-0.023	(0.08)
Social grant	-0.041	(0.10)	0.140	(0.13)	-0.128*	(0.07)	0.030	(0.11)	-0.049	(0.07)
Christianity-Religious affiliation										

Traditionalism	0.035	(0.05)	-0.023	(0.06)	0.029	(0.04)	-0.022	(0.06)	0.004	(0.03)
Polytheism	0.103	(0.14)	0.010	(0.16)	0.216**	(0.10)	0.021	(0.16)	0.118	(0.09)
Shembe	0.130**	(0.06)	0.167**	(0.07)	-0.038	(0.04)	0.136*	(0.07)	0.049	(0.04)
Single-Marital status										
Married	-0.000	(0.06)	0.033	(0.07)	0.021	(0.04)	-0.097	(0.07)	-0.038	(0.04)
Divorced	-0.021	(0.04)	-0.026	(0.05)	-0.005	(0.03)	-0.060	(0.05)	-0.032	(0.03)
Widowed	0.019	(0.07)	0.052	(0.09)	0.031	(0.05)	0.040	(0.08)	0.036	(0.05)
Farm Size	0.045	(0.05)	-0.004	(0.06)	0.023	(0.03)	-0.033	(0.05)	-0.005	(0.03)
Association Memberships	0.113	(0.07)	-0.003	(0.08)	-0.066	(0.05)	-0.045	(0.08)	-0.056	(0.05)
Extension Interaction	0.047	(0.08)	0.006	(0.10)	0.054	(0.06)	-0.153	(0.09)	-0.049	(0.06)
NEP Score	-0.020	(0.04)	-0.020	(0.05)	0.067**	(0.03)	-0.028	(0.05)	0.020	(0.03)
Constant	1.234***	(0.32)	1.095***	(0.38)	1.536***	(0.22)	1.025***	(0.35)	1.280***	(0.21)
R-squared	0.233		0.184		0.116		0.175		0.142	
Degrees of Freedom	310		309		310		310		310	
BIC	346.4		456.1		99.4		423.4		75.3	

378 * p < 0.1, ** p < 0.05, *** p < 0.01

4.4. Discussion

4.4.1. General attitudes of farmers towards human excreta

This study explored farmers' recycling behavioral intentions in the traditional and rural community of Vulindlela in the KwaZulu-Natal province of South Africa, by employing the theory of planned behavior as a conceptual framework. The attitudes towards human excreta use in agriculture were highly positive. The farmers also showed moderate positive environmental attitudes with a mean attitude score, which significantly differed across the perceived behavioral control and subjective norms. Environmental consciousness was positively related to willingness to recycle human excreta. The influence of proenvironmental attitudes on human excreta confirm the results reported elsewhere (Khalid, 2018). Environmental consciousness was found to influence the willingness to adopt urine-diverting toilets and human waste recycling in Hawaii (Lamichhane and Babcock, 2013). Using university participants (Simha et al., 2018a), reported a different result, where environmental attitudes did not influence urine recycling attitudes. The different contexts (India vs. South Africa/Hawaii), study participants (farmers vs. university students), human excreta product (urine vs. urine and co-compost), and research methods may explain the different outcomes observed in the two studies.

This study has already confirmed differences in farmer preferences between urine and human faeces, with the latter being more preferred than urine. The result can be explained by the fact that farmers could be willing to work with products that they are most familiar with since co-compost is similar in attributes to ordinary compost or livestock manure. The study findings also validate the result that 70% of the farmers use compost-like material as soil conditioners namely, cow manure, poultry manure, organic compost, and farm residues. This result confirms the findings from US farmers where the perceived benefits and social acceptance was higher for biosolid-based fertilizers when compared to human urine-derived fertilizers (Segrè Cohen et al., 2020). This study also indicated that farmers were generally willing to use human excreta-based fertilizers, suggesting presence of a potential demand or social acceptance. The estimated production attitude consumption attitude score, score, and the subjective norms indicated that farmers were willing to use, buy, and consume products produced using human excreta. Perceived benefits may positively influence attitudes towards co-compost reuse. Empirical evidence shows that perceived benefits may include economic benefits (Khalid, 2018; Simha et al., 2017), and soil health improvement (Duncker and Matsebe, 2008; Ignacio et al., 2018; Jensen et al., 2008; Mojid et al., 2010; Saliba et al., 2018; Simha et al., 2017). Co-compost application could also enhance crop-fertilizer response thereby supplementing and complementing chemical fertilizers (Sommer et al., 2014, 2013; Vanlauwe et al., 2014c).

Results indicate that farmers reported negative perceived behavioral control which implies perceived health risk and low self-efficacy, or self-evaluation of skills required to use human excreta potential. The negative perceived behavioral control has been reported elsewhere where respondents were less confident of urine recycling due to perceived pathogen risk and pharmaceuticals (Simha et al., 2018c). Health risk perception has been reported in several studies as the main barrier to human excreta reuse in agriculture (Jensen et al., 2008; Mojid et al., 2010; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Phuc et al., 2006; Saliba et al., 2018). The perceived health risks span from the awful smell, skin infections, and other occupational hazards (Memon et al., 2016). Socio-cultural factors, norms, religion, and taboos were also found to be barriers to human excreta use in previous studies (Andersson, 2015; Buit and Jansen, 2016; Khalid, 2018; Lagerkvist et al., 2015; Mariwah and Drangert, 2011; Elisa Roma et al., 2013b; Simha et al., 2021). On average, the farmers were moderately positive on whether human excreta should be disposed, confirming their moderate environmental consciousness. However, the farmers expressed doubt on whether family members would eat food produced using human excreta, indicating strong influence of subjective norms.

4.4.2. The implications of attitudes of farmers towards human excreta for policy, and development practice

A total of ten variables significantly influenced the attitudinal dimensions. These include awareness, religion, education, age, interaction with extension officer, environmental consciousness, gender, farming experience, income, and source of income. Awareness, religiosity, education, and environmental consciousness positively influenced overall attitudes. The findings of this study fortify the significance of mainstreaming context-specific dissemination strategies in circular nutrient economy initiatives. Farmer awareness of human excreta reuse was the most important factor. Early studies confirm the positive relationship between awareness and recycling behavioral intention (Vining and Ebreo, 1990). The effect of awareness on attitudes also confirms the reported positive influence of mass media communication on subjective norms (Lamichhane and Babcock, 2013). Six studies reported the lack of awareness as a perceived barrier to human excreta reuse in farming (Appiah-Effah et al., 2015; Ignacio et al., 2018; Knudsen et al., 2008; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Saliba et al., 2018). Awareness and education were reported elsewhere to reduce the perceived health risks (Samuel, 2016). This study therefore demonstrates that raising awareness and educating farmers could improve self-confidence and reduce perceived health risks. The level of education has been previously reported to have a positive effect on the attitude towards human excreta recycling (Mariwah and Drangert, 2011; Mugivhisa et al., 2017; Phuc et al., 2006).

Religiosity was the second most variable regressor across the five attitudinal scores increasing for a unit change from Christianity to other religions. The result is surprisingly paradoxical given the importance of ecological sanitation in the Deuteronomic code of the Biblical text. In Deuteronomy 23:10-15, the Israelites were instructed by God in the Deuteronomic laws (chapters 12-26) to practice complete burial of human excreta on the ground, which has been linked to the concept of ecological sanitation by theologians and ethicists who are shifting their understanding to tracing the roots of environmental concerns in biblical sources (Hiers, 1996). The positive link between religious education and environmental attitudes is also well established in the literature (Awuah-Nyamekye, 2019). However, sensitivity to religious view is important for customer prospecting, and the designing and implementation of dissemination strategies.

Other variables such as age, farming experience, income, and income source were found to negatively influence subjective norms and consumption-related attitudes. Five variables, namely, household size, marital status, farm size, membership to an association, and extension officer interaction did not influence behavioral intentions. Younger farmers were more positive towards reusing human excreta. The result confirmed the findings from two other studies in South Africa, which indicated that younger farmers had more positive attitudes (Mugivhisa and Olowoyo, 2015; Wilde et al., 2019). These results contradicted with findings in India, where older farmers expressed a more positive attitude (Simha et al., 2017). The results also indicate that the more experienced farmers are in agriculture are more comfortable with their current technologies, and the less likely they accept new technologies. The negative income effect indicated that lower-income farmers were more willing to use human excreta, validating the results reported in other studies (Cofie et al., 2010; Dansol et al., 2002).

Targeting low-income groups as champions in the demonstration of circular bioeconomy innovations could guarantee the social acceptance. The older farmers and middle-income groups who source their income from non-agricultural sources (such as social grants and casual labour) could only adopt the innovation if they see it working with the innovators. The influence of socioeconomic farmer characteristics, such as experience in farming, income, farm size, and agronomic benefits on the attitude towards human excreta reuse in agriculture, has been reported in other studies (Cofie et al., 2010; Dansol et al., 2002). Male farmers perceived that negative influence of subjective norms. Female farmers showed a negative attitude compared to male farmers as reported in(Mariwah and Drangert, 2011), and male farmers had a positive attitude towards eating human excreta fertilized food compared to female farmers (Duncker and Matsebe, 2008).

There is substantial evidence indicating the significance of addressing the local context for the exploitation of the potential of new information and communication technologies in developing countries (Burlakovs et al., 2017). Policymakers could integrate the circular bioeconomy ideas based on indigenous knowledge systems to add value to the development policy practice while shifting the existing paradigms. Policy incentives for co-composting could include viability gap funding, clean development mechanisms, fair competition from mineral fertilizers, and an enabling regulatory environment for circular bioeconomy approaches. The public institutions, private sector, non-government organizations, and co-operative development partners could provide the capital required for setting up scalable, and viable co-composting projects. The donor support could help absorb the start-up costs such as awareness building, activating demand, and technical training (Kohl and Foy, 2018).

A transdisciplinary dissemination approach that appreciates human excreta reuse as more than a technology, but an innovation process operating within a socio-technical system, could help to co-design and co-develop farmer-driven dissemination plans and marketing strategies. The study results could enhance market segmentation and prospecting of innovative farmers to champion the on-farm testing and piloting of scalable co-compost innovations. The use of the World Health Organisation sanitation safety-planning manual as a template for developing local training material could lower the perceived risks and low self-efficacy. Awareness campaigns could enhance self-confidence by the end-users to maintain the technologies and to use the products (Lüthi et al., 2011). This could be enhanced by early community involvement through assessing the possible products needed from FS and willingness to produce and use these products (Bassan et al., 2012). Demonstration projects are among the most effective marketing strategies used to penetrate new markets (Rouse et al., 2008). A sustainable systemic wide-scale adoption of innovations is only possible through the public and the private sector, which can sustain the change over time (Cooley and Howard, 2019). Scaling occurs when there is sustained and systemic change to a new normal beyond the funded project’s time frame (Woltering et al., 2019).

4.4.3. Other driving forces and potential barriers and future research direction

The effect of crop type, processing, and cooking influenced farmers’ perceptions on the use of human excreta. South Africa's experiences with domestic treated wastewater effluent show the importance of choosing the right crops by avoiding crops that are consumed raw, while prioritizing crops with edible parts wrapped in husks, pods, and peels (Okem and Odindo, 2020). Moving away from crops such as cucumbers, carrots, and lettuce towards maize and beans may enhance social acceptance. The effect of treating human excreta, crop type, processing, and cooking food on farmers' attitudes was not investigated in the literature. The results of this study therefore provide a preliminary insight to these issues and create an interesting point of departure for in-depth future studies. The study findings show the importance of treatment and certification, processing, and cooking in promoting the use of human excreta in agriculture.

The results from the research from the social acceptance of genetically modified and organic foods reinforce the influence of processing on consumer willingness to accept (Bredahl, 1999; Bredahl et al., 1998; Costa-Font et al., 2008; Grunert et al., 2003, 2001). The further the distance of human excreta-derived fertilizers from the consumer, and change in form through processing, the more likely farmers are willing to consume the food produced from it. Processing tomatoes into tomato sauce, maize into instant porridge, or sugarcane into table sugar may enhance social acceptance. Our findings show that most farmers in rural South Africa choose their main fertilizers based on availability, price, safety, and certification. Empirical evidence shows that availability, transport, storage costs, and perceived self-efficacy are potential barriers to reusing human excreta in agriculture (Andersson, 2015; Cofie et al., 2010; Lagerkvist et al., 2015).

Other desirable characteristics investigated in this study include the nutrient content, packaging, credit facilities, pelletization, and recommendation by trusted sources (Table S9). Specific to co-compost, the most reported desirable characteristics include soil health productivity, treatment, and the fact that it enables farmers to buy fewer chemical fertilizers. The importance of providing compost in the right attributes to farmers and the cost of providing such attributes have been investigated elsewhere although it remains a nascent and an important area for future research (Gwara et al., 2020). The farmers who were not willing to use co-compost reported smell, current use of chemical fertilizer, fear of being mocked, the need for more research, health risk, organoleptic/tastes, disgust, and religions or taboos as the potential reasons for resistance to using human excreta in agriculture (Table S.13 and S.14). For instance, findings from the US suggest that disgust is not a major driving force to acceptance (Schreiber et al., 2021). While most of these elements can be addressed by raising awareness, hygiene practices, and education, the health risk perception are of technical concern for contaminant elimination. Using the World Health Organization Sanitation Safety Plans to perform microbial risk assessment across the human excreta recovery, and reuse chain is recommended for protecting farmers' health (Okem and Odindo, 2020).

4.5. Limitations

Some exciting elements were not explored to reduce the length of the paper. The environmental attitudes could have been explored further, primarily, the effects of demographic, socioeconomic, and cultural factors, and the nature of the ecological dispositions of rural farmers. Another interesting dimension would be to block the study by different environments so that attitudes can be evaluated for farmers in rural and urban settings and compare the results for a more targeted development approach. The latent structure and the dimensionality of the NEP scale against the five worldviews: 1) reality of limits to growth, 2) antianthropocentrism, 3) fragility of nature's balance, 4) rejection of human exemptionalism (the belief that humans are exempt from environmental forces), and 5) the possibility of an ecocrisis was not evaluated in this study. The issues may provide an interesting area for future research.

4.6. Conclusion

Behavioral intentions to use human excreta were evaluated using the theory of planned behavior in this study. The segregated attitudes were evaluated for production attitudes, consumption attitudes, subjective norms, perceived behavioral control, and the overall or combined attitudes. Attitudes towards the reuse of human excreta are mainly sensitive to subjective norms and perceived behavioral control suggesting the importance of understanding local context when mainstreaming recycling initiatives and when designing and implementing dissemination plans and strategies. The findings of this study suggest that there is demand for human excreta derived fertilizers in rural agricultural communities of South Africa. The farmers exhibited positive attitude towards the recycling of human excreta in agricultural food systems.

The effect of farmer characteristics, such as religiosity, income, education level, gender, and environmental consciousness need to be understood and tailor interventions and target customer segments, rather than implementing blanket recommendations. The perceived behavioral control was reported to be a potential barrier to human excreta reuse in agriculture, indicating strong influence of health risk perception and demand for skills. Behavioral intentions to use human excreta were driven by age, awareness, religiosity, income, income source, and environmental disposition. Understanding the nature, and direction of the influence of attitudinal dimensions and farmer characteristics is important for mainstreaming circular bioeconomy interventions.

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CHAPTER 5: PSYCHOMETRIC ANALYSIS OF THE ECOLOGICAL DISPOSITIONS OF RURAL FARMING COMMUNITIES IN SOUTH AFRICA: IMPLICATIONS FOR HUMAN EXCRETA REUSE IN AGRICULTURE.

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Abstract

The established link between anthropogenic activities and environmental problems calls for the understanding of public perceptions of the environment. Circular bioeconomy approaches promote sustainable and resilient food systems, and are critical to address soil, human, and environmental health. This study endeavours to understand the ecological worldviews of rural farming communities and implications for human excreta reuse in agriculture. The study adopted the social psychology theory and the new ecological paradigm scale, which measures environmental attitudes. The Cronbach's alpha factoring indicated high internal consistency and reliability of the questions. The results show that rural farmers are moderately environmentally conscious. The hierarchical regression results show that age, education, and household income negatively influence environmental attitudes. Pro-environmental farmers perceived lower health risk and believed that they were more capable of using human excreta. The study recommends that the reuse of human excreta in agriculture be marketed as a sustainable and environmentally friendly innovation to increase social acceptance by rural farmers in agri-food systems.

Keywords: *Ecological worldview; new ecological paradigm; dominant social paradigm; environmental attitude; human excreta; agriculture.*

5.1. Introduction

Agriculture is the main source of food for the rapidly growing global population and is responsible for more than 90% of global water consumption (Food and Agricultural Organization (FAO), 2003; Hamdy et al., 2003; Jury and Vaux, 2007; Misra, 2013; Pimentel et al., 1997). Agriculture also accounts for up to 90% of reactive nitrogen that enters the earth (Bodirsky et al., 2014; Erisman et al., 2011) and for more than 20% of greenhouse gas emissions (Bennetzen et al., 2016; Frank et al., 2017). The circular bioeconomy approach is essential for promoting sustainable and resilient food systems and is critical for improving soil, as well as human and environmental health (Bovea et al., 2018; Drechsel et al., 2018; Millward-Hopkins et al., 2018). The continued loss of natural resources and environmental quality and the advent of potential global catastrophes, such as climate variability and global warming, increase the interest in understanding the nature of society-environment relationships (Dunlap et al., 2000). A circular bioeconomy is important for building resilient and sustainable food systems (Giampietro, 2019; Kardung et al., 2021; Leong et al., 2021; Stegmann et al., 2020). Conventional agricultural intensification practices have a negative impact on the environment (Lin et al., 2019; Savci, 2012; Sonntag et al., 2005) and are therefore not sustainable (Tilman et al., 2011). Sustainable agricultural intensification could help to meet the growing food demand (including water and energy), while replacing the use of external inputs (Kleijn et al., 2019b). The United Nations Sustainable Development Goals (SDGs), specifically SDG 2 and SDG 12, emphasise responsible production and consumption, seek to end hunger, and promote sustainable food and nutrition security for the growing global population (UN, 2015).

The past decade has also seen the emergence of a new and growing field of research called 'sustainability science', which is dedicated to understanding human-nature interactions (Bettencourt and Kaur, 2011; Kates, 2015). Sustainability science seeks to understand the socio-ecological interaction of human society and its natural environment, and how the relationship influences sustainability, namely intergenerational redistributive justice, poverty, and maintaining the balance of nature (Anderson et al., 2015; Bettencourt and Kaur, 2011; Kates, 2015). The relationship between society and nature has previously been explained by the dominant social paradigm (DSP), which has been criticised for environmental decline (Kilbourne et al., 2002; Kilbourne and Carlson, 2008). The new ecological paradigm (NEP) challenges the DSP to hypothesise five facets, namely limits to growth, anti-anthropocentrism, balance of nature, anti-exemptionalism, and the existence of an ecological catastrophe or eco-crisis (Dunlap et al., 2000). The contribution of anthropogenic activities to issues such as land degradation, environmental pollution, and global warming is well established in the literature, which provides a rationale for understanding the environment-nature relationship (Lange and Dewitte, 2019). For instance, climate scientists generally agree on anthropogenic global warming (Mackay and Schmitt, 2019). Furthermore, earlier, and new empirical evidence suggests a positive relationship between environmental consciousness and pro-environmental behaviour (Escario et al., 2020; Weigel and Newman, 1976).

While the validity of measuring environmental attitudes through the NEP is established (Dunlap et al., 2000), understanding how society relates to the environment and its ecosystem services is vital for mainstreaming circular bioeconomy initiatives in specific contexts. In environmental psychology, self-reported environmental attitudes are used as a latent indicator of behavioural intentions of the human concern for their natural environment. Previous psychometric analyses utilising the NEP scale have reported two-, four-, and five-dimension models as opposed to the hypothesised unidimensionality of the 15-item scale (AlMenhali et al., 2018). The explicit measurement technique of a direct self-report method using a questionnaire is the most popular method to measure environmental attitudes (AlMenhali et al., 2018).

There is however, a dearth of knowledge regarding how rural farmers relate to their agricultural environment. This study endeavoured to close this knowledge gap by investigating the environmental attitudes of rural farming communities and the implications for human excreta reuse in agriculture. The recovery and reuse of human excreta have several benefits as they link with circular bioeconomy and circular sanitation economy in agriculture (Ganesapillai et al., 2016; Giampietro, 2019; Stegmann et al., 2020; Toilet Board Coalition, 2017). The upstream benefits of human excreta recovery and reuse are related to the emptying of full pit latrines, which acts as a way of providing sanitation for communities that mainly depend on on-site sanitation (Harrison and Wilson, 2012; Still et al., 2010). The downstream benefits are related to the reuse of human excreta to build soil organic matter and therefore helping to restore soil health and complement the agronomic efficiency of chemical fertilisers (Harder et al., 2019; Heinonen-Tanski and van Wijk-Sijbesma, 2005; Khalid, 2018; B Moya et al., 2019). Other benefits of human excreta recycling are associated with waste management, and sustainability issues related to reduction in net emissions, reduction in environmental contaminants, and resource efficiency from the offset use of chemical fertilisers (Al-Khateeb et al., 2017; Drechsel et al., 2018; Gardner et al., 1993; Otoo et al., 2015)

Understanding how to raise awareness of environmental impacts is one of the main justifications of understanding environmental worldviews (Ogunbode and Arnold, 2012). This study endeavoured to investigate the reliability, validity, and latent structure of the NEP scale as applied to South

African rural farmers. The psychometric analysis of environmental attitudes was investigated, firstly, to determine the suitability of the 15-item NEP scale in the African rural farming context, and, secondly, to provide baseline knowledge on the influence of environmental attitudes on pro-environmental behavioural intentions. It is also important to note that both the DSP and the pro-ecological components of the NEP scale were originally based primarily on Western concepts of environmentalism and technology and that the NEP scale does not seem to be valid in all cultural settings. This study therefore endeavoured to validate and at least test the consistency of the NEP when applying it outside of its original context. Understanding how rural African farmers relate to their environment through the identification of demographic and socio-economic farmer characteristics that influence the environmental attitudes may help to mainstream dissemination strategies and promote environmental consciousness.

5.2. Materials and methods

5.2.1 Study area and research design

The survey data were collected using a structured questionnaire, which was administered through personal household interviews in the Vulindlela rural farming community (30.1466°S, 30.6603°E) in the KwaZulu-Natal province of South Africa. The study was ethically reviewed and granted full ethical approval by the university's Humanities and Social Sciences Research Ethics Committee (approval number HSSREC/00001499/2020). Informed verbal consent was obtained from the participants before beginning the survey; with participants being provided the freedom to withdraw from the study at any time. Details of the informed consent are provided in the survey instrument, which is available at https://enketo.ona.io/x/#EkSVyazm. Sample power analysis was performed using the G*Power software based on a power of 0.95, alpha of 0.05, and Cohen's *d* effect size of 0.15 to provide a sample size of 153, although the total sample size was increased to 341 farmers based on resource availability and to accommodate other choice experiment studies that used the same survey instrument. A multi-stage sampling procedure was used to select two wards that were the farthest from the main city. A systematic random sampling procedure was used to select households where the sampling interval was calculated to systematically select household units. From each household, the main decision maker or head of the household was selected for the interview. To accommodate non-responses, absentees, or inaccessible households, the closest household was selected and then resampled from the newly selected household.

The Vulindlela Traditional Council consists of nine wards; all under the sole trustee of the king (Kharsany et al., 2015; Msunduzi Municipality, 2016). The traditional community provides residence to the more than 150 000 predominantly Zulu-speaking population (Kharsany et al., 2015). A multi-stage sampling procedure was implemented to select 341 farming households to interview. The study implemented two-day training of enumerators to enhance face validity, identify avertable problems, and improve data quality. The elicitation of environmental attitudes using the NEP scale requires enumerators with exceptional language translation skills and a relatively high conceptualisation level, including the ability to have sensitive conversations with rural farmers. A revised, 15 item five-point Likert NEP scale was used to elicit the participants' environmental attitudes (Dunlap et al., 2000; Stern et al., 1995)

5.2.2 Data analysis

This study elicited environmental attitudes and general attitudes towards using human excreta-derived material in agriculture from a sample size of 341 rural farmers in South Africa. The study used binary response-type questions, where 2 represents agreement (2 = 'yes') and 1 represents disagreement (1 = 'no'), to give a mean response of $1 \leq \mu \leq 2$ (Lamichhane and Babcock, 2013). A mean score of 1.5 was considered neutral, with a mean score above 1.5 indicating a positive attitude. The reason for using single-response, closed-ended yes-no questions was to reduce the cognitive burden on the respondents. Although responses from open-ended qualitative questions may provide a richer dataset, it can be unwieldy to make conclusions from such data. Demographic and socio-economic data such as the age, education, farm experience, income, income sources, gender, religious affiliation, interaction with extension, farm size, and family size of the household head were also collected.

The five-point Likert NEP scale item responses were coded 1 to represent strong disagreement and 5 to represent strong agreement with the question (Dunlap et al., 2000). The seven even-numbered NEP statements where disagreement with each statement represented a pro-environmental/ecological worldview were reverse coded for analysis purposes from the original survey coding to follow the same direction of agreement with the rest of the questions (Ogunbode, 2013; Ogunbode and Arnold, 2012; Simha et al., 2018a; Singleton et al., 2021). The overall NEP rating ($1 \leq \mu \leq 5$) indicated the mean of all responses (Ogunbode, 2013), with 3 being neutral, 1 being strongly anti-ecological, and 5 representing strongly pro-ecological worldviews (Van Petegem and Blieck, 2006). The study used Cronbach's alpha (α) to test the participant responses' internal consistency and the reliability of the NEP statements. Using the results of the exploratory factor analysis, the latent structure and the dimensionality of the NEP scale were evaluated against the five facets, namely reality of limits to growth, anti-anthropocentrism, fragility of nature's balance, rejection of human exemptionalism (the belief that humans are exempt from environmental forces), and the possibility of an eco-crisis (Dunlap et al., 2000; Ogunbode, 2013).

5.2.3 Segregated environmental attitudes

The study used the theory of planned behaviour to predict the farmers' behavioural intentions to use human excreta (Gorton and Barjolle, 2014; May et al., 2021), which is empirically tested and validated. The assumption is that, if farmers report positive attitudes towards human excreta recycling in their agricultural systems, there should be strong intentions to practise the actual behaviour (Simha et al., 2018a). The theory has been empirically applied to evaluate various pro-environmental behavioural intentions (Hu et al., 2018; Ignacio et al., 2018; Simha et al., 2021; Vassanadumrongdee and Kittipongvises, 2018; Wang et al., 2016). The farmer characteristics identified include gender (1 = male, 0 = female), age of the household head (in years), years of education, years of farming experience, religious affiliation (1 = Christianity, 0 = others), and income as categorical variables. Segregated environmental attitudes were analysed using the hierarchical regression models to test the influence of farmers' demographic and socio-economic characteristics. The latent class-based regression models were used to allow the data dimension reduction of the outcome variable, and to test the hypothesised link between the psychometric NEP scale and the demographic, cultural, sociological, and economic farmer-specific variables. The model provides a robust probabilistic approach to capture the unobserved heterogeneity in the response variable (Ortega-Egea et al., 2014). The suitability of factor analysis was examined using a correlation matrix to filter out coefficients less than 0.3 as problematic (Tabachnick and Fidell, 2001) The study used the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity to assess the correlation matrix factorability. Values greater than 0.5 were used as the minimum for the KMO test and values less than 5% for Bartlett's test (Kaiser and Rice, 1974) Orthogonal varimax rotation was adopted for easy interpretation of the factor-loading structure. The factors were analysed and saved for use as dependent variables in the regression models. The hierarchical regression analysis requires the dependent variable (attitudinal dimensions) to approximate a normal distribution and to be on a continuous scale (Mishra et al., 2019)

5.2.4 The influence of environmental attitudes on human excreta reuse in agriculture

The segregated attitude scores were evaluated to estimate the effect of environmental worldviews on the six dimensions of attitudes inspired by the theory of planned behaviour, namely (i) the attitude score, (ii) the production attitude score, (iii) the consumption attitude score, (iv) the perceived behavioural control, (v) the subjective norms, and (vi) the combined attitude score. The attitude score was computed by taking the mean scores of the following six attitudinal questions, namely (a) are you willing to use co-compost in agriculture, (b) are you willing to use human urine, (c) do you think human excreta should be disposed and never used, (d) would you buy food produced using human excreta, (e) would you eat food produced using co-compost, and (f) would you consume food produced using human urine? The production attitude score was calculated from the mean score of three of the six attitudinal questions above (a, b, and c). The consumption attitude score was computed by taking the mean score of three of the questions above (d, e, and f).

The perceived behavioural control score was calculated based on the mean score of the four question items, namely (i) do you think that you have enough skills to use human excreta in agriculture, (ii) do you think that treating human excreta reduces health risk, (iii) do you think that treated human excreta contain disease-causing agents, and (iv) do you think that pharmaceuticals can still be found in food produced using human excreta? The perceived behavioural control was expected to capture the respondents' self-evaluation of their confidence or skill (self-efficacy) and their risk-benefit perception. The subjective norms score was calculated by taking the mean score of the following questions: (i) do you think others would use human excreta in agriculture, (ii) do you think others would buy food grown with co-compost, (iii) do you think your family would eat food grown with human excreta, and (iv) do you think relatives, neighbours, or friends would eat food grown using human excreta? The subjective norms were expected to capture the existence of convergent human behaviour and the influence of individual attitudes by the behaviour of others through social learning.

The influence of the environment on behavioural intentions helps to test the attitude-intention hypothesis, namely whether environmental dispositions influence recycling behavioural intentions. The analysis of variance (ANOVA) was used to compare the mean scores of the environmental dispositions. The study used Fisher's least significant difference (LSD) to report the significant mean group comparisons. The effect of environmental disposition was evaluated for endorsement of NEP or pro-ecological worldviews ($\mu > 3$), neutral ($\mu = 3$), and the DSP ($\mu < 3$).

5.3. Results

5.3.1 Environmental attitudes of farmers

The NEP scale's reliability was tested, and a Cronbach's alpha of a respectable 0.76 indicated high internal consistency of the scale (see Table 5.1). The achievement of internal consistency is a necessary but not sufficient condition for unidimensionality. The mean NEP rating of the dataset was 3.12, which indicates moderate environmental consciousness (see **Table 5.1**). Further examination of item mean scores shows that farmers strongly agreed with the ecological crisis and the balance of nature. The results also indicate that rural farmers are anti-anthropocentric; that is, they disagreed with the domination of other species by humans (Items 2 and 12). Rural farmers also disagreed with the exemption of human beings from environmental forces and their capability to adapt (Items 4 and 14).

Table 5.1. Exploratory factor analysis of the New Ecological Paradigm (NEP) scale items

Item	Item scale	Mean	Std. dev	Cronbach's alpha	Five facets
1	We are approaching the limit of the number of people the earth can support.	3.57	1.01	0.74	Limits
2	Humans have the right to modify the natural environment to suit their needs.	2.32	1.00	0.76	Anti-anthro.
3	When humans interfere with nature, it often produces disastrous consequences.	3.65	0.90	0.74	Balance
4	Human intelligence will ensure that we do not make the earth unliveable.	2.49	1.02	0.75	Anti-exempt.
5	Humans are seriously abusing the environment.	3.87	1.04	0.74	Eco-crisis
6	The earth has plenty of natural resources if we just learn how to develop them.	2.18	0.85	0.77	Limits
7	Plants and animals have as much right as humans to exist.	3.63	1.14	0.76	Anti-anthro.
8	The balance of nature is strong enough to cope with the impacts of modern industrial nations.	2.86	0.96	0.74	Balance
9	Despite our special abilities, humans are still subject to the laws of nature.	3.91	0.85	0.76	Anti-exempt.
10	The so-called 'ecological crisis' facing humankind is greatly exaggerated.	3.08	1.09	0.76	Eco-crisis
11	The earth is like a spaceship with very limited room and resources.	3.32	1.04	0.74	Limits
12	Humans were meant to rule over the rest of nature.	2.14	1.04	0.76	Anti-anthro.
13	The balance of nature is very delicate and it can easily be upset.	3.57	0.82	0.74	Balance
14	Humans will eventually learn enough about how nature works to be able to control it.	2.37	0.88	0.76	Anti-exempt.
15	If things continue on their present course, we will soon experience a major ecological catastrophe.	3.77	0.89	0.74	Eco-crisis
	Mean NEP rating	**3.12**	**0.47**		

The dimensionality of the NEP scale revealed three unique constructs (extracted using Kaiser's rule) against the hypothesised unidimensional constructs or the five facets (Dunlap et al., 2000). Based on Kaiser's rule, the first component explained 25.42% of the data variation, while the second component explained 14.52% and the third explained 7.34% of the variation in the data. The eigenvalues pattern (3.81, 2.18, 1.10) can be interpreted as suggesting the presence of one main factor that fortifies the strong evidence of internal consistency (Dunlap et al., 2000). The three constructs cumulatively explained 47.28% of the variation in the scale (see **Table 5.2).**

Table 5.2. Principal component analysis to test the dimensionality of the NEP scale

Factor	**Initial eigenvalues**			**Extraction sums of squared loadings**		
	Total	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	3.81	25.42	25.42	3.16	21.04	21.04
2	2.18	14.52	39.94	1.57	10.43	31.48
3	1.10	7.34	47.28	0.35	2.34	33.82
4	0.99	6.58	53.86			
5	0.91	6.06	59.92			
6	0.83	5.56	65.48			
7	0.78	5.23	70.71			
8	0.71	4.75	75.46			
9	0.68	4.53	79.99			
10	0.64	4.27	84.26			
11	0.57	3.78	88.04			
12	0.52	3.46	91.50			
13	0.50	3.32	94.82			
14	0.42	2.79	97.61			
15	0.36	2.39	100.00			

The latent structure examination using extracted component loadings greater than 0.3 shows that the first component loaded heavily on nine of the 15 items (see **Table 5.3).** Close examination of the first component loading shows two loadings on limits items (Items 1 and 6), two balance of nature items (Items 3 and 8), two ecological crisis items (Items 5 and 15), and two anti-anthropocentrism items (Items 2 and 7), and one anti-exemptionalism item (Item 4) loading of the first factor. The loading structure indicates that all the dimensions or facets loaded on the first factor, which further confirms the unidimensionality assumption. The second factor-loading structure has two anti-anthropocentrism items (Items 7 and 12), one of each remaining facet (Items 9, 10, and 11), and no loading on the balance of nature item. The third component heavily loaded on the balance of nature item (Item 13), the anti-exemptionalism item (Item 14), ecological crisis (Item 15), and the limits to growth (Item 11), and did not load on the anti-anthropocentrism dimension. The three discernible dimensions are not unreasonable but indicate sample variations in belief systems and the organisation of items into unique and coherent frameworks (Dunlap et al., 2000).

Table 5.3. Principal component analysis of the NEP scale showing factor loadings

Items	Five hypothesised facets	Component loadings		
		1	2	3
1	Limits	0.77		
2	Anti-anthro.	0.72		
3	Balance	0.67		
4	Anti-exempt.	0.67		
5	Eco-crisis	0.67		
6	Limits	0.63		
7	Anti-anthro.	0.54	0.30	
8	Balance	0.38		
9	Anti-exempt.		0.70	
10	Eco-crisis		0.66	
11	Limits		0.63	0.38
12	Anti-anthro.		0.62	
13	Balance			0.72
14	Anti-exempt.			0.62
15	Eco-crisis	0.31		0.55

5.3.2 Segregated environmental attitudes: A measure of construct validity

Segregated environmental attitudes evaluate the influence of the farmers' demographic and socio-economic characteristics using the latent class models and hierarchical regression. The NEP scale's construct validity indicates whether the item scores are related expectedly with individual farmer characteristics, namely age, education, gender, religiosity, and income. Using the mean NEP score as the dependent variable, the age, level of education, and extension officer interaction significantly influenced environmental attitudes. The more sensitive environmental attitudinal dimension was the first component extracted using factor analysis. Age, education, experience in farming, religiosity, extension officer interaction, and household income all significantly influenced the farmers' environmental disposition. The age variable behaved as expected, where younger farmers endorsed the NEP scale. The rationale is that younger farmers will be willing to try new technologies, instead of older farmers who are firm in their traditions. With a 10% increase in age, the environmental attitude score reduced by 0.2 ($p \leq 0.01$), which validates the construct validity of the NEP score (see **Table 5.4).**

The level of education negatively and counterintuitively influenced environmental attitudes. The intuitive results would be that the more educated farmers are, the more likely they are to be exposed to environmental issues and would therefore be more pro-ecological (Dunlap et al., 2000). The study results show that a 10% increase in years of education reduces the mean NEP score by a non-negligible 0.4 units. A shift from the lower-income group to the middle and towards higher income results in a significant reduction of 0.15 score points in the NEP score. The more educated rural farmers are, the less likely they are to care about the environment. This is counterintuitive as empirical evidence from the Global North suggests a positive influence of education on environmental concern (Jones and Dunlap, 2010).

Extension officer interaction and years of farming experience were the only variables that positively affected environmental attitudes as measured by the NEP scale. A change from not interacting with an extension officer to at least one interaction per year shifts the NEP score by a considerable 0.46 score points. A 10% increase in farming experience results in a 0.1 score points increase in the NEP score. Interaction with an extension officer provides new information about changes in the environment; increased frequency of interaction should therefore, as expected, be linked positively to endorsing the NEP scale.

To check for robustness, the results of the exploratory factor analysis were used as dependent variables to identify the influences of farmer characteristics on environmental attitudes. The effect of farming experience is likely to be different from that of the age of the household head. Farming experience indicates the number of years that the farmer has been fully engaged as a farmer. One would expect a more experienced farmer to be in touch with the environment and therefore more environmentally conscious, as indicated by the results. Religiosity (coded 1 = Christianity) also had a significant negative effect on the farmers' environmental dispositions. Moving from Christianity to other religions increased the likelihood of supporting pro-environmental behavioural intentions. Household income negatively correlated with pro-environmental attitudes and thus with social acceptance of excreta use. The findings for education and household income were particularly in contrast to the findings of similar studies in other populations, in which higher education and income tended to be associated with stronger pro-environmental attitudes and greater acceptance of the agricultural utilisation of human excreta.

Table 5.4. Segregated environmental attitudes using the mean NEP score and factor analysis

Dependent variables	Mean NEP score	Component 1	Component 2	Component 3
Independent variables	Coefficient (std. error)	Coefficient (std. error)	Coefficient (std. error)	Coefficient (std. error)
(Constant)	3.67(0.19)***	1.50(0.40)***	0.55(0.32)	0.75(0.27)***
Gender	-0.03(0.06)	0.02(0.12)	-0.12(0.10)	0.08(0.08)
Age (in years)	-0.01(0.00)	-0.02(0.01)***	0.01(0.01)	-0.02(0.01)***
Years of education	-0.02 (0.01)***	-0.04(0.02)**	-0.02(0.02)	-0.02(0.01)
Farming experience (in years)	0.00(0.00)	0.01(0.01)***	-0.02(0.00)***	0.01(0.00)***
Religious affiliation	-0.03(0.02)	-0.12(0.05)**	-0.42(0.13)***	-0.20(0.11)

Extension officer interaction	0.22(0.11)**	0.46(0.22)**	0.07(0.18)	0.08(0.16)
Annual income	-0.03(0.03)	-0.15(0.05)***	-0.10(0.05)	-0.03(0.05)

** p < 0.05, *** p < 0.01

5.3.3 The influence of environmental attitudes on human excreta reuse in agriculture

The general attitudes of rural farmers were positive (1.62), which indicated that 62% of the farmers were willing to use human excreta-based fertilisers. The production attitude score (1.59), consumption attitude score (1.66), and subjective norms (1.59) all indicated willingness to use human excreta in agricultural systems, consume and buy food produced from it, and low restrictions from subjective norms, respectively. The perceived behavioural control (1.43) was negative, which indicated a lack of self-efficacy and perception of health risks (see **Table 5.5).** To provide empirical evidence of the influence of ecological dispositions on human excreta recycling behavioural intention, the ANOVA results show that the effect is complex. Environmental attitudes measured using the NEP score significantly affected perceived behavioural control and subjective norms, but not attitudes towards behaviour. Pro-environmental attitudes had a positive and significant effect on perceived behavioural control. The findings indicate that eco-centric farmers, on average, exhibit higher self-confidence (self-efficacy) and lower risk perception in terms of human excreta reuse in agriculture. The attitude-intention hypothesis confirmed the positive influence of environmental attitudes on the behavioural intention to recycle human excreta. However, farmers who endorsed the DSP perceived that subjective norms positively influenced the behavioural intention to recycle human excreta.

Table 5.5. Influence of ecological worldviews on the attitudes towards human excreta reuse using analysis of variance (ANOVA)

Attitudinal dimensions		**Perceived behavioural control**		**Subjective norms**		**Attitude score**		**Combined attitude score**		**Production attitudes**		**Consumption attitude**	
Variables	N	*Mean*	*P*	*Mean*	*P*	*Mean*	*P*	*Mean*	*P*	*Mean*	*P*	*Mean*	*P*
LSD tests		NEP>DSP=0.05		DSP >NEP=0.13									
DSP	119	1.40		1.67	0.01***	1.67	0.28	1.54	0.25	1.63	0.18	1.71	0.22
Neutral	21	1.37		1.58		1.58		1.48		1.49		1.67	
NEP	201	1.45		1.54		1.60		1.50		1.58		1.63	
Total		1.43		1.59		1.62		1.51		1.59		1.66	

***p* < 0.05; ****p* < 0.01 N: Number of observations

5.4. Discussion

5.4.1 Understanding environmental attitudes in the context of human excreta reuse in agriculture

The study findings demonstrate that rural farmers in South Africa have moderate eco-centric or pro-ecological attitudes ($\mu = 3.12$). The study also indicates that rural farmers are generally positive in almost all dimensions of the attitudes except the perceived behavioural control, which indicated lack of self-efficacy and the strong influence of risk perception in terms of using human excreta in agriculture. The relatively high scoring of the ecological crisis and the balance of nature dimensions may indicate the influence of environmental publicity and the possibility that farmers are currently experiencing the impacts of climate variability or other environmental catastrophes. The results also suggest that rural farmers are anti-anthropocentric and anti-exemptionalistic, which makes it easier for sustainable production systems to appeal to their attitudes. The rural farmers do not believe that humans should dominate over other species, nor be exempted from nature. The findings could indicate the dependence of rural farmers on their environment, especially through land use and climatic forecasts for rain-fed production systems. The reuse of human excreta in agriculture needs to be marketed as sustainable and environmentally friendly behaviour for it to appeal to the environmental dispositions of rural farmers.

The study also unpacked segregated environmental attitudes against the farmers' demographic and socio-economic characteristics. A meta-analysis of the adoption of agricultural technologies indicates the influence of socio-economic and demographic factors on the adoption of agricultural technologies (Ruzzante et al., 2021). The dissemination of agricultural technologies could therefore be enhanced through the identification of the factors that influence the farmers' decisions to adopt technologies by focusing on early adopters (Kreps, 2017). The identification of early adopters may prevent known barriers to adoption before introducing an innovation (Rogers, 2003). The findings illustrate that the champions of human excreta reuse in agriculture are younger, less formally educated, and non-religious farmers who are not wealthy, but have experience in farming and interact with extension officers. Resource-constrained farmers in rural communities face environmental challenges from waste management, sanitation, pollution, and environmental degradation. The farmers experience first-hand the decline in crop productivity, soil degradation, climate variability, health problems, and environmental pollution. An increase in income could mean that farmers can afford decent sanitation and chemical fertilisers and would therefore lead to farmers not being willing to recycle human excreta. For instance, farmers in the area who cannot afford to empty their full pit latrines may be motivated to want to find ways of dealing with their full pits, such as through recycling, as compared to farmers who can afford to hire pit-emptying services. While empirical evidence suggests a positive relationship between education and human excreta recycling (Mariwah and Drangert, 2011; Mugivhisa et al., 2017; Phuc et al., 2006) an interesting explanation for this would be the interaction of indigenous knowledge stock and the level of formal education. Rural communities often retain indigenous knowledge, which can influence their relationship with the environment. The local formal education system may lack environmentally responsive curricula and national environmental awareness campaigns; to the extent that being formally educated may not necessarily reflect environmental consciousness. The effect of the interaction between variables such as education and income was insignificant and were dropped-out of the analysis during the hierarchical regression process. The impact on the environment on them is higher among experienced farmers in agriculture since human excreta reuse augments soil health and the soil's resilience to climatic shocks. The results, however, did not find any effect of gender on environmental attitudes. Other studies suggest a positive relationship between women and pro-environmental attitudes, where men perceived risk in urine recycling (Pahl-Wostl et al., 2003).

The theory of planned behaviour posits that attitude towards behaviour, perceived behavioural control, and subjective norms influence behavioural intentions (Ajzen, 2015, 2011, 1991). The fundamental axiom of consistency underlines the attitude-behaviour theory in that, if the direction of the attitudinal dimensions can be established, the human behaviour towards the 'attitude object' can be determined. The findings suggest a positive influence of pro-environmental attitudes on the perceived behavioural control dimension. Empirical evidence supports this attitude-intention hypothesis, where eco-centric and biospheric individuals were reported to exhibit pro-environmental behaviour (Barr, 2004) Empirical evidence from focus group discussions indicates a correlation between environmental awareness and eco-centric behaviour (Pahl-Wostl et al., 2003). Using communication approaches that promote environmental awareness may therefore be sufficient to influence behaviour change and may enhance the demand for sustainable waste-based soil inputs. The 'awareness-information-decision-action' approach, for instance, promotes awareness of environmental concerns of interest by promoting factual, evidence-based information and recommendations while assuming behaviour change (Barr, 2004). Additional costs and efforts could become a barrier to consequential behaviours, especially if the ecologically friendly technologies are not financially supported (Pahl-Wostl et al., 2003). The empirical evidence suggests that environmental attitudes are the main drivers for recycling, but financial incentives, rewards, and convenience (through enabling policies) could bridge the value-action gap (Vining and Ebreo, 1990).

5.4.2 Implications for research and development practice

The findings of this study suggest that there is a considerable number of farmers to champion the use of human excreta in agriculture. The general attitudes are positive, which indicates support for the reuse of human excreta in the rural communities of South Africa. The findings, however, show the strong negative influence of perceived behavioural control, namely self-efficacy and risk perception. A higher degree of perceived behavioural control (associated with negative attitudes towards excreta use) indicates lower self-efficacy but higher risk perception. The technology adoption models, such as the technology acceptance model, posit that the acceptance of an innovation depends on its perceived ease of use and perceived usefulness (Mathieson, 1991). Self-efficacy, as proposed by Bandura (Bandura, 1971), refers to how well one perceives that they can execute the 'attitude object' or technology under investigation; subject to skills, resources, and opportunities, among other factors (Matsumori et al., 2019). The theories have been expanded to incorporate risk and benefit perception. Risk perception refers to subjective judgments of the probability of negative outcomes from adopting a technology, such as diseases, injury, and death (Freimuth and Hovick, 2012; Oh et al., 2015; Paek and Hove, 2017).

The low score on perceived behavioural control indicates that a high perception of health risks and low self-efficacy could negatively influence behavioural intentions and social acceptance. Farmers will only be willing to reuse human excreta in agriculture if the perceived benefits can cognitively compensate for the perceived risks associated with the technology. The positive mean scoring of the other attitudinal dimensions may illustrate this cognitive compensatory behaviour. The results of the scoping review (Gwara et al., 2021) concluded that health risk perception was reported as the main potential barrier to the use of excreta-based fertilisers in 12 out of 22 studies included in the review (Duncker and Matsebe, 2008; Jensen et al., 2008; Knudsen et al., 2008; Mojid et al., 2010; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Phuc et al., 2006; Saliba et al., 2018). The findings suggest that with proper messaging and targeting, it is possible to identify farmers to champion the dissemination of technological innovations. The findings indicate that championing human excreta reuse in agricultural systems requires young low-income farmers, with fewer years of formal education, as well as experienced, agnostic farmers to represent pro-ecological champions in the South African context. The result is, however, counterintuitive as studies suggest a positive income elasticity of demand for environmental services. Environmental quality is often considered a luxury good, as demonstrated empirically by consumer expenditure surveys, which report an income elasticity of demand greater than 1 (Barbier et al., 2017; McConnell, 1997). However, there is empirical evidence to suggest contextual variation in the factors that explain environmental and sanitation attitudes. More research is also needed to explore the effect of religiosity on environmental attitudes in rural contexts.

The findings indicate the importance of designing context-specific and relational dialectical messaging that appeal to different demographic, sociological, and socio-economic farmer characteristics. Failure to provide targeted messaging may result in technology backlash and criticism. Backlash is likely in the reuse of human excreta, which has been considered taboo in ‘faecophobic’ African contexts (Buit and Jansen, 2016). The diffusion of innovation theory states that technology diffusion is explained by the perceptions and social influence of the champions or innovators on potential adopters and the influence of the broader socio-political context (Dearing and Cox, 2018). Based on the analysis of innovation theory (Rogers, 2003), early adopters or opinion leaders are unconstrained by social norms, and adopt technologies based on their risk-benefit perception. Dissemination and diffusion processes are distinct in that dissemination refers to activities by the development practice to inform farmers and raise awareness of the benefits and sustainability of the innovation. Implementation science, which deals with what happens before, during, and after adopting an innovation, is required to validate the extent to which evidence-based innovation can be effective under practical conditions (National Academies of Sciences Engineering and Medicine, 2016).

The predominance of perceived health risk presents the importance of piloting and pretesting technologies under realistic farmer conditions. Pilot testing not only helps to avoid avertable actual risks and perceived risks, but also ensures that the technologies are tested for financial feasibility, economic impact, and social and environmental sustainability. The influence of environmental attitudes on perceived behavioural control also indicates the importance of appealing to ecological attitudes. Given that pro-ecological farmers are more confident about reusing human excreta in agriculture, raising awareness on environmental benefits of human excreta reuse in agriculture can easily appeal to the already environmentally conscious rural farmers. Community-based pilot-type on-farm demonstration trials could stir a sense of inclusivity and knowledge co-creation, co-investigation, and co-learning, while transferring scientist-farmer knowledge in a relatable dialectical manner. There is evidence that the effectiveness of community-based pilot projects led to community acceptance in other excreta reuse cases (Andersson, 2015)

5. Conclusions

The environmental dispositions of rural farmers were explored in this study, by drawing from a sample of 341 rural farmers in the Vulindlela Traditional Authority area, South Africa. The study findings demonstrate that rural farmers in South Africa have embraced the NEP. The findings also indicate that rural farmers are generally positive in almost all dimensions of the attitudes except the perceived behavioural control, which indicated a lack of self-efficacy and the strong influence of risk perception in using human excreta in agriculture. The findings, however, suggest restrictive perceived behavioural control, where farmers exhibited low self-efficacy and strong risk perception in the use of human excreta. The influence of environmental attitudes on perceived behavioural control highlights the importance of environmental awareness in terms of behavioural change. The study results echoed the findings in other studies on the influence of farmer characteristics on behavioural intentions to use human excreta in agri-food systems. However, context-specific differences were noted in the effects of socio-economic and demographic factors on ecological attitudes. Policy and institutional support systems were also discussed to bridge the value-action gap between behavioural intention and practical action.

6. Study limitations and future research directions

There is some caution that needs to be taken in interpreting the results of this study. The influence of environmental attitudes on reported behavioural intentions to reuse human excreta in agriculture differs from actual observed behaviour. There is a gap between recycling behavioural intention and observed behaviour that requires supporting policies. The implementation of human excreta reuse interventions requires financial resources, effort, skills, and time. Suitable sanitation systems designed for resource recovery and reuse are needed to separate faecal matter from urine to reduce cross-contamination (Simha and Ganesapillai, 2017). The construction of such systems may require financial investments beyond the reach of many poor rural farmers. Emptying the contents and applying treatment to remove contaminants to the acceptable levels stipulated by the World Health Organization’s guidelines for reuse of human excreta in agriculture require further investments in time, skill, effort, and finance. Financial incentives and non-pecuniary support structures may enhance the functioning of the recovery value chain while helping to support efforts to promote the social acceptance of human excreta reuse in agriculture. The business models in resource recovery and reuse often lack financial incentives to support the actual treatment and the purchase of end products by the end users. Providing financial support through credit facilities could help young and resource-constrained farmers to start high value chain agricultural activities, including small-scale co-composting ventures. The farmers could be willing to use the co-compost but may lack the ability to finance the required capital investments. The financial constraints can still apply to more organised farmers such as farmer cooperatives, which may also fail to finance investments in human excreta recovery and reuse innovations.

The comparison of this study's findings with other similar studies suggests some methodological and contextual differences. More contextual studies may be required to validate the findings while providing contextual barriers and opportunities for the adoption of recycled human excreta in agricultural production systems. The influence of education on environmental attitudes was counterintuitively negative; possibly indicating the effect of indigenous knowledge stock. Studies from developed economies indicate the positive influence of education on environmental awareness. Rural communities are commonly endowed with indigenous knowledge stock, which cannot be evaluated using formal education, and hence may positively influence their relationship with the environment. Understanding the nature of this relationship provides an interesting area for future research with implications for the design and dissemination of agricultural technologies in rural contexts.

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CHAPTER 6. EX-ANTE DEMAND ASSESSMENT AND WILLINGNESS TO PAY FOR HUMAN EXCRETA DERIVED CO-COMPOST: EMPIRICAL EVIDENCE FROM SOUTH AFRICA

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Abstract

Recovering plant nutrients from human excreta streams through circular bioeconomy initiatives like co-composting may offer a cross-sectoral solution to waste management, sanitation, and agriculture. However, the failure of composting innovations is attributed to a lack of a ready market for the compost produced. The current study hypothesizes that improving the market attributes of compost through pelletization, fortification, packaging (with labelling), and certification of co-compost could enhance the market demand for co-compost. Socioeconomic variables such as income, religiosity, and environmental attitudes as measured by the new ecological paradigm, were also hypothesized to influence the willingness to pay for co-compost. Based on Lancaster's theory, the efficient Bayesian design, and the discrete choice experiment, we administered a mobile-based survey to 341 rural farmers. The conditional logit, random parameters, and latent class models show that the rural farmers were willing to pay for all the attributes included, especially certification by relevant authorities (ZAR1.70/kg) and fortification with inorganic mineral fertilizers (ZAR1.49/kg). The findings also indicate the influence of income, religiosity, and environmental attitudes on farmers' willingness to pay for co-compost. The results demonstrate the importance of addressing perceived and actual health risk through certification and the complementary role of co-compost in enhancing the agronomic efficiency of chemical fertilizers through fortification in farming systems. Redesigning compost to include the identified attributes could enhance its market appeal. Mainstreaming dissemination strategies and targeting customer segments could improve social acceptance of human excreta derived compost in agriculture.

Keywords: Human excreta; efficient design; choice experiment; co-compost; willingness to pay; demand assessment

6.1. Introduction

High-input agricultural intensification and high per-capita consumption continue to deplete farming land, which calls for alternative and sustainable methods of restoring productive land (Kopittke et al., 2017; Sasmal and Weikard, 2013; van den Born et al., 2000). The challenges associated with using organic soil inputs include high labor demand, variable product quality, low agronomic response, and limited availability of sufficient quantities (Janssen, 1993). There is also a growing narrative in the integrated soil fertility management literature suggesting the failure of alternative ways of improving soil health and recommending the use of chemical fertilizers as an important element to meeting the growing demand for food (Vanlauwe et al., 2014c). However, there are bottlenecks in the adoption of chemical fertilizers by poor farmers, especially in Africa, where annual nutrient depletion rates exceed 60kgNPK/ha (Noble, 2012). In such contexts, the yearly average fertilizer application rates cannot meet the soil nutrient mining rates or the plant requirements for crop production (Mwangi, 1996). The use of inorganic fertilizer is often associated with low agronomic response due to poor soil quality associated with low soil organic carbon, and rainfall variability (McIntire and Gryseels, 1987). The low usage of chemical fertilizers is also associated with high transaction costs, and low farmgate prices reducing return on investment (Mwangi, 1996).

Long-term fertility trials in sub-Saharan Africa (SSA) show that long-term yield benefits are possible by combining organic and inorganic soil inputs using integrated soil fertility management (Byerlee and Heisey, 1996; McIntire and Gryseels, 1987). More recent studies demonstrate the long-term benefits of the combined use of organic and inorganic fertilizers in SSA (Chivenge et al., 2009; Sileshi et al., 2022, 2019). The presence of negative environmental externalities associated with the excessive use of chemical fertilizers (Han et al., 2015; Lin et al., 2019; Savci, 2012) and external inputs (Foley, 2005; Tilman et al., 2011) drives the rationale for adding organic carbon into the soil. Using co-compost produced by mixing human fecal matter or wastewater treatment sludge with compostable organic matter such as food and green waste has climate change mitigating effects through the sequestrating or sinking and storage of stable organic carbon into the soil. There are also reported soil health benefits by incorporating soil organic carbon (Adamtey et al., 2010; Cofie et al., 2009; Nikiema et al., 2014, 2012; Wang et al., 2019). The free carbon makes weak bonds with nutrients in the soil and prevent nutrient loss while making them available to crops (Chivenge et al., 2009; Sileshi et al., 2022, 2019; Vanlauwe et al., 2011).

Incubation studies and field experiments shows significant benefits of applying human excreta-derived plant nutrients on soil health and crop productivity (Odindo et al., 2016; Glæsner et al., 2019; Lemming et al., 2019; Simha and Ganesapillai, 2017). Globally, full resource recovery and reuse of waste-based streams could help to recover approximately 41 million tons of nutrients, making up 28% of the present annual nitrogen (N), phosphorus (P), and potassium (K) utilization (Otoo et al., 2018). Closing the nutrient loop through the circular bioeconomy approaches can help to mitigate the challenges of resource scarcity, nutrient depletion, and promote sustainable economic growth based on waste resources (Burlakovs et al., 2017; Ellen MacArthur Foundation, 2015; Korhonen et al., 2018). The excreta-based waste streams include green waste, food waste, non-sewered and sewerage-based waste streams, which presents potential cross-sectorial benefits to the sanitation, waste management, health, environmental, and agricultural sectors (Cofie and Koné, 2009; Khadra et al., 2019; Koné et al., 2007).

Technically, the low calorific value (high moisture content), of waste streams in most developing countries favor biological treatment compared to thermal treatment alternatives (Pandyaswargo et al., 2012). The benefits of composting are also related to the high level of degradation of organic materials, simplicity, low set-up costs, and the creation of economic value-added agricultural products from waste streams (Sabkia et al., 2018; Saer et al., 2013). The composting technology is a mature innovation in terms of technology readiness level and wide-scale applicability (Egle et al., 2016; Harder et al., 2019). As a nutrient recovery technology, the thermophilic composting technology can inactivate pathogens to the World Health Organization (WHO) acceptable levels for agricultural use (Khadra et al., 2019; Koné et al., 2007). When compared to alternative disposal methods, such as incineration and landfilling, the co-composting system could be a more sustainable waste management option in terms of environmental performance (Cleary, 2009; Rahman et al., 2019; Recycled Organics Unit, 2003; Saer et al., 2013).

Despite the stated benefits, the failure of most composting initiatives to scale up is chiefly due to technical feasibility and economic viability (Pandyaswargo and Premakumara, 2014). The typical economic failure of composting technologies is attributed to the lack of a ready market for the compost produced (Pandyaswargo et al., 2012). This suggest that high investments in compost marketing is critical to the viability of the composting system. Research evidence indicate potential institutional, financial, market, technological, and behavioral barriers to its wide-scale acceptance (Viaene et al., 2016). Pathogen detection, low product value, and slow mineralization have been reported to reduce the market acceptance of compost (Ayilara et al., 2020). The challenges are not unique to compost marketing but are faced by most rural chemical fertilizers markets (Mwangi, 1996). Institutional and policy bottlenecks have also been often reported to suppress the use of organic and inorganic fertilizers in sub-Saharan Africa (Mwangi 1996).

The scoping review of literature on social acceptance and willingness to recycle human excreta shows that the perceived health risk associated with agricultural use of human excreta may be a potential barrier to social acceptance (Duncker and Matsebe, 2008; Jensen et al., 2008; Knudsen et al., 2008; Mojid et al., 2010; Mugivhisa and Olowoyo, 2015; Okem et al., 2013; Saliba et al., 2018). Socio-cultural factors, norms, religion, and taboos associated with disgust, smell, and the visual appeal of human excreta-derived material are reported as potential barriers to social acceptance (Andersson, 2015; Buit and Jansen, 2016; Khalid, 2018; Lagerkvist et al., 2015; Mariwah and Drangert, 2011; Elisa Roma et al., 2013a). Notwithstanding the potential barriers, perceived economic benefits and soil health improvement have been reported to drive the reuse of human excreta in specific contexts (Duncker and Matsebe, 2008; Ignacio et al., 2018; Jensen et al., 2008; Mojid et al., 2010; Saliba et al., 2018; Simha et al., 2017). However, the findings from the scoping review of the literature indicate a paucity of research evidence on understanding the market demand for waste-based fertilizers in agriculture (Gwara et al., 2021). Providing the compost to farmers in its suitable form requires funding, and potential consumers should be willing to pay for the cost of delivering the compost in its acceptable attributes (Gulbrandsen, 2009; Malele et al., 2019).

Preceding the current study and following the recommendations by (Arksey and O’Malley, 2007) and (Colquhoun et al., 2014; Levac et al., 2010), two scoping reviews of literature were contacted to clarify the key concepts, examine research methodologies, and identify the critical attributes of co-compost that would enhance its social acceptance and willingness to pay (Gwara et al., 2021, 2020). The product attributes identified to improve the market feasibility of co-compost consist of fortification (Adetunji et al., 2019; Danso et al., 2017; Heinonen-Tanski and Van Wijk-Sijbesma, 2005; Nikiema et al., 2012), pelletization (Kuwornu et al., 2017; Nikiema et al., 2014, 2013, 2012; Septien et al., 2018), packaging (European Commission, 2018; Klaiman et al., 2016), and certification (Danso et al., 2017; European Commission, 2007; Keraita and Drechsel, 2015; Berta Moya et al., 2019). The potential economic and agronomic benefits of these attributes are discussed in detail in the next section, including how they may help to improve stated challenge of co-compost demand. The benefits associated with the attributes are related to improving the market appeal of compost.

The findings of this study may help to guide new business models in effective market entry, customer segmentation, product design, and pricing strategies required to meet the purchasing decisions (Otoo et al., 2018). Estimating the willingness to pay for co-compost provides some relevant information for the sustainability assessment of the co-composting systems and other recycling initiatives based on methods of lifecycle science (Wang et al., 2018). Since the costs and benefits of providing the compost attributes can be accurately analyzed using either cost benefit analysis, technoeconomic analysis or life cycle assessment, the utility derived from the attributes could be understood by learning the willingness to pay or maximum amount that farmers are willing to pay for the compost attributes. The rationale for this study is that, if less effort is spent on finding ways of improving its market appeal and whether customers find it appealing, the outcome will be the production of costly waste-based products with no market appeal in agricultural systems (Rouse et al., 2008).

6.2. Methodology

6.2.1. Theoretical foundations of the choice experiment approach

The current study takes a choice-based approach by assuming that the respondent's choice decisions truthfully reveal their preferences and are based on the utility or social benefit associated with different alternatives in each choice set. The choice-based model follows Lancaster's theory, which argues that the value of a good (hedonic or implicit price) can be decomposed to its observed characteristics or attributes (Lancaster, 1966). The willingness to pay is an estimate of the societal benefit, preference or desirability of a product attribute technology or innovation. The analytical foundations for discrete choice experiment approach are based on the random utility theory, which decomposes the demand or utility U of a good into the observable vector V of deterministic product attributes, the individual-specific idiosyncrasies i, and the unobservable and stochastic error component ε, for the j alternatives in a choice set (McFadden, 1998, 1974) as illustrated in **Equation 6.1.**

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (6.1)$$

Two methods are used in the evaluation of the willingness to pay for non-marketed goods, namely the choice experiment and the contingent valuation approaches. A systematic review of literature in health, environmental, and agricultural economics suggests the popularity of choice experiments compared to other stated preference approaches (Mahieu et al., 2014). The advantage of the choice experiment approach is in the theoretical simulation of the consumer purchasing decisions (Danso et al., 2017; Hanley et al., 1998). The choice experiment method also reduces ethical protesting and strategic responses and provides an in-depth knowledge of how decision-makers trade-off between attributes (Adamowicz et al., 1995). Empirical evidence suggests that the choice experiment methodology provides more precise estimates than alternative approaches (Adamowicz et al., 1995). Although the choice experiment approach may suffer from hypothetical bias and incentive compatibility (Lusk and Schroeder, 2004), correct framing of questions, pretesting, certainty scales, and cheap talk scripts may improve the accuracy of choice experiments (Johnston et al., 2017). The current study endeavoured to implement the best practices following the recommendations from the contemporary guidance for implementing stated preference studies (Johnston et al., 2017).

6.2.2. Data

A cross-sectional study design was implemented using a household survey tool to elicit the farmers' preferences and willingness to pay for the various attributes of co-compost. The data were gathered from 341 rural farmers in Vulindlela Traditional Council, located (28.8583°S, 31.8378°E) in the KwaZulu-Natal province of South Africa. The Vulindlela Traditional Council consists of nine wards under the sole trustee of the King (Kharsany et al., 2015; Msunduzi Municipality, 2016). The area occupies 40% of the Msunduzi Local Municipality, covering approximately 25 000 hectares with more than 85 000 households and about 150 000 people (Kharsany et al., 2015). Humanities and Social Sciences Research Ethics Committee (H.S.S.R.E.C./00001499/2020) ethical clearance and verbal consent were obtained from the university research office. The ethics approval provided study participants with the study purpose, confidentiality clause, and the freedom to withdraw from the study. The survey instrument is readily available at the following link https://enketo.ona.io/x/#EkSVyazm. Power tests were performed using the G*Power software $\alpha = 5\%$, and seven variables, power of 95% and Cohen's *d* effect size =15% (Cohen, 2013, 1992; Daly and Cohen, 1978; Kang, 2021). The sample size was estimated to be 153 participants although additional participants were added to incorporate other studies integrated in the survey tool.

The household survey (preparation, training, and interviews) was administered from 10 to 26 November 2021 during a national lockdown and university Covid-19 window, where household surveys were temporarily allowed. The enumerators were always encouraged to adhere to the country's Covid-19 lockdown level 1 regulation. The study used a multistage sampling procedure because a complete list of all population members was not available. The multistage approach was implemented by first selecting two wards, (wards 8 and 9) based on the maximum distance from Pietermaritzburg metropolitan city. This was followed by a systematic selection of households in each ward. The sampling unit was defined as a household consisting of people living together and eating from the same pot and making important livelihood or food security decisions. The household head was the primary decision-maker on most farming activities.

Initially, the sampling interval was creating large distances for enumerators to walk between the sampled households. Therefore, the enumerators were dropped into clusters where they randomly selected five households per day. A neighbouring farmer was selected in the absence of the sampled farmer. The study did not record any non-response due to protesting. The survey tool incorporated cheap talk scripts and certainty scales to improve the incentive compatibility and consequentiality of the value elicitation approach (Arrow et al., 1993; Johnston et al., 2017). Incentive compatibility and consequentiality were also reinforced by emphasizing the implications of the farmers' response to designing current and ongoing projects in the area, which was assumed to reveal their preferences truthfully. The survey instrument was checked for construct validity by being subjected to expert evaluation from scientists within the RUNRES project (Taherdoost, 2016). The survey tool provided some information cues to enhance the accurate framing of attributes (Kragt and Bennetta, 2010) to improve the instrument's incentive compatibility (Zawojska and Czajkowski, 2017). The survey instrument was additionally piloted on 25 rural farmers to test for face validity before being subjected to the study participants (Taherdoost, 2016). More details of the survey methodology and instrument can be found in the supplementary information of a related published study on social acceptance of human excreta reuse in agriculture (Gwara et al., 2022).

6.2.3. Product attributes

The five attributes for improving the market appeal for co-compost identified through the scoping review of literature include pelletization, fortification, packaging, certification, and price (**Table 6.6**). Pelletization is an attribute that improves the co-compost product structure, reducing bulkiness, and transportation costs, while lowering handling costs during application (Danso et al., 2017; Kuwornu et al., 2017; Nikiema et al., 2014). Locally available materials such as pre-gelatinized starch and clay may increase the pellet structure and may help to reduce volatilization of nutrients when used as binders (Adamtey et al., 2009; Nikiema et al., 2013).

Fortification of co-compost with inorganic fertilizers adds value and reduces the bulkiness of co-compost and transportation costs per nutrient mass while enhancing the applicability to various crops (Danso et al., 2017). Fortification with ammonium nitrate has a liming effect and increases the temperature in the co-composting thermophilic stage, which is important for killing pathogens in the co-compost (Adamtey et al., 2009; Vinnerås, 2007; Vinnerås et al., 2003). Packaging of co-compost allows for easy handling and specification of nutrient information, branding, and application instructions if correctly labelled (Agyekum et al., 2014; Rouse et al., 2008). The certification by the relevant authorities can reduce the perceived and actual health risks associated with co-compost use, enhancing social acceptance (Danso et al., 2017) and improve the product appeal through quality assurance (Rouse et al., 2008). The price attribute representing the lowest through to the choke price was decided based on the scoping review, expert opinion, and current local market prices of other types of fertilizers in the city-region of Msunduzi municipality.

Table 6.6. Description of attributes and levels

Attribute	Levels	Description
Price (Rands/kg)	5	1.5; 2.0; 2.5; 3.0;3.5
Packaging (Labelled)	2	Yes (packaged with application instructions), No
Fortification	2	1=Yes (fortified with inorganic fertilizer), No
Pelletization	2	Yes (pelletized), No (powder form)
Certification	2	Yes (certified), No (not certified)

6.2.4 Choice experiment design

The study used the **idefix** package in **R** software and applied the modified Fedorov algorithm to estimate a Bayesian efficient design (Kessels et al., 2011, 2006). The approach resulted in the eight choice sets, where an example is shown in

Table 6.7 and **Fig 6.1**. The efficient Bayesian design applies the common experimental design principles such as orthogonality, level balance, minimal overlap, and utility balance (Huber and Zwerina, 1996). The efficient design helps to produce robust estimates at smaller sample sizes and choice tasks compared to orthogonal designs (Bliemer and Rose, 2010; Rose and Bliemer, 2009). Although the modified Fedorov algorithm is much slower than the coordinate exchange algorithm due to computational burden, it allows the user to put some restrictions on the design through specification of priors to improve the efficiency of the design (Traets et al., 2020). The modified Fedorov algorithm help to minimize the D(B)-error following a multinomial logit model by looping through every profile from the start of design and evaluating the D(B)-error for every profile until the maximum iteration is reached or when no additional information is obtained. The DB-error of the retained design, calculated as the mean of the D-errors, was estimated to be 2.86.

Table 6.7. An example of the choice task of the eight tasks presented to the farmers

Co-compost Attributes	A	B	C
Pelletization	No pelletization	Yes pelletization	If options A & B were all
Fortification	Yes fortification	No fortification	that were available at my
Packaging	No packaging	No packaging	local farm input shop, I
Certification	No certification	Yes certification	would not purchase co-
Price	R2.50/kg	R3.50/kg	compost from that shop.

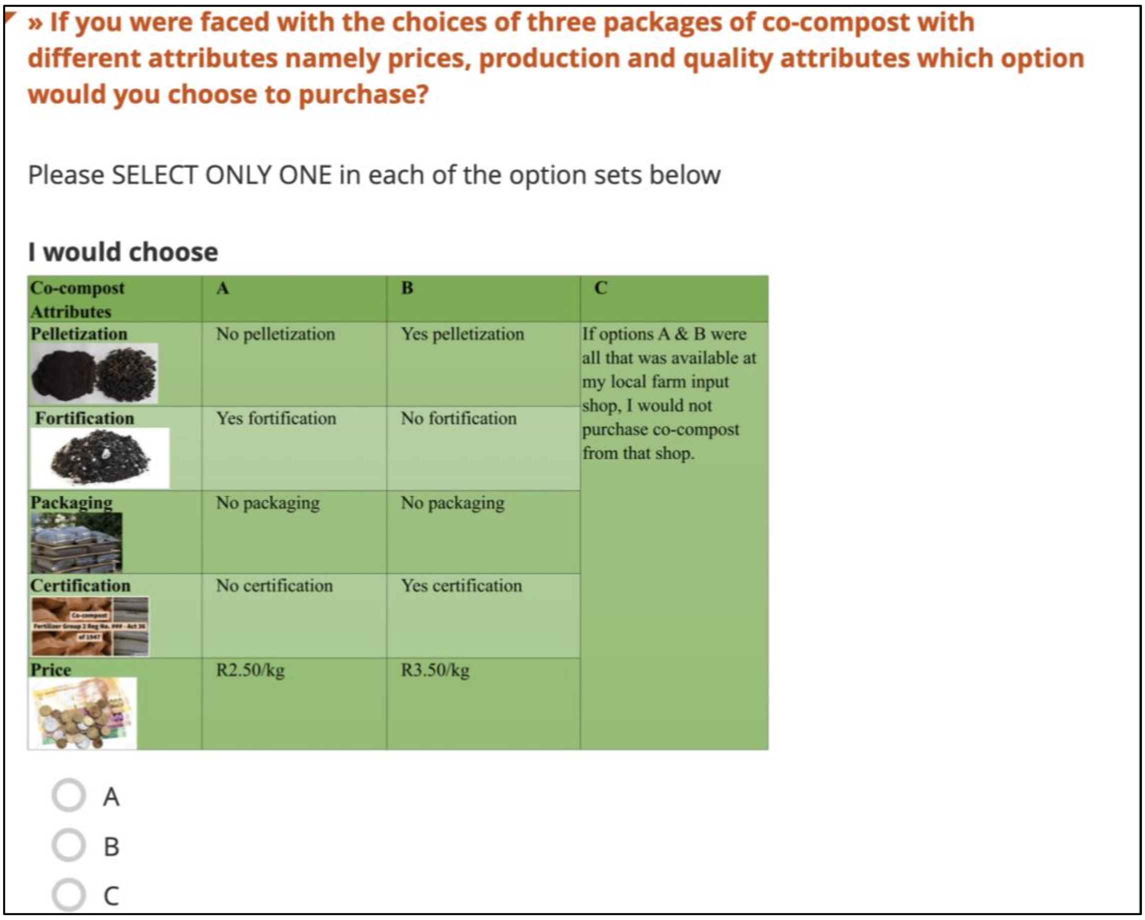

Fig. 6.3. An excerpt of a choice task from the survey instrument

6.2.5. Empirical model

To estimate the empirical model, the farmer i presented with the j alternatives in a choice set, the model assumes that the farmer always selects the option that provides the highest utility. The study initially assumed a linear random utility function with additive error, as presented in **Equation 6.2.**

$$U_{ij} = \beta_0 + \beta_p Pellet_{ij} + \beta_f Fort_{ij} + \beta_k Package_{ij} + \beta_c Cert_{ij} + \beta_r Price_{ij} + \varepsilon_{ij} \quad (6.2)$$

The random utility model was used to specify different models based on assumptions of the distribution of the error terms. The conditional logit (CL) model assumes that tastes are homogeneous, and the idiosyncratic errors are independently and identically Gumbel extreme value type 1 distributed (IID) across individuals and choices, and that the probability of choosing an alternative *j* is given by **Equation 6.3** (Louviere et al., 2000).

$$P_{ij} = \frac{\exp(\beta' X_j)}{\Sigma_{j'=1}^{J} (\beta' X_{j'})} \quad (6.3)$$

The IID assumption leads to further independence of irrelevant alternatives (IIA) assumption, which assumes that the probability of choosing the choices depends exclusively on the utility of the options and that the main effects can be stochastically and independently determined (Kassie et al., 2017; Morrison et al., 1998). The random parameters logit (RPL) model relaxes the IIA property by allowing preference heterogeneity across the observed attributes (Kassie et al., 2017). The model results in the attribute utility function expressed as a vector of; a) the population mean attribute utility weights and b) the variance of the individual taste parameters (diagonal matrix), and c) the unobserved individual idiosyncratic error component with 0 mean and unit variance (Kassie et al., 2017). Mixed logit models can accurately estimate any preference distribution because it does not impose any theoretical restrictions on the choice model and allows for all sources of correlation (Hess and Train, 2017b). The alternative specific constants can be used to review the effect of unobserved but systematic factors influencing the individual's choices (Bahamonde-Birke et al., 2017). The constants technically reflect the mean of the differences in the idiosyncratic error terms (Prashker, 1988; Uncles et al., 1987).

The empirical models were estimated as CL, RPL, and the latent class (LC) models to examine how the parameters respond to different model specifications (robustness). The CL model was used to benchmark the results and then compared with the RPL model using the likelihood ratio test. The RPL is however, theoretically superior to the CL as it relaxes both the IID and the IIA assumptions using the lower triangular matrix of correlation (Cholesky matrix) to determine correlations among coefficients. The RPL allows for all sources of correlation in the data including intra-personal heterogeneity (intraDraws) and inter-personal farmer to farmer preference heterogeneity (interDraws). The LC serves a different function from the CL and RPL because it infers the predicted probability to belong to each class or market segment and helps to identify the presence of different homogeneous classes of preference. The decision to keep the three models, therefore, is to benchmark the theoretically appealing RPL with the fixed parameters in CL and use the LC identify the presence of different homogeneous classes of preferences in the data. The individual-specific variables included religiosity, annual household income, and environmental attitudes. Following numerous iterations, the simple CL model was estimated, assuming that the preferences are IID across individuals and alternatives illustrated in **Equation 6.4.**

$$U_{ij} = ASC_0 + \beta_p Price_{ij} + \beta_k Packaging_{ij} + \beta_f Fortification_{ij} + \beta_c Certification_{ij} + \beta_r Pelletization_{ij} + \beta_r Polytheism_i + \beta_y Income_i + \beta_k NEPscore_i + \varepsilon_{ij} \quad (6.4)$$

The RPL and the latent class (LC) models were estimated to account for preference heterogeneity. The empirical model for the RPL assumed normal distribution for inter-individual draws. The RPL incorporated population mean attribute utility weights, the variance (sigma) of the individual taste parameters, and three observed individual-specific variables that interacted with alternative specific constants. Following several iterations, the best model in terms of parsimony and fit was estimated as illustrated in **Equation 6.5.**

$$U_{ij} = ASC_0 + \beta_p Price_{ij} + \beta_k Packaging_{ij} + \beta_f Fortification_{ij} + \beta_c Certification_{ij} + \beta_r Pelletization_{ij} + \delta_{fk} Fortification\_Pelletization_{ij} + \delta_{ck} Pelletization\_Packaging_{ij} + \beta_r Polytheism_i + \beta_y Income_i + \beta_k NEPscore_i + \varepsilon_{ij} \quad (6.5)$$

The RPL model assumes continuous preferences distribution across the population, making it challenging to identify class heterogeneity. Therefore, a latent class model was estimated to determine the presence of different homogeneous classes of preferences. Unlike the RPL, where you must create interactions with the alternative specific constants, in the LC model, the sociodemographic variables were incorporated in the Apollo package as ‘gammas’ to influence the probabilities of belonging to the different classes. For identification of the probability model, one class was fixed to zero. The LC model with three classes was estimated, where the delta _Δ represents the latent class components for the three classes as illustrated in **Equation 6.6**.

$$U_{ij} = ASC_i + \beta_p Price\_\Delta_{ij} + \beta_k Packaging\_\Delta_{ij} + \beta_f Fortification\_\Delta_{ij} + \beta_c Certification\_\Delta_{ij} + \beta_r Pelletization\_\Delta_{ij} + \beta_r Polytheism\_\Delta_i + \beta_y Income\_\Delta_i + \beta_k NEPscore\_\Delta_i + \varepsilon_{ij} \dots \quad (6.6)$$

6.2.6. Sociodemographic variables

The sociodemographic variables may not be directly incorporated into the utility functions as they do not vary across the alternatives in a choice set. Therefore, they can only be incorporated as interaction terms with the alternative specific constants (Morrison et al., 1998). Income, religiosity, and environmental attitudes were incorporated to estimate their influence on willingness to pay for compost. The rationale came from the impact of these factors on social acceptance from the literature review (Gwara et al., 2021, 2020) and the initial study performed on the social acceptance of human excreta in agriculture (Gwara et al., 2022). Therefore, testing their influence may inform whether marketing decisions should be sensitive to such factors and how? The coding structure followed a continuous income and environmental attitudes scale and a dummy coding for religiosity. The descriptive results indicate that almost half of the respondents were Christians and were coded as 1, while non-Christians were coded as 0. The coding structure was chosen over the individual dummy coding for identification. The environmental attitudes were measured using the 15-item new or revised ecological paradigm (NEP) scale, with the overall rating ($1 \leq \boldsymbol{\mu} \leq 5$) indicating the mean scores of all responses (Ogunbode, 2013). The mean score of 3 represents neutrality, while 1 represent extreme environmentally unfriendly, and 5 extreme eco-friendly worldviews (Van Petegem and Blieck, 2006). The descriptive results show a mean distribution of 3.2, representing moderately environmentally-conscious farmers.

6.2.7. Marginal willingness to pay calculations

The implicit price, defined as the marginal rate of substitution between the non-price and the price attribute, reflects the willingness to pay for a marginal improvement in the co-compost attribute, holding all other attributes constant. The study used the Delta method to calculate marginal willingness-to-pay estimates by taking the ratio of each attribute to the price coefficient. The Delta method provides an approximation of the true standard errors following Daly et al., (2012), who demonstrated that parameters estimated using maximum likelihood are also maximum likelihood estimates. The Delta method can accurately estimate the standard errors of any maximum likelihood functions as it does not depend on the model used to estimate the parameters (Daly et al., 2012). The inverse of the Hessian matrix of second derivatives of the estimated likelihood functions forms the Cramér-Rao lower bound of the minimum variance of the estimates and is therefore consistent following the Slutsky theorem. For model comparison, unconditionals were estimated in the LC model by estimating the average willingness to pay that considers the multivariate nature of the individual-specific parameters across classes (Hess and Palma, 2021).

6.3. Results

6.3.1. Characteristics of rural farmers in Vulindlela

Out of the 341 interviewed rural farmers, about 68.2% were female, while 31.8% were male

Appendix A: Extra Tables. The average age of the farmers was 54 (14.2) years, with on average years 8 (4.1) years of education. The experience in farming was, on average, 23.2 (3.3) years. The average household size was 6.3 members (**Table 6.8**). On average, 43.7% of the interviewed farmers were married, while others were single (32.0%), widowed (22.3%), or divorced 2.1%. The most popular religion was Christianity (50.1%, while others were polytheism (23.4%), traditionalism (12.6%), Nazarene (7.9%), or atheism (5%). The data showed that 34.6% earn less than R12 000 per year, while 31.4% earn R12 000-R60 000, with 18.2% earning R60 000-R100 000, while 15% earn above R150 000 per annum (exchange rate 1USD ≈ R16). The sources of income were social grants (60.7%), formal salary work (10.9%), casual work (7.6%), remittances (6.2%), wages (4.4%), agricultural sales (3.8%), formal business (3.7%), informal trading (2.6%), and gifts (0.6%). About 77.4% of the farmers owned less than one hectare of farming land. In terms of the level of organization, about 8.5% of the rural farmers were a member of a farming association, while about 6% had ever interacted with an agricultural extension officer.

Table 6.8. Characteristics of survey respondents.

Household characteristic	Mean	Median	Max	Min	Standard Dev
Age (years)	54	57	88	20	14.2
Years of education	7.9	8	19	0	4.1
Farming experience	23.2	20	70	1	15.6
Household size	6.3	6.0	17	1	3.3

6.3.2. Current agricultural practices

The primary type of fertilizer used by the respondents in their production systems was cow manure (59.3%), followed by inorganic fertilizers (19.5%), poultry manure (6.5%), compost (5.3%), and farm residues (2.9%). Approximately 6.5% of the farmers used other fertilizers or did not use fertilizers at all in their farming systems (**Table 6.9**). The use of cow manure and compost by most rural farmers in their agricultural production systems means that it is easy for farmers to evaluate co-compost whose physical attributes are like the available fertilizers in their farming systems.

Table 6.9. Driving forces for co-compost recycling intentions

Fertilizer type	Frequency	Percentage (%)
Cow manure	201	59.3
Inorganic fertilizer	66	19.5
Poultry manure	22	6.5
Others	22	6.5
Organic compost	13	3.8

Farm residues	10	2.9
Co-compost	5	1.5
Total	339	100

Of the farmers using some form of fertilizers or soil amendment, about 80% of the farmers chose their dominant fertilizer based on availability (

Table 6.10). Other reasons include improving soil health (14.8%), price or affordability (3.6%), and environmental benefits (2.1%). The primary source of these fertilizers was free, making up 48.6% of the respondents, while 41.4% were producing it on the farm (

Table 6.10). From our investigations, the free fertilizers are usually animal manure freely obtained from neighboring farmers who own livestock, as it is uncommon to sell animal-based fertilizers in the community. The farming systems are such that farmers only use the manure for vegetables, and the size of these plots is usually small, therefore, farmers do not make use of this excess manure. The rest of the farmers bought their fertilizers (8.6%).

Table 6.10. Reasons for the dominance and sources of fertilizers

Reasons for the type of fertilizer use	Percentage (%)	Frequency
Availability	79.6	269
Soil health	14.8	50
Price	3.6	12
Environmentally friendly	2.1	7
Total	100	140
Fertilizer sources		
Produce it on the farm	58	41.4
Produce it elsewhere	2	1.4
Buy it	12	8.6
Get it for free	68	48.6
Total	140	100.0

6.3.3. Driving forces and potential barriers to using human excreta in agriculture

More than 77.4% of the respondents were willing to recycle human excreta in agriculture. The farmers were asked what would drive the recycling of co-compost in their agricultural systems. In terms of the production factors, 87.6% of the farmers agreed that the organic matter content and safety were the most important driving factors for the use of co-compost. Farmers also put importance on the source of information and certification, which shows the importance of the perceived health risk in using human excreta-based co-compost. The price of co-compost was considered the most critical marketing variable, followed by a convenient location. The nutrient value, credit facility, and pelletization were also important driving forces for co-compost recycling. Packaging was among the least important variables driving force for co-compost recycling.

Table 6.11 shows the driving forces ranked from the most crucial variable to the least as ranked by the farmers.

Table 6.11. Driving forces for co-compost recycling

Statement	Level of agreement %					
Desirable characteristic	Strongly Disagree	Disagree	Don't know	Agree	Strongly Agree	Total Agree

Organic matter	1.8	1.8	8.8	53.1	34.5	87.6
Safety	1.8	1.8	8.8	53.1	34.5	87.6
Trusted sources	6.2	7.7	10.3	45.7	30.1	75.8
Certification	5.6	7.6	14.1	38.8	33.8	72.6
Price	10.6	9.1	8.2	39.4	32.6	72
Location	5	10	12.9	48.2	23.8	72
NPK content	2.4	4.4	22.6	41.5	29.1	70.6
Credit offer	7.1	15.7	24.6	39.6	13	52.6
Pelletization	8.3	17.1	22.7	26.5	25.4	51.9
Packaging	8.9	22.6	19.6	33.2	15.7	48.9

6.3.3. Preferences and willingness to pay for the attributes

The RPL model performed better than the CL model, both in terms of the loglikelihood and the model parsimony based on the the loglikelihood ration test (p <= 0.000), Akaike information criterion (AIC), Bayesian information criterion (BIC) and the McFadden Rho-square tests as indicated in

Table 6.12. The CL and RPL models show that the price coefficient is negative and significant ($p <= 0.05$) as expected), indicating that as the price of compost increases, the utility decreases. The results of both the conditional logit (CL) and the random parameters logit (RPL) model indicate farmer preferences ($p <= 0.05$) for the pelletized, fortified and certified co-compost (

Table 6.12). The results of the CL show the positive influence of the sociological (religiosity), socioeconomic status (income), and ecological dispositions on willingness to pay for co-compost. The results indicate that farmers who were non-Christians expressed a higher willingness to pay for co-compost. The results also show positive income elasticity of demand for co-compost where farmers may aspire to pay more as income rises. Pro-environmental attitudes and higher annual income positively influenced the willingness to pay for co-compost. The packaging appears not to affect the farmers' preferences for co-compost in both models as the estimated parameters were insignificant.

Table 6.12. Estimates of conditional logit and random parameters logit models

Model	Conditional logit	Random parameters logit
Parameter	Coefficient (standard error)	Coefficient (standard error)
Opt-out	3.30 (0.49) ***	-5.03 (0.75) ***
Price	-0.49 (0.05) ***	-0.96 (0.08) ***
Packaging	0.09 (0.06)	0.10 (0.10)
Pelletization	0.30 (0.05) ***	0.45 (0.17) ***
Fortification	0.82 (0.05) ***	1.63 (0.16) ***
Certification	0.72 (0.05) ***	1.34 (0.14) ***
Certification_Packaging		-0.40 (0.00)
Sigma (Packaging)		0.50 (0.17) ***
Sigma (Pelletization)		2.25 (0.17) ***
Sigma (Fortification)		2.04 (0.17) ***
Sigma (Certification)		1.87 (0.16) ***
Sigma (Certification_Packaging)		0.52 (0.13) ***
Religion (1 = Polytheism)	0.68 (0.13) ***	0.63 (0.21) ***
Income	0,15 (0.06) **	0.21 (0.10) **
Environmental attitude score	0.35 (0.13) ***	0.54 (0.21) ***
McFadden Rho-square	0.23	0.35
Loglikelihood	-2190	-1858
Akaike information criterion	4398	3746
Number of individuals	323	323
Number of observations	2584	2584
Likelihood ratio test-value	664.38	
Likelihood ratio test p-value	0.0000	

Notes: ** means significant at 5% and *** means significant at 1% level

The LC model with three classes was chosen as the best model to disentangle class heterogeneity (

Table 6.13). The class allocation results show that the respondents had an 84% probability of belonging to class A, 7% probability of belonging to class B, and 9% probability of belonging to class C. Class A farmers preferred all the co-compost attributes, including packaging, which was insignificant in both the CL and the RPL model. The class B segment revealed positive preferences for fortification and negative preferences for packaging, pelletization, and certification. Farmers in Class C showed positive preferences for certification. Higher income increased the probability of belonging to class A and decreased the probability of belonging to class B but had no significant impact on the probability of belonging to class C. The positive sign for income in class A represents income as a probability shifter of belonging to class A.

Table 6.13. Latent class model results with three classes

Classes Parameter	Class A Coefficient (standard error)	Class B Coefficient (standard error)	Class C Coefficient (standard error)
ASC	2.60 (0.27) ***	- 2.65 (0.27) ***	0.00 (fixed)
Price	- 0.63 (0.06) ***	- 1.06 (0.21) ***	- 1.84 (0.87) **
Packaging	0.25 (0.06) ***	- 0.31 (0.11) **	- 3.54 (1.94)
Pelletization	0.50 (0.08) ***	- 12.62 (2.30) ***	-0.98 (4.52)
Fortification	1.03 (0.10) ***	0.78 (0.20) ***	1.25 (2.91)
Certification	0.56 (0.06) ***	- 0.45 (0.09) ***	7.78 (2.61) ***
Income	0.26 (0.18)	0.56 (0.26) **	0.00 (fixed)
Environmental attitude score	0.02 (0.50)	- 0.19 (0.65)	0.00 (fixed)
Religiosity (1=non-religious)	-0.08 (0.56)	1.00 (0.68)	0.00 (fixed)
Delta	-0.08 (0.56)	-1.39 (2.29)	0.00 (fixed)
Class probability	0.84	0.07	0.09
McFadden Rho-square		0.34	
Log-likelihood		-1870	
Akaike information criterion		3788	
Number of individuals		323	
Number of observations		2584	

Notes: ** means significant at 5%, and *** means significant at 1%

6.3.4. Marginal willingness to pay estimates

The implicit price, defined as the marginal rate of substitution between the non-price and the price attribute, reflects the willingness to pay for a marginal improvement in the co-compost attribute, holding all other attributes constant. The estimates from the CL and RPL models were comparable with a downward preference pattern where the preferable attributes were fortification, certification, and pelletization, with packaging as the least preferred attribute, in line with the descriptive results of co-composting driving forces. Comparing the implicit prices from the two models, the heterogeneity in farmer preferences showed a negligible effect on the implicit price estimates (Wu et al., 2015). The RPL model results showed the highest willingness to pay an estimate of R1.70/kg[1] of fortified co-compost. At the same time, the second preferred attribute was certification, with a willingness to pay an estimate of R1.40/kg for certified co-compost. Farmers were willing to pay about R0.45/kg for pelletized co-compost. Based on the RPL results, the willingness to pay for packaging (R0.10/kg) was insignificant (**Error! Reference source not found.**).

Table 14. Comparison of the willingness to pay estimates (ZAR/kg) for different models

Variables	Conditional Logit Model estimate (standard error)	Random Parameters Logit Model estimate (standard error)
Fortification	1.67 (0.26) ***	1.70 (0.25) ***
Certification	1.49 (0.24) ***	1.40 (0.23) ***
Pelletization	0.61 (0.15) ***	0.45 (0.17) ***
Packaging	ns	ns

Notes: ** means significant at 5%, *** means significant at 1%, and ns means insignificant

The results of the LC model reveal that class A was willing to pay a positive price for all attributes with utility ranking like both the CL and RPL models (**Table 6.15**). In customer segment A, farmers were willing to pay more for packaging (R0.40/kg) and pelletization (R0.82/kg), certification (R1.65/kg), and fortification (R0.91/kg) when compared to the CL and RPL models. Farmers in class B expected compensation for packaging (R0.23/kg) and pelletization (R5.63/kg) but were willing to pay more for fortification (R0.83/kg) and certification (R1.65/kg). Class C farmers were willing to pay, above all classes, for certification (R4.31/kg). Class B farmers indicate risk aversion where more value is placed on the certification attribute. Unconditional post-estimation of the LC model was calculated to generate a comparison with the CL and RPL Comparing the willingness to pay estimates of the three models (CL, R.P.L., and LC), a similar utility pattern is observed (**Table 6.15**). However, the LC model produced more precise estimates with smaller standard errors than the CL and the RPL models.

Table 6.15. Marginal willingness to pay (ZAR/kg) estimates latent class with three classes

Variables	Class A estimate (standard error)	Class B estimate (standard error)	Latent Class Unconditionals estimate (standard error)
Certification	0.89 (0.15) ***	1.42 (0.03) ***	1.50 (0.00) ***
Fortification	1.64 (0.24) ***	0.73 (0.10) ***	1.12 (0.01) ***
Pelletization	0.78 (0.15) ***	- 11.91 (3.90) ***	0.21 (0.03) ***
Packaging	0.40 (0.10) ***	- 0.30 (0.10) ***	0.13 (0.04) ***

[1] 1 USD is equivalent to approximately 15 South African Rands

Notes: ** means significant at 5%, and *** means significant at 1%

Comparing the current study with a related study shows relatively similar results in terms of the magnitude of the marginal willingness to pay estimates. A market feasibility study of co-compost in Uganda indicated marginal willingness to pay of USD0.40/kg for certification, USD0.13/kg for pelletization, and compensation of USD0.09/kg for fortification (Danso et al., 2017). However, the current study demonstrates that the farmers investigated were willing to pay for fortified co-compost, although they required compensation for the same attribute in Uganda (**Table 6.16**). After converting the current result to the same currency, the marginal willingness to pay for certified co-compost was higher in Uganda than in South Africa. Certification is a preferred attribute in both countries, and this has implications for health risks, as will be discussed in the next section.

Table 6.16. Comparison of the marginal willingness to pay estimates for two related studies

Author (Year)	Attributes	Conditional Logit Model (USD/kg) estimate (standard error)	Random Parameters Logit Model (USD/kg) estimate (standard error)	Latent Class Unconditionals estimate (standard error)
Current study (2021)	Certification	0.10 (0.02) ***	0.09 (0.02) ***	0.10 (0.00) ***
	Fortification	0.11 (0.02) ***	0.11 (0.02) ***	0.08 (0.00) ***
	Pelletization	0.04 (0.01) ***	0.03 (0.01) ***	0.01 (0.00) ***
(Danso et al., 2017)	Certification	0.42 (0.05) ***	0.40 (0.06) ***	nr
	Fortification	-0.01 (0.05) ***	- 0.09 (0.04) ***	nr
	Pelletization	0.08 (0.03) ***	0.13 (0.03) ***	nr

Notes: ** means significant at 5%, *** means significant at 1%, and nr means not reported

6.4. Discussion

The findings of this study show that there is indeed a high demand for co-compost in the rural farming areas of South Africa. The results indicate a willingness to pay for all the selected attributes with greater demand for fortification and certification. Correct pricing of compost should reflect the willingness to pay by the market segment, in this case, rural farmers. If the price that farmers are willing to pay does not cover the production cost or the ability to pay, various strategies should be in place. These may include credit terms, ash discounts, trade discounts, payment periods, subsidies, and other allowances to enhance market demand (Rouse et al., 2008). It is essential to separate the willingness to pay from the ability to pay as the two concepts are different. The ability to pay reflects the budget position-a function of financial flows and the income streams of consumers and is usually fixed. The willingness to pay depends on the preferences and perceptions of the farmers and reflects the appreciation for compost instead of the actual market price (Rouse et al., 2008). Therefore, willingness to pay can be increased through raising awareness, education, branding, and advertising.

The attributes selected for this study namely packaging (Klaiman et al., 2016; Kojima and Ishikawa, 2017), pelletization (Hettiarachchi et al., 2016; Kuwornu et al., 2017; Nikiema et al., 2014, 2013, 2012), fortification (Adetunji et al., 2019; Nikiema et al., 2012; Opoku, 2015), and certification (Husted et al., 2014; Keraita and Drechsel, 2015; Berta Moya et al., 2019) could also increase the market viability of compost. The findings also reflect significant demand for fortification, which could mean that farmers do not consider chemical fertilizers a substitute but rather a complementary input that could improve agronomic efficiency. Compost application increases the agronomic response to chemical fertilizers and is used either as livestock manure or compost for garden use in rural farming areas. Because compost contains soil organic matter, the carbon is responsible for withholding nutrient loss in the soil by making weak bonds while making them available to crops (Chivenge et al., 2009; Sileshi et al., 2022, 2019; Vanlauwe et al., 2011). Therefore, compost should not be considered as substituting chemical fertilizer as it cannot supply the same amount of nutrients but instead augment the chemical fertilizer use efficiency. Farmers should be well informed of what constitutes the benefits of compost to avoid the inaccurate perception that compost can have a similar effect on crops (Rouse et al., 2008).

The higher willingness to pay for certification indicates the influence of the perceived health risk associated with the reuse of co-compost. Compost certification by relevant regulating authorities could enhance product standardization and quality assurance to farmers. Certification ensures compost is free of pathogens, heavy metals, and other emerging chemicals of human health and environmental concern often present in human excreta waste streams (Bartrons and Peñuelas, 2017; Bischel et al., 2015; Carter et al., 2014; Schürmann et al., 2012; X. Wu et al., 2015). The use of the World Health Organization sanitation safety plan (Winkler et al., 2017; World Health Organization, 2015), careful selection of crops with minimum contamination, and proper handling of co-compost by farmers could also improve the demand for co-compost (Okem and Odindo, 2020).

The willingness to pay for a pelletized compost could help address the challenges of bulkiness (transportation), difficulty in handling, and ease of use (Kuwornu et al., 2017; Nikiema et al., 2013, 2012; Pampuro et al., 2018). Pelletized compost could be achieved using low-cost technologies and locally available materials such as clay as starch binders to increase the pellet strength and reduce the disintegration of the pellet structure (Hettiarachchi et al., 2016; Nikiema et al., 2014). Pelleted compost has reduced bulkiness and associated storage and transport while making it easier to apply due to a lower dust generation (Nikiema et al., 2013). Consequently, providing compost in pelleted form may enhance the market appeal of co-compost, social acceptance, and willingness to pay by farmers.

The findings of the study indicated the influence of the sociological (religiosity), socioeconomic status (income), and ecological dispositions on willingness to pay for co-compost. The findings suggest significant cultural and religious taboos that may prevent farmers from using compost and reduce their willingness to pay. For instance, Christians presented a negative willingness to pay for compost, and therefore essential to consider this when formulating awareness campaigns and dissemination material to target market segments. When promoting co-compost, the mainstreaming of dissemination plans could ensure sensitivity to religious and cultural beliefs. Research evidence in construction industries shows that the knowledge of circular economy may have the highest effect on the willingness to pay for recycled products (Véliz et al., 2022). Sensitivity to religious beliefs helps focus resources on behavior change communication in certain groups. The positive income elasticity of demand for co-compost and the pro-environmental attitudes could inform the segmentation and targeting of the farmers or customers. The more accepting market segments are also used to champion the benefits of the co-composting technologies, for instance, through the implementation of the lead farmer approach (Kiniso, 2022; Ragasa, 2020).

The class allocation probability from the latent class model indicates that the utility preferences of 84% of the farmers preferred all the attributes included in the model, including packaging. There were, however, a smaller segment of farmers in class B and C results who were not willing to pay for pelletization and packaging. The findings for the two classes indicate that low-income customer segments may need to be compensated through public support or government subsidies. Another approach could be to sell unpackaged and unpelleted co-compost to the two customer segments. Training farmers in the segments on the importance of pelletization and packaging may improve the demand for the compost while increasing resource efficiency by targeting the low-income and the Christian segments. Ensuring that the dissemination materials are sensitive to different religious groups could enhance social acceptance while averting unnecessary and costly backlash.

The positive influence of environmental dispositions on willingness to pay may also provide a basis for marketing co-compost as an environmentally sustainable product. With the increasing global interest in protecting the environment, it could be a good marketing strategy to brand co-compost as a sustainable product that helps diverting organic waste from landfills while providing sanitation through the emptying of full pit latrines and protecting the environment through reduced emissions and resource efficiency. Thus, going beyond the nutrient value of compost to include this sustainability dimension could enhance the demand for co-compost by farmers while allowing for public support from the various stakeholders in the composting value chain. Branding using catch-phrasing and logos, training, and awareness campaigns to reflect the co-compost sustainability component may help enhance its willingness to pay and social acceptance (Rouse et al., 2008). Implementing stringent environmental policies and regulations could promote nutrient recovery from waste streams (Otoo et al., 2015).

6.5. Conclusions

This study shows a great opportunity for co-compost as an alternative and sustainable soil input with significant benefits to farmers and new businesses in the waste recovery and reuse value chain. The benefits may extend far beyond its agricultural use to include benefits to the environment, waste management, human health, and sanitation sectors. However, enhancing the co-compost market feasibility may require an analysis beyond the demand elements investigated in this study. One potential opportunity could be to advance circular bioeconomy initiatives in the policy sphere. The potential competition from chemical fertilizers could be easily mitigated through fair government co-compost subsidy programs and viability gap financing for co-composting business models to boost their revenue streams. While chemical fertilizer use in most developing countries is generally low, public support may present an opportunity for alternative business cases in waste recovery and reuse that complement existing practices. More studies are also required to validate the willingness to pay for waste-based soil inputs in different contexts, as the current study results may be context-specific.

Appendix A: Extra Tables

Table A.1. Characteristics of survey respondents.

Household characteristic	Percentage (%)	Frequency
Gender	*100%*	*341*
Female	68.6	234
Male	31.4	107
Marital Status	*100%*	*341*
Married	43.7	149
Single	32.0	109
Widowed	22.3	76
Divorced	2.1	7
Religious affiliation/practice?	*100%*	*341*
Christianity	50.1	171
Polytheism	23.4	83
Traditionalism	12.6	43
Shembe/Nazarene	7.9	27
Others	5	17
Annual Income	*100%*	*341*
< R12 000	34.6	118
R12 000≤ Y< R60 000	31.4	107
R60 000≤ Y<R100 000	18.2	62
Greater than R150 000	15.8	54
Source of Income	*341*	*100*
Social grant	60.7	207
Formal salary work	10.9	37
Casual labour	7.6	26
Remittances	6.2	21
Wage work	4.4	15
Sale of farm produce	3.8	13
Formal business	3.7	11
Informal economy	2.6	9
Gifts	0.6	
Farm Size	*100%*	*341*
≤ 1 ha	77.4	264
1–2 ha	19.6	67
3–4 ha	1.8	6
> 4 ha	1.2	4
Membership	*100%*	*341*
Yes	8.5	29
No	91.5	312
Extension officer interaction	*100%*	*341*
Never	93.8	320
Less than once a year	2.6	9
Once a year	2.3	8
At least twice a year	0.3	1
More than twice a year	0.9	3

1

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CHAPTER 7: SYNTHESIS

7.1. Overview

The study endeavoured to assess the demand for human excreta in agriculture within the context of the circular bio-based economy. The circular bioeconomy approach was introduced as an alternative to the extractive linear system to deal with the challenges of soil nutrient mining and depletion, waste management, and sanitation and environmental sustainability while helping to build the resilience and sustainability of food systems. The deliberate focus on the demand for human excreta-based waste streams was based on its non-reducibility and nexus with promoting sanitation, waste management and human and environmental health. The co-composting value chain was selected based on the simplicity of the technology, the readiness level of the composting technology and its contribution to the multiplicity of challenges faced by both rural and urban communities. The human excreta-based circular bioeconomy approach contributes to sustainable food systems through improved soil health based on local sustainable soil inputs, sanitation goals through proper toilet use and emptying, waste management through the recycling of organic waste.

7.2. Revisiting the study objectives and outcomes

The main aim of this study was to assess the demand of human excreta recycling in agricultural systems. This exercise is critical in the design and implementation of innovations to ensure that pertinent contextual nuances are incorporated in the piloting and implementation of bioeconomy innovations. Understanding the drivers of purchasing and recycling decisions of farmers could also help evidence-based policymaking and business practice with pertinent market information on which to direct scarce resources and maximise returns on investment. The empirical objectives were informed by the knowledge gaps identified from two published scoping reviews of literature. The findings of the two scoping reviews of literature performed in this study show that the success of circular bioeconomy initiatives, especially composting initiatives has been mainly attributed to the failure to understand the market demand elements. The study explores the three main identified knowledge gaps and achieved the following empirical outcomes:

(i) First, the study identified, ex ante, the sociological, cultural, demographic and economic farmer characteristics that influence the behavioral intentions of farmers to use human excreta in agriculture. The major finding of this study was that there in indeed high demand among rural farmers to recycle human excreta in agri-food systems. The social acceptance is however influenced by religious, demographic, and sociological farmer characteristics and environmental dispositions of rural farmers. Mainstreaming of such nuances in research, policymaking and development practice could enhance circular bioeconomy initiatives.

(ii) Second, the study undertook an ex ante psychometric analysis of the ecological dispositions of rural farmers in South Africa. Using the well validated new ecological paradigm, the study found out that the rural farmers are moderately environmentally conscious and their ecological dispositions are influenced by demographic and sociological factors. The study also sheds some light on the influence of environmental attitudes on behavioral intentions to recycle human excreta in agriculture. The study findings could help in mainstreaming research and policy efforts as well as in customer segmentation, prospecting, targeting and market feasibility.

(iii) Thirdly, the study used the random utility theory, experimental design and choice modeling approaches to assess the market feasibility and willingness to pay of rural farmers for the marketable, competitive, and quality attributes of co-compost in food systems. The assumption was that, if the quality of compost could be identified then improving its quality should mitigate the main challenge faced by composting innovations, namely, market demand. The study found out that farmers were willing to pay for all the identified attributes including packaging and pelletization, but especially certification and fortification. Research and development efforts could be tailored to support efforts on improving the viability of such efforts.

7.4. Challenges

The greatest challenge in ex ante demand assessment studies is that they rely on elicitation of stated preferences from the study participants. There is a gap between reported recycling behavioral intentions and observed behavior. To bridge the intention-behaviour gap requires enabling policy and institutional environment, skills, efforts, and financial support. Farmers may be willing to accept, use, and pay for co-compost, but this depends so much on whether the product is accessible and whether the farmers have the ability to pay for the products. Therefore, the reported results, may differ from actual behavior in the absence of an enabling economic environment. The second challenge relates to response, hypothetical, order and yea saying bias which are common in survey studies. Although measures were taken to reduce the systematic bias through questionnaire design, pretesting, randomisation, validity testing, certainty scales and cheap talk scripts, it is not always possible to completely eliminate bias in survey studies especially ex ante studies of hypothetical nature. The data collection was also conducted during Covid-19 pandemic and towards local authority elections and therefore a comparative study could not be done for the urban area due to the prevailing restrictions. Blocking the study to investigate differences between farmers in rural and urban could have provided more important insights. Finally, cross-country studies would improve the applicability of results in several contexts other than South Africa. Although limited to just one community, the dissertation makes important findings that highlight the potential to promote waste reuse in agriculture. The limitation is that the study only focused on one location hence the strength of conclusions may be limited.

7.5. Future possibilities

This study unpacked several insights for future research, particularly involving the designing of successful bioeconomy projects. It is imperative to reiterate that innovations are disseminated as projects, and therefore the designing and piloting of such projects is crucial. The scaling-up of these innovations is a phase that occurs after the piloting. Correct selection of successful interventions may require more than just an understanding of the demand elements, but the quantification of the sustainability of such innovations. The environment-society-economy pillars of sustainability should be addressed in any bioeconomy innovations to avoid investing resources on pretesting unsustainable projects. Sustainability implies the ability to meet current resource requirements without compromising the ability to meet future generational needs. An endeavour to undertake a comprehensive environmental accounting of the sustainability of circular bioeconomy initiatives using methods of life cycle-based science could help to account for the impacts of bio-based circular economy approaches on the economy, society, and environment.

An evaluation of environmental performance presents an imperative future research direction, especially considering the limited skills and data on undertaking such approaches in the developing countries. Life cycle-based science could help to fully integrate the impact on ecosystem services, namely, provisioning, regulating, supporting, and cultural services. Science-based evidence could also support market-based payment mechanisms such as public support, private-public partnerships, tax exemptions/incentives or subsidies, clean development mechanisms; and other regulatory mechanisms such as certification. Life cycle-based science could make use of national policy targets to quantify environmental performance of circular bioeconomy approaches and promote public awareness.

APPENDIX A: SUPPLIMENTARY INFORMATION

This appendix contains all the detailed information that could not be included in the main text as it would distract the reader from the main theme. The supplementary information soft-copy information such as specific details of statistical analyses, the results of questionnaires, spreadsheets of data, and the other materials reference in the main in the main chapters.

A.1: Detailed study area description

Vulindlela Traditional Council consists of nine wards under the Ingonyama Trust Board administration and the sole trustee of His Majesty the King (Isilo/Ingonyama) Goodwill Zwelithini (Kharsany et al., 2015; Msunduzi Municipality, 2016). The ten wards include wards 1 to 9 (Piper and Deacon, 2008) and recently incorporated ward 39 (**Table A.2 and Table A.3**). The area occupies 40% of the Msunduzi Municipality, covering approximately 25 000 hectares. The Vulindlela area accommodates more than 85 000 households and approximately 150 000 predominantly IsiZulu-speaking population (Kharsany et al., 2015). The land-use patterns include a mix of dwellings, grazing areas, individual farmlands, community gardens, indigenous forests, and timber plantations. The structures within the Vulindlela consists of the traditional structures (Amakhosi-chiefs and Izinduna-chief's headmen), political structures including community development structures and municipal councilors, government departments, para-state structures in energy and water, and other non-governmental organisations (Chirowodza et al., 2009). The location of Vulindlela as a ‘gateway’ to the city (25-40km from the city center) is of importance for building a resilient city-region food system. Rural and peri-urban agriculture contributes to a more diversified food basket and provides access to fresh perishable foods while generating income and employment, not only for farmers and farm labourers, but through multiplier effects in the economy. Peri-urban agriculture helps to save economic and environmental costs of transportation and cooling facilities for perishable food commodities (Hofny-Collins, 2006).

A.2: Detailed study design, survey training, and budget

We adopted a cross-sectional study design for this study which obtains all the respondents' measurements at a specific point in time. In this study, each farmer was interviewed once, although different households were interviewed on different dates. The household survey (preparation, training, and interviews) was administered from 10 to 26 November 2021 during a national lockdown and university Covid-19 window where household surveys were temporarily allowed with the actual fieldwork taking less than ten days. The enumerators were always encouraged to adhere to the country's Covid-19 lockdown level 1 regulation. The hiring of enumerators for training was advertised within the School of Agriculture, Earth and Environmental Sciences, requiring enumerators with minimum qualifications of being an enrolled master's degree student with exceptional skills of the IsiZulu language. Hiring qualified students came at a higher cost because universities use stipulated daily remuneration guides for fixed-term appointments. The rough order of magnitude estimates increased upwards by R60 000 (average exchange rate at the time 1USD ≈ R16), including the costs of car hire, enumerators, field guides, and electronic gadgets (**Table A.4**).

A two-day training was implemented to ensure validity, identify unforeseen and avertable problems, and improve data quality and accuracy. The study, therefore, required enumerators with exceptional translation skills and a high level of conceptualisation, including the ability to make sensible conversations with rural farmers. The questions that required exceptional skills from our experience include the New Ecological Paradigm (NEP) and the attitudinal questions. The field supervisor was a student in agricultural economics. The training covered survey methodology, review of mobile-based cloud data collection methods, the survey instrument, fieldwork principles, and interview hints and tips. The accuracy of the data can be assumed to be moderately high, considering the investment in training and recruiting qualified enumerators.

A.3: Survey questions

The survey mostly included single response and closed-ended questions that were either binary (Yes /No) or multiple-choice type after seeking participant consent and ethical approval (Fig S3). A choice was made between the two types of questions commonly used in cross-sectional surveys: open-ended and closed-ended questions. Closed-ended questions were used mostly to reduce the respondents' cognitive burden in trying to respond with an explanation to issues they may not be knowledgeable about. This explains why the selection of closed-ended questions in studies with smaller samples or populations is preferred, which treat each response as a unique opinion. For instance, only a few cases, 'other reason(s)', were open-ended where the respondents were given an opportunity to give their opinion other than those defined by the researcher. Although respondent answers from open-ended qualitative questions almost always provide a richer quality data, it can be unwieldy to make useful conclusions from the data. Demographic and socioeconomic questions such as the age, education, farm experience, income, income sources, gender, and religious affiliation, interaction with extension, farm size, and family size of the household head were also collected. Other question types included a 5-point Likert scale type question, for instance, in eliciting the New Ecological Paradigm (NEP) scale to assess environmental attitudes.

A.4: Sampling strategy

The study used a multi-stage sampling procedure, which may not be as effective as the true random sampling but may solve the challenges inherent in random sampling, which is used when a complete list of all members of the population is available. The use of multistage sampling averts the large, and perhaps unnecessary, costs associated with traditional cluster sampling by not using all sample units in all selected clusters. A multistage procedure was implemented by first purposively selecting 2 wards, randomly selecting villages and households in each ward. The selected wards (ward 8 and 9) were based on the maximum distance from the city. The number of households and people within each of the 10 wards that make up the Vulindlela Traditional Authority was accessed from the online data available at https://wazimap.co.za (**Table A.3)**. The data from https://census2011.adrianfrith.com and a map from the Msunduzi Municipality website were used to map and estimate the smallest sampling units within each of the 10 wards for which demographic data is available (**Figure A.1**).

For this study, the sampling unit - a household - was defined as people living together for more than three months, eating from the same pot, and making important livelihood or food security decisions together. The household head was the primary decision-maker on farming activities and not necessarily the head in the traditional/cultural/contextual sense. Initially, the sampling interval - the space between each selected household - was calculated by dividing the total number of households in each ward by the sample size. However, we saw that the sampling interval was creating large distances for enumerators to walk between houses, including the high non-response rates, the selection of households was therefore done by dropping enumerators into clusters where they would select five households. The relative homogeneity of the farmers in the community should not significantly affect the randomness of the sample. A neighbouring farmer was selected in the event of non-response or absence of the selected farmer.

Table A.2 Traditional Councils in Vulindlela

Traditional Councils in in Vulindlela Community (25 209.68ha)	Wards in each Traditional Council	The Inkosi/Leadership
Mpumuza Traditional Council	1, 2, 8	Inkosi N.W Zondi
Inadi Traditional Council	3, 4, 5, 9	Inkosi SG Zondi
Mafunze Traditional Council	7, 39	Inkosi MSP Ngcobo
Ximba Traditional Council	6	Inkosi S Malaba
Nxamalala Traditional Council	3	Inkosi E.S Zuma

Table A.3. Sampling information for Vulindlela Tradional Council

Wards-in Vulindlela Community (25 209.68ha)	Estimated enumeration areas or villages *(isigodis)* in each ward	Names of the smallest sampling units (Isigodis/EAs) for which data is available	Estimated population in sampling unit	Estimated household units in sampling unit	Population in each ward	Households in each ward
1	1	Mpumuza/*Phayapini*	11668	2678	18587	4043
2	2	Zayeka/Mthoqotho	8762+6699=15461	+1791+1387=3178	17444	3604
3	4	KwaMpande/Mgwagwa/Kwadlulela/Ebaleni	6710+2135+1766+873=11484	1201+413+323+148=2085	16909	3361
4	1	Eshowe/Esimbovu	1182	236	11239	2314
5	2	Gezubuso/Noshezi	5656+777=6433	1179+156=1335	17040	3761
6	2	Qanda/Etafuleni/Ntembeni	2164+1104=3268	379+238+=617	15236	2836
7	4	Embabane/Enzondweni/eMunywini+eMunyini	3118+1924+2320+394=7756	559+384+486+66=1495	14342	2717
8	2	*Emaswazini*/Madladla/Elandskop/*Mcane*/	3669+10229=13898	713+1902 =2615	11330	2145
9	1	Mafakatini/Taylor's Halt/	8085	1524	15540	2 971
39	1	39	13586	2 544	13586	2 544
Total			79 235	15 823	151253	24781

https://census2011.adrianfrith.com/place/566

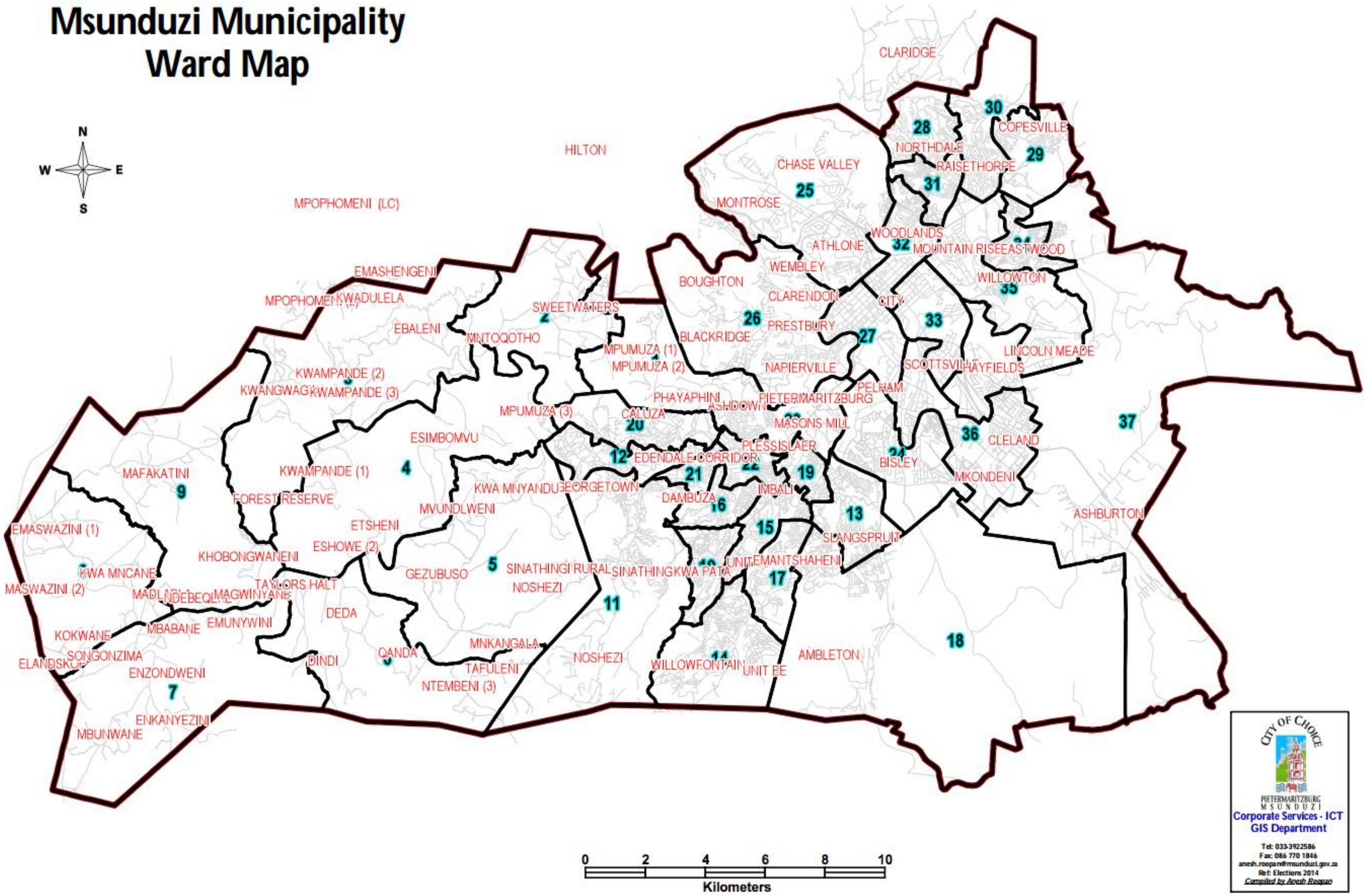

Figure A.1. Sampling area map http://www.msunduzi.gov.za/site/search/downloadencode/Ward_Map_2014_A4.pdf

Table A.4. First cut survey budget-including pilot testing and training

Item		Unit cost [R/day]	No. of persons	Number of days	Total Cost[R/day]
Per diems	Supervisors	500	1	10	5 000
	Enumerators	500	8	10	40 000
Allowances	Field assistants	350	2	10	7 000
Car Hire		700	2	15	24 000
Grand total					75 000

Table A.5. Characteristics of survey respondents (continuous scale)

Household characteristic	Mean	Median	Max	Min	Standard Dev
Age (years)	54	57	88	20	14.2
Years of education	7.9	8	19	0	4.1
Farming experience	23.2	20	70	1	15.6
Household size	6.3	6.0	17	1	3.3

Table A.6. Characteristics of survey respondents (nominal scale)

Household characteristic	Percentage (%)	Frequency
Gender	100%	341
Female	68.6	234
Male	31.4	107
Marital Status	100%	341
Married	43.7	149
Single	32.0	109
Widowed	22.3	76
Divorced	2.1	7
Religious affiliation/practice?	100%	341
Christianity	50.1	171
Polytheism	23.4	83
Traditionalism	12.6	43
Shembe/Nazarene	7.9	27
Other	2.6	9
Atheism	2.1	7
Agnosticism	0.3	1
Annual Income	100%	341
< R12 000	34.6	118
R12 000≤ Y< R60 000	31.4	107
R60 000≤ Y<R100 000	18.2	62
Greater than R150 000	15.8	54
Source of Income	341	100
Social grant	60.7	207
Formal salary work	10.9	37
Casual labour	7.6	26
Remittances	6.2	21
Wage work	4.4	15
Sale of farm produce	3.8	13
Formal business	3.7	11
Informal economy	2.6	9
Gifts	0.6	
Farm Size	100%	341
≤ 1 ha	77.4	264
1–2 ha	19.6	67
3–4 ha	1.8	6

> 4 ha	1.2	4
Membership	100%	341
Yes	8.5	29
No	91.5	312
Extension officer interaction	100%	341
Never	93.8	320
Less than once a year	2.6	9
Once a year	2.3	8
At least twice a year	0.3	1
More than twice a year	0.9	3

Table A.7. Main or dominant fertilizer in production system

Fertilizer type	Frequency	Percentage (%)
Inorganic fertilizer	66	19.5
Poultry manure	22	6.5
Cow manure	201	59.3
Organic compost	13	3.8
Co-compost	5	1.5
Farm residues	10	2.9
Others	22	6.5
Total	339	100

Table A.8. Reasons for the dominant fertilizer

Fertilizer type	Percentage (%)	Frequency
Availability	79.6	269
Price	3.6	12
Environmentally friendly	2.1	7
Soil health	14.8	50

A.5. Fertilizer types, reasons for use, and sources

The farmers' main type of fertilizer in the study area is cow manure (59,3%), followed by inorganic fertilizers, used by 19.5% of the respondents (Table A.6). Other types include poultry manure (6.5%), organic compost (3.8%), co-compost (1.5%), and farm residues (2.9%). A total of 22 farmers, constituting 6.5%, relied on other forms of fertilizers or did not use fertilizers at all in their farming systems (Table A.7). Most farmers in this community use cow manure, making it easy for farmers to accept similar products. Approximately 80% of the farmers chose their dominant fertilizer based on availability. Other reasons include soil health (14,8%), price (3.6%), and environmental benefits (2.1%). The main source of these fertilizers was free, making up 48.3% of the respondents, while 41.4% were producing it on the farm. The rest of the farmers bought their fertilizers (8.6%) or produced them elsewhere (1.4%) (Table A.8).

Table A.9. Sources fertilizer

Source	Frequency	Percentage (%)
Produce it on the farm	58	41.4
Produce it elsewhere	2	1.4
Buy it	12	8.6
Get it for free	68	48.6
Total	140	100.0

Table A.10. Factors influencing consumers' purchasing behavior

Statement	Level of agreement %

Desirable characteristic	Strongly Disagree	Disagree	Don't know/neutral	Agree	Strongly Agree
Price	10,6	9,1	8,2	39,4	32,6
NPK content	2.4	4.4	22.6	41.5	29.1
Organic matter	1.8	1.8	8.8	53.1	34.5
Safety	1,8	1,8	8,8	53,1	34,5
Packaging	8.9	22.6	19.6	33.2	15.7
Certification	5,6	7,6	14,1	38,8	33,8
Credit offer	7.1	15.7	24.6	39.6	13.0
Convenient location	5.0	10.0	12.9	48.2	23.8
Pelletization	8.3	17.1	22.7	26.5	25.4
Recommended by sources I trust	6.2	7.7	10.3	45.7	30.1

Table A.11. Effect of crop type on attitudinal score

Attitude item	Frequency (Yes)	Percentage (Yes)	Total number of responses
Does crop type to be fertilized with co-compost matter to you?	103	30.8	334
If crop type matters to you, would you eat leafy vegetables fertilized with co-compost?	54	52.4	103
If crop type matters to you, would you eat roots crops/tubers fertilized with co-compost?	42	40.8	103
If crop type matters to you, would you eat maize fertilized with co-compost?	87	84.5	103

Table A.12. Factors that drive farmers to use co-compost on their crops

Statement	Percentage	
	Yes	No
Co-compost is good for my soil	96.2	3.8
Co-compost will increase my crop productivity	96.6	3.4
Co-compost is good if it is sanitised and used safely	88.8	11.2
If I use co-compost, I must buy less fertiliser from the market;	85.4	14.6

Table A.13. Any other reasons for using co-compost (post-coded)

Any other reasons for using co-compost (post-coded)	Number of respondents
Appearance	1
Applies to more crops-promotes diversification	7
Availability	3
Fertility	1
Good yields	42
Lower price	6
Safety	3
Sanitation improvement	12
Sustainable	2
Uses manure	1
Number of respondents	78

Table A.14. Factors that prevent farmers from using co-compost on their crops

Statement	Percentage (%)		
	Yes	No	Valid number
I would need to do some more research before I can consider using co-compost in my farming systems	62.3	37.7	77
I would eat food fertilised with human excreta if the fertilizer was treated and certified	49.4	50.6	77
I would eat food fertilised with human excreta if the food was processed	38.2	61.8	77
I would eat food fertilised with human excreta if the food is going to be consumed cooked or boiled	31.2	68.8	
Crops can die if fertilised with co-compost	23.4	76.6	77
The taste of crops and vegetables will change if I use co-compost	57.1	42.9	77
I use chemical fertilizer, so I don’t need co-compost	80.5	19.5	77
There are health risks associated with co-compost, so I will not use it	57.1	42.9	77
The smell of co-compost is a hindrance/disgusting	94.7	5.3	77
People will mock me or make fun of me	68.4	31.6	77
Taboo or religious belief	56.0	44.0	77

Table A.15. Any other reasons for not using co-compost

Reason	Number of respondents
Damages the soil	1
Dehumanising	2
Disgusting	14
Health risk	3
Not aware	5
Use cow manure	2
Total	27

Table A.16. NEP scale Cronbach's Alpha factoring test for internal consistency

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of N items
0.762	0.763	15

Table A.17. NEP scale exploratory factor analysis

Item scale	Mean	Std. Dev	Cronbach's Alpha if Item Deleted
We are approaching the limit of the number of people the Earth can support	3.57	1.01	0.74
Humans have the right to modify the natural environment to suit their needs	2.32	1.00	0.76
When humans interfere with nature it often produces disastrous consequences	3.65	0.90	0.74
Human intelligence will ensure that we do not make Earth un–liveable	2.49	1.02	0.75
Humans are seriously abusing the environment	3.87	1.04	0.74
The Earth has plenty of natural resources if we just learn how to develop them	2.18	0.85	0.77
Plants and animals have as much right as humans to exist	3.63	1.14	0.76
The balance of nature is strong enough to cope with the impacts of modern industrial nations	2.86	0.96	0.74
Despite our special abilities, humans are still subject to the laws of nature	3.91	0.85	0.76
The so–called "ecological crisis" facing humankind has been greatly exaggerated	3.08	1.09	0.76
The Earth is like a spaceship with very limited room and resources	3.32	1.04	0.74
Humans were meant to rule over the rest of nature	2.14	1.04	0.76

The balance of nature is very delicate and easily upset	3.57	0.82	0.74
Humans will eventually learn enough about how nature works to be able to control it	2.37	0.88	0.76
If things continue on their present course, we will soon experience a major ecological catastrophe	3.77	0.89	0.74
Mean NEP rating	3.12	0.47	

Table A.18. The dimensionality of the NEP scale against hypothesized facets

Factor	Initial eigenvalues (unrotated)			Extraction sums of squared loadings (varimax rotation)		
	Total	% of variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.59	25.27	25.27	2.951	20.80	20.80
2	1.94	13.68	38.95	1.907	13.44	34.24
3	1.19	8.39	47.34	1.526	10.75	44.98
4	1.12	7.87	55.21	1.451	10.22	55.21
5	0.89	6.30	61.51			
6	0.84	5.89	67.40			
7	0.79	5.57	72.97			
8	0.64	4.49	77.46			
9	0.60	4.26	81.72			
10	0.53	3.72	85.44			
11	0.52	3.64	89.08			
12	0.50	3.49	92.56			
13	0.42	2.93	95.50			
14	0.33	2.29	97.79			
15	0.31	2.21	100.00			

Table A.19. NEP scale factor loadings

Variables/questions	5 hypothesized facets	Component loadings			
		1	2	3	4
1	Limits	**0.68**	-0.30	0.18	0.05
2	Antianthro	**0.68**	-0.29	0.26	0.21
3	Balance	**0.64**	-.026	0.18	0.23
4	Antiexempt	**0.64**	-0.10	0.07	0.05
5	Eco-crisis	**0.63**	-0.21	0.04	0.11
6	Limits	**0.62**	0.02	-0.07	-0.26
7	Antianthro	**0.54**	0.25	-0.06	0.27
8	Balance	**0.42**	**0.65**	0.06	0.03
9	Antiexempt	0.22	**0.58**	0.11	-0.06
10	Eco-crisis	0.09	**0.56**	0.04	-0.07
11	Limits	**0.38**	**-0.53**	0.14	-0.12
12	Antianthro	**0.37**	**0.39**	**-0.35**	0.30
13	Balance	**0.47**	-0.19	**-0.64**	**-0.51**
14	Antiexempt	**0.30**	0.26	**-0.37**	**0.35**
15	Eco-crisis	**0.36**	**0.41**	**0.45**	**-0.52**

Table A.20. Exploratory factor analysis of the attitudinal questions or scale items

Item scale/attitudinal question	Mean	Std. Dev	Cronbach's Alpha if Item Deleted

Do you think you have enough skills/knowledge/resources to use human excreta in your farming systems	1.09	0.29	0.82
Do you think human excreta can be treated so as to NOT pose a health risk?	1.83	0.37	0.82
Do you think treated human excreta contains pathogens (microorganisms that can cause diseases) when applied to crops?	1.42	0.49	0.83
Do you think pharmaceuticals/medicines can be found in crops growth with human excreta derived fertilizer like co-compost?	1.37	0.48	0.85
Do you think co-compost can be used to fertilise crops?	1.77	0.42	0.80
Do you think human urine can be used to fertilise crops?	1.48	0.50	0.81
Do you think human excreta should be disposed and never be reused	1.51	0.50	0.81
Would you buy fertilizer made from human excreta or co-compost?	1.73	0.45	0.79
Would you buy food that was fertilised with human urine?	1.57	0.49	0.80
Would you buy food that was fertilised with human faecal matter?	1.66	0.47	0.79
Do you think other people in general, would use human excreta in their fields to fertilize crops	1.63	0.48	0.80
Do you think other people in the market will buy food produced using co-compost as fertiliser?	1.71	0.46	0.80
Do you think your family members would eat food that was fertilised with human excreta?	1.42	0.49	0.80
Do you think your, neighbours, friends, relatives or other people would eat food that was fertilised with human excreta?	1.59	0.49	0.79

Table A.21. Principal component analysis with varimax rotation to compute attitudinal scores

Factor	Initial eigenvalues (unrotated)			Extraction sums of squared loadings (varimax rotation)		
	Total	% of variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.15	38.82	38.82	0.77	26.02	26.02
2	0.34	11.27	50.08	0.68	22.70	48.72
3	0.28	9.36	59.45	0.32	10.72	59.45
4	0.21	7.11	66.56			
5	0.18	5.99	72.54			
6	0.16	5.23	77.77			
7	0.13	4.22	81.99			
8	0.11	3.77	85.77			
9	0.10	3.50	89.27			
10	0.08	2.53	91.79			
11	0.07	2.49	94.29			
12	0.07	2.17	96.65			
13	0.06	1.88	98.33			
14	0.05	1.69	100.00			

Table A.22. The named dimensionality of the attitudinal scale

Item scale	Component 1 (high loadings on perceived behavioral control, production, market, subjective norms,)	Component 2 (high loadings on production. market attitudes and subjective norms)	Component 3 (low loadings of all questions)
Do you think you have enough skills/knowledge/resources to use human excreta in your farming systems	0.81		
Do you think human excreta can be treated so as to NOT pose a health risk?	0.80		
Do you think treated human excreta contains pathogens (microorganisms that can cause diseases) when applied to crops?	0.77		0.32
Do you think pharmaceuticals/medicines can be found in crops growth with human excreta derived fertilizer like co-compost?	0.74		
Do you think co-compost can be used to fertilise crops?	0.73		0.31
Do you think human urine can be used to fertilise crops?	0.69		
Do you think human excreta should be disposed and never be reused	0.66	-0.41	0.43
Would you buy fertilizer made from human excreta or co-compost?	0.63		
Would you buy food that was fertilised with human urine?	0.59		-0.42
Would you buy food that was fertilised with human faecal matter?	0.54	0.31	
Do you think other people in general, would use human excreta in their fields to fertilize crops	0.41		
Do you think other people in the market will buy food produced using co-compost as fertiliser?		0.78	0.32
Do you think your family members would eat food that was fertilised with human excreta?			
Do you think your, neighbours, friends, relatives or other people would eat food that was fertilised with human excreta?	-0.32	0.50	0.55

APPENDIX B: R SCRIPT FOR CHOICE EXPERIMENT DESIGN

The modified Fedorov algorithm achieves the principles of good DCE design, namely orthogonality, minimal overlap, and level and utility balance by reducing the D-error. The first four attributes have two levels each, while the fifth price attribute has five levels. Each of the five attributes is dummy coded as shown in code "D". The matrix M, contains the draws from the prior multivariate prior distribution with mean=mu and covariance matrix sigma specified in par.draws. The eight elements in mu include the first, second, third and fourth parameters are for the first, first, second, third and fourth attributes, while the last four are for the price attribute. In mu, we have eight priors because we are omitting a level per attribute and the amount of coefficients in the priors vector is (s-k) where s is the number of levels and k is the number of attributes (13-5=8).

```
#Installing and activating packages#
install.packages(AlgDesign)
library(AlgDesign)
#Creating the fullfactorial with 2*2*2*2*5
fullfactorial<-
gen.factorial(c(2,2,2,2,5),varNames=c("Packaging","Pelletization","Fortification","Certification","Price"),factors="all")
data.frame(fullfactorial)
fullfactorial
#Creating the fractional factorial design
#A modified Fedorov algorithm#
library("idefix")
library("AlgDesign")
library("OptimalDesign")

code <- c("D","D","D","D","D")
cs <- Profiles(lvls = c(2,2,2,2,5), coding = code)
mu <- c(0.01, 0.01, 0.01, 0.4, -0.01, -0.4, -1, -2)
sigma <- diag(length(mu))
set.seed(123)
M <- MASS::mvrnorm(n = 300, mu = mu, Sigma = sigma)
D <- Modfed(cand.set = cs, n.sets = 8, n.alts = 2, alt.cte = c(0, 0), par.draws = M)
D
lvls <- list( c("No-product packaging", "Yes-product packaging"),c("No-product pelletization", "Yes-product pelletization"),c("No-product fortification", "Yes-product fortification"),c("No-product certification", "Yes-product certification"),c("R1.5/kg", "R2/kg", "R2.5/kg", "R3/kg", "R3.5/kg"))
DD <- Decode(des = D$design, lvl.names = lvls, coding = code, n.alts = 2)
DD
save(DD, file="C:/Users/Carol Bassinger/Desktop/SimonUP CEEPA/designMODFED2.xls")


$error
[1] 2.858163

$inf.error
[1] 0

$probs
     Pr(alt1)  Pr(alt2)
set1 0.6739056 0.3260944
set2 0.5617153 0.4382847
set3 0.6332607 0.3667393
set4 0.5426803 0.4573197
set5 0.4282428 0.5717572
set6 0.4590943 0.5409057
set7 0.4979603 0.5020397
set8 0.2924425 0.7075575
```

APPENDIX C: ETHICS APPROVAL

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

28 July 2020

Mr Simon Gwara (218086735)
School Of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear Mr Gwara,

Protocol reference number: HSSREC/00001499/2020
Project title: Socio-economic viability of the agricultural use of human excreta derived material
Degree: PhD

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 19 June 2020 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

<u>This approval is valid until 28 July 2021.</u>
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

All research conducted during the COVID-19 period must adhere to the national and UKZN guidelines.

HSSREC is registered with the South African National Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Professor Dipane Hlalele (Chair)

/dd

Humanities & Social Sciences Research Ethics Committee
UKZN Research Ethics Office Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Tel: +27 31 260 8350 / 4557 / 3587
Website: http://research.ukzn.ac.za/Research-Ethics/

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

APPENDIX D: SURVEY QUESTIONNAIRE

Instructions to Enumerators

- Visit the respondents.
- Explain who you are and what you are doing summarizing the purpose of the study, the time it takes to complete the survey and confidentiality.
- Read the verbal consent statement to the respondent. If she/he agrees, you may begin the interview.

Good morning/afternoon, my name is _

Study purpose

The objective of this experiment is to elicit Farmers' Attitudes, Perceptions and Willingness to Pay for Human Excreta Derived Material in Agriculture with specific focus on co-compost; a mix of human excreta and organic green waste. The selection of co-compost was based on contextual analysis and various stakeholder meetings held with farmers through an on-going project titled "The rural-urban nexus – Establishing a nutrient loop to improve city region food system resilience" also known as the RUNRES project. This study is part of Mr Simon Gwara's PhD study in Agricultural Economics funded through the Pollution Research Group (PRG) of the University of KwaZulu-Natal.
In this study, you will be asked to take part in a Choice Experiment to estimate your Willingness to Pay for a labelled, packaged, fortified and certified co-compost product. Co-compost is one among many innovations to provide sanitation and return nutrients to the soil by carefully mixing green organic waste with human excreta-based sludge from Ventilated Improved Pit (VIP) latrines that are now full and require emptying. Other sources of faecal sludge may include urine diversion dehydration toilets (UDDTs). The co-composting process is very simple and cheap. Pathogens and odours are eliminated during the thermophilic stage of co-composting. Co-compost can be provided in the traditional powder form or in pellets that are easy to handle, spread and not blown by wind. This product can be used to substitute or complement inorganic fertilizers. It can also be sold in bulk or packaged and labelled with application instructions, fortified with inorganic nutrients and certified by relevant authorities. To be certified means that the product has met the requirements of the Fertilizer and Farm Feeds Act 36 of 1947 and is safe for use in agriculture. However, to provide these attributes comes at a cost and accurately stating and estimating your WTP for these attributes may assist policy makers and development practitioners in evidence-based decision making.
The outcome of this study may, therefore, provide pertinent information for informing the direction of on-going and future development projects focusing on Circular Nutrient Economy initiatives.

How to complete the survey?

The survey questions provided in this study were made very simple closed-ended questions or statements which require a response. Respondents are also given an opportunity to explain their responses in a closed-ended fashion later in the survey. Some questions responses are radio (select one) or checkbox (select many) type while in some cases you may have a chance to express your opinion in the form of comments or reasons. Please kindly note that you are required to provide consent by clicking the 'I consent to participate' button at the end of this page. This is done in compliance with the UKZN Ethics Policy.
This study has been approved by the Humanities and Social Sciences Research Ethics Committee (HSSREC) which is registered with the South African National Research Ethics Council-REC-040414-040 (see enclosed approval)

Time of study

The study takes a maximum of 25 minutes to complete and you will be one of approximately 320 randomly selected participants. You will not be compensated for participating in this study.

Confidentiality

Any information collected through this study shall remain anonymous and shall be kept confidential to the extent mandated by the South African Law. However, findings from this study may be published and/or shared with other research organisations and interested parties but you will not be identified personally. You are at liberty to stop or withdraw from the survey at any point. There are no health risks or discomfort from participating in this study.

Contact details

If you have any questions or concerns about this study, you may email Mr. Simon Gwara at simmonsgwara@yahoo.co.uk or 218086735@ukzn.ac.za (+27-60-402-5935) or Professor Edilegnaw Wale at walee@ukzn.ac.za or Dr. Alfred Odindo at odindoa@ukzn.ac.za or Professor Chris Buckley at cbuckley@ukzn.ac.za

Consent

Clicking the "I consent to participate in this survey" button below means you acknowledge that you have understood the all the information stated above including the purpose of this study and voluntarily agree to participate in this study. Although your personal details/identity will not be disclosed, consenting also means that you agree that your responses can be usedfor academic research otherwise you are free to select do not consent and leave the survey.

I consent to participate in this survey

(●) Yes, I consent to participate in this survey ( ) No, I do not consent

THE SURVEY BEGINS…

DETAILS OF STUDY

Date of the interview

yyyy-mm-dd

Name of Enumerator

- ◯ a
- ◯ b
- ◯ c
- ◯ d
- ◯ e
- ◯ f
- g ◯
- h ◯

Ward name

Village /enumeration area name

Location of farm (rural/peri-urban)

- ◯ Urban
- ◯ Peri-urban
- ◯ Rural

Household local Name

This could be an informal name for the household, but most commonly used by the locals.

» HOUSEHOLD HEAD DEMOGRAPHIC INFORMATION

Note: A household denotes all the people living in the same compound, eating from the same "pot" and working to sustain the family members. Household head is the one who is currently generating the income the household depends very much on and/or who makes the most important decisions in the household If husband and wife jointly manage the crops, both should be interviewed together. Participation of the wife should be encouraged.

Name of household head?

Gender of the household head?

- ○ Male
- ○ Female

What is the household head age in years?

Age must be less than 120. Please reenter the age

Marital status of household head?

- ○ Single
- ○ Married
- ○ Divorced
- ○ Windowed

Years of education of household head?

Experience of household head in farming in years

Period of Time on the Farm

What is household head's religious affiliation/practice

- ○ Christianity
- ○ Tradionalism
- ○ Islam
- ○ Atheist
- ○ Shembe
- ○ Agnostic
- ○ Other

What is the size of household?

How many people live on your farm?

What is the annual income of family?

Please estimate annual income accounting for expenses and revenues of all enterprises

- ○ < R12 000
- ○ R12 000≤Y< R30 000
- ○ R30 000≤Y<R60 000
- ○ R60 000≤Y<R100 000
- ○ R100 000≤Y<R150 000
- ○ Greater than R150 000
- ○ I do not wish to disclose

What is the main source of income?

- Sale of farm produce
- Formal salary work
- Wage work
- Casual labour
- Informal economy
- Rentals
- Remittances
- Gifts
- Social grant
- Formal businesses

Farm Size (How much land is there on your property that you use for farming or farm activities)

Answer in hectares

- ≤1 ha
- 1–2 ha
- 2–4 ha
- > 4 ha

Are you a member of any association or co-operative?

- Yes
- No

How often do you interact with the extension officer?

- Never
- Less than once a year
- Once a year
- At least twice a year
- More than twice a year

How do you MAINLY dispose your household waste that is not immediately biodegradable?

glass, metal, textile, furniture, bricks and rubbles, ewaste,

- Throw in the field
- Use a pit/dump site
- Throw in the toilet pit
- Bury on the ground
- Burn
- Compost
- Dump at a designated place
- Dump at an undesignated place
- Other

How do you MAINLY dispose your household waste that is immediately biodegradable?

food waste, garden refuse, wood chippings/sawdust,

- Throw in the field
- Use a pit/dump site
- Throw in the toilet pit
- Bury on the ground
- Burn
- Compost
- Dump at a designated place
- Dump at an undesignated place
- Other

What is the COMMON practice when your toilet is full?

- Use neighbors' toilet
- Construct a substandard/makeshift toilet
- Use chemical additives/shibhoshi
- Build a new one

- ◯ Use the field or open defecation
- ◯ Move the structure and dig a new pit
- ◯ Manual emptying
- ◯ Mechanical emptying

» ATTITUDE AND PERCEPTIONS TOWARDS CO-COMPOST

In this section, we would like to know your attitudes and perceptions on fertilizers made from organic waste and human excreta. A perception is what one thinks about something after analyzing some concrete logical facts about it and it is not highly subjective. Please answer the following questions and assess the suitability of these products for your farming activities, if given the opportunity.

Do you think co-compost can be used to fertilise crops?

◯ Yes
◯ No

Do you think human urine can be used to fertilise crops?

◯ Yes
◯ No

Do you think human faecal matter should be used to fertilise crops?

◯ Yes
◯ No

Do you think that using human excreta as a crop fertiliser/soil amendment is?

◯ More sustainable than using a chemical fertiliser
◯ Less sustainable than using a chemical fertiliser
◯ Similar to using a chemical fertiliser

Do you think human excreta should be disposed and never be reused

◯ Yes
◯ No

Does crop type to be fertilized with co-compost matter to you?

roots/tubers vs leafy vegetables vs maize vs fruit trees

◯ Yes
◯ No

If crop type matters to you, would you eat leafy vegetables fertilized with co-compost?

◯ Yes
◯ No

If crop type matters to you, would you eat roots crops/tubers fertilized with co-compost?

◯ Yes
◯ No

If crop type matters to you, would you eat maize fertilized with co-compost?

◯ Yes
◯ No

Do you think food produced using human excreta would be more acceptable if it was processed?

tomatoes vs sauces, sugar vs sugarcane, maize cobs vs instant poridge e.t.c.

◯ Yes
◯ No

Do you think food produced using human excreta would be more acceptable if it was cooked?

cooked vs consumed raw

◯ Yes
◯ No

Would you buy fertilizer made from human excreta?

◯ Yes
◯ No

Would you eat food that was fertilised with organic compost?

Would you eat food that was fertilised with human urine?

◯ Yes
◯ No

Would you eat food that was fertilised with human faecal matter?

◯ Yes
◯ No

I would eat food fertilised with human urine

- ◯ Even if it costs more than what I usually pay
- ◯ Only if it costs less than what I usually pay
- ◯ Only if it costs the same as what I usually pay
- ◯ Only if it is being given for free
- ◯ I will not use it regardless of cost

Subjective norms refer to the belief that an important person or group of people will approveand support a particular behavior.

Do you think other you know would use human excreta in their fields to fertilize crops

- Yes
- No

Do you think other people in the market will buy food produced using co-compost as fertiliser?

- Yes
- No

Do you think your family members would eat food that was fertilised with human excreta?

- YES all members would eat
- NO all members will not eat
- Some members might not eat

Do you think your, neighbours, friends, relatives or other people would eat food that was fertilised with human excreta?

- Yes
- No

Perceived behavioral control refers to people's perceptions of their ability to perform a given behavior

Are you aware of the use of human excreta in agriculture

Awareness

- Yes
- No

Do you think you have enough skills/knowledge to use human excreta in your farming systems

self efficacy

- Yes
- No

Do you think you have enough resources to use human excreta in your farming systems

self efficacy

- Yes
- No

Do you think fresh/untreated human excreta poses a health risk to you as a consumer?

risk perception

- Yes
- No

Do you think human excreta can be treated so as to NOT pose a health risk?

risk perception

- Yes
- No

Do you think treated human excreta contains pathogens (microorganisms that can cause diseases) when applied to crops?

risk perception

- Yes
- No

Do you think pharmaceuticals/medicines can be found in crops growth with human excreta derived fertilizer like co-compost?

risk perception

- Yes
- No

» Please indicate your reasons for using co-compost in the following questions

Co-compost is good for my soil
perceived benefits
Yes
No

Co-compost will increase my crop productivity
perceived benefits
Yes
No

Co-compost is good if it is sanitised and used safely
perceived benefits
Yes
No

If I use co-compost, I have to buy less fertiliser from the market;
perceived benefits
Yes
No

Any other reasons for using co-compost
perceived benefits

____

» Please indicate your reasons for not using co-compost in the following questions

I would need to do some more research before I can consider using co-compost in my farming systems
risk perception
Yes
No

I would eat food fertilised with human excreta if the fertilizer was treated and certified
risk perception
Yes
No

I would eat food fertilised with human excreta if the food was processed
risk perception
Yes
No

I would eat food fertilised with human excreta if the food is going to be consumed cooked or boiled
risk perception
Yes
No

Crops can die if fertilised with co-compost
risk perception
Yes
No

The taste of crops and vegetables will change if I use co-compost
risk perception
Yes
No

I use animal manure, so I don't need co-compost
risk perception
Yes
No

There are health risks associated with co-compost, so I will not use it;
risk perception
Yes
No

The smell of co-compost is a hindrance/disgusting
risk perception
Yes
No

People will mock me or make fun of me

risk perception

- Yes
- No

Taboo or religious belief

risk perception

- Yes
- No

Any other reasons for not using co-compost

risk perception

» Factors influencing consumers' purchasing behavior (driving forces for co-compost purchasing decisions)

Price is the most important factor

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

NPK levels content is the most desirable characteristic

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Safety is the most desirable characteristic

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Packaging is the most important characteristic

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

A label showing the fertilizer is certified by relevant authorities (DALRD, Act 36 of 1947) is the most desirable characteristic

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Suitable credit offer is the most important factor

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

A convenient location to buy the product is the most important characteristic

- Strongly Disagree

- Disagree
- Neutral
- Agree
- Strongly Agree

Recommended by sources I trust

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I would buy compost made with human excreta if it was at least 50% cheaper than other types compost.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I would buy compost made with human excreta if it was at least 20% cheaper than other types of compost.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Regardless of price, I try to avoid buying fertilizer pellets derived from human excreta

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

I would prefer the pellet form over the powder form for any compost

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

» The New Ecological Paradigm Scale (NEP) is used as a unidimensional measure of environmental attitudes. Please indicate how strongly you agree or disagree with the following statements of theNew Ecological Paradigm:

We are approaching the limit of the number of people the Earth can support

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Humans have the right to modify the natural environment to suit their needs

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

When humans interfere with nature it often produces disastrous consequences

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Human intelligence will ensure that we do not make the Earth un–liveable

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Humans are seriously abusing the environment

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

The Earth has plenty of natural resources if we just learn how to develop them

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Plants and animals have as much right as humans to exist

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

The balance of nature is strong enough to cope with the impacts of modern industrial nations

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Despite our special abilities, humans are still subject to the laws of nature

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

The so–called "ecological crisis" facing humankind has been greatly exaggerated

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

The Earth is like a spaceship with very limited room and resources

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Humans were meant to rule over the rest of nature

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

The balance of nature is very delicate and easily upset

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Humans will eventually learn enough about how nature works to be able to control it

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

If things continue on their present course, we will soon experience a major ecological catastrophe

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

» Farm Production Characteristics and Experiences

What do you use fertilizer for?

- ☐ Farming
- ☐ Gardening
- ☐ Grounds-keeping
- ☐ Park maintenance
- ☐ Other

What is the dominant fertilizer in your activities?

- ☐ Inorganic fertilizer
- ☐ Poultry manure
- ☐ Cow manure
- ☐ Organic compost
- ☐ Co-compost
- ☐ Farm residues
- ☐ Other

Please provide main reason why this is the dominant fertilizer?

- ○ Availability
- ○ Price
- ○ Environmentally friendly
- ○ Human health
- ○ Soil health

Do you use compost?

- ○ Yes
- ○ No

How do you mainly obtain it?

- ○ Produce it on the farm
- ○ Produce it elsewhere
- ○ Work for it
- ○ Buy it
- ○ Get it for free

Do you know how to make compost?

- ○ Yes
- ○ No

Do you make enough for your farm requirements?

- ○ Yes
- ○ No

Have you ever sold compost?

- ○ Yes
- ○ No

» Instructions for Eliciting Willingness to Pay

Before you make a decision on the choice of this product, it is important to note that previous studies have found that farmers willingness to pay for products in a hypothetical market is different than in real life situations (Lusk and Schroeder, 2004). Thus, consider thoroughly how the extra costs or incentives would affect your family budget so that you are completely certain that you are willing and able to pay the costs associated with the alternative that you choose. There are already some projects that are trying to implement the innovations (co-compost) in this community and beyond and therefore this information would benefit many farmers including your family.

» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

Please SELECT ONLY ONE in each of the option sets below

I would choose

Co-compost Attributes	**A**	**B**	**C**
Pelletization 	No pelletization	Yes pelletization	If options A & B were all that was available at my local farm input shop, I would not purchase co-compost from that shop.
Fortification 	Yes fortification	No fortification	
Packaging 	No packaging	No packaging	
Certification 	No certification	Yes certification	
Price 	R2.50/kg	R3.50/kg	

- ◯ A
- ◯ B
- C

How certain are you that given the chance you would actually choose this option and spend money this way?

- ◯ 1 (very uncertain)
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 (very certain)

» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

Please SELECT ONLY ONE in each of the option sets below

Co-compost Attributes	**A**	**B**	**C**
Pelletization 	Yes pelletization	No pelletization	If options A & B were all that was available at my local farm input shop, I would not purchase co-compost from that shop.
Fortification 	Yes fortification	No fortification	
Packaging 	Yes packaging	No packaging	
Certification 	No certification	No certification	
Price 	R1.50/kg	R2.50/kg	

I would choose

- ◯ A
- ◯ B
- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

- ◯ 1 (very uncertain)
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 (very certain)

» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

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Fortification 	No fortification	Yes fortification	
Packaging 	Yes packaging	Yes packaging	
Certification 	No certification	No certification	
Price 	R3.00/kg	R3.50/kg	

I would choose

- ◯ A
- ◯ B
- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

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- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 (very certain)

» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

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- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
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» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

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Certification 	No certification	Yes certification	
Price 	R1.50/kg	R2.00/kg	

I would choose

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- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

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Co-compost Attributes	**A**	**B**	**C**
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Price 	R3.00/kg	R2.50/kg	

I would choose

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- ◯ B
- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

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- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
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» If you were faced with the choices of three packages of co-compost with different attributes namely prices, production and quality attributes which option would you choose to purchase?

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Fortification 	Yes fortification	No fortification	
Packaging 	Yes packaging	Yes packaging	
Certification 	Yes certification	No certification	
Price 	R2.50/kg	R2.00/kg	

I would choose

- ◯ A
- ◯ B
- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

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- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
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Packaging 	Yes packaging	No packaging	
Certification 	No certification	Yes certification	
Price 	R3.00/kg	R1.50/kg	

I would choose

- ◯ A
- ◯ B
- ◯ C

How certain are you that given the chance you would actually choose this option and spend money this way?

- ◯ 1 (very uncertain)
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 (very certain)

Please take a GPS point

Geopoint with maps

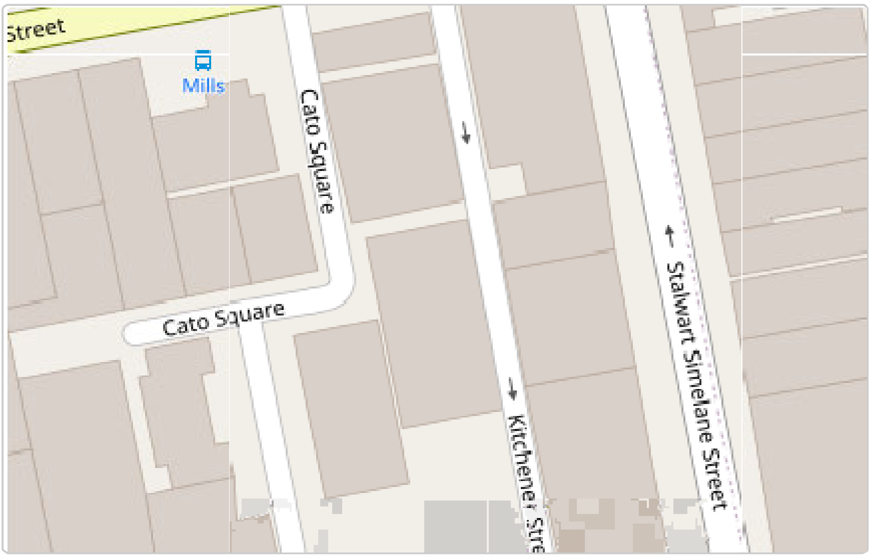
latitude (x.y °)

____

longitude (x.y °)

____

altitude (m)



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