Centering Farmer Perspectives on a Dry-Fertiliser Made from Human Urine

A case study on Gotland, Sweden

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LUCSUS
Lund University Centre for Sustainability Studies

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Abstract

To reduce eutrophication and close the nutrient loop between sanitation and agriculture, innovations to recycle human waste are being further developed. As there is little research on Swedish farmer perspectives towards human urine fertilisers, this study investigates Gotlandic farmer perspectives on a dry-fertiliser derived from human urine, developed by Sanitation360. Diffusion of innovation theory is utilised to investigate urine's relative advantage, compatibility, complexity, trialability and observability and how these pose as barriers or potentials for adoption. Qualitative data collection included semi-structured interviews with nine farmers, two key informant interviews and informal discussions with Sanitation360's CEO. Findings show farmers are positive towards its circular benefits, dry-form and locally produced aspects but there is low awareness regarding that urine can be used in conventional farming. Worries about hazardous substances due to Sweden's ongoing sludge debate, scepticism towards consumer acceptance and legislative barriers for organic farmers stand in the way of adoption.

Keywords: circular nutrient economy, human urine fertiliser, farmer perspectives, agriculture, ecological sanitation, eutrophication

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Abbreviations

HUF – human urine fertiliser that has been treated in some way i.e. not raw urine

UDT – urine diverting toilets

CAP – Common Agricultural Policy

WWTP – wastewater treatment plant

DOI – Diffusion of Innovation (theory)

(side note: human urine is referred to as urine throughout the thesis)

1 Introduction

The growing concern about the future availability of fertilisers has highlighted the need for reusing the nutrients that exist in our sanitation system (Harder et al., 2019). Like today's linear economy, big proportions of fertiliser flows follow a linear pattern where extreme amounts of nutrients are simply leaked into the environment (Chojnacka et al., 2020). However, recovering nutrients derived from human excreta could advance a transition to a global circular nutrient economy by linking increasingly urban populations to rural agricultural land (Trimmer & Guest, 2018). A circular nutrient economy entails ensuring high recovery rates of nutrients and biomass from human waste, such as human excreta and food waste, and recirculating it back to agriculture (Harder et al., 2019). This would reduce the need for synthetic fertilisers, which require large amounts of fossil fuels to be chemically manufactured (Glibert et al., 2014).

Raw materials to produce synthetic fertilisers are also being extracted at rates that are depleting global resources, such as in the case of phosphorus which is extracted from mining (Reijnders, 2014), whereas nitrogen is extracted from the atmosphere through the Haber-Bosch method (Menegat et al., 2022; Steffen et al., 2015). In 2022, global fertiliser demand reached almost 200 million metric tons, 110,8 of which was nitrogen, 50 was phosphorus and 39,1 was potassium (Statista, 2023a). Excessive or inefficient use of fertilisers lead to nutrient accumulation in water bodies, fostering plant growth (Jansson et al., 2019). This ends up depleting oxygen reserves, causing eutrophication which is devastating for marine life (Jansson et al., 2019). Despite already having breached the planetary boundary of biogeochemical flows, mainly due to our excessive use of fertilisers (Steffen et al., 2015), the global fertiliser demand is expected to increase to 208,3 million metric tons in 2026 (Statista, 2023b).

A heavily impacted region is the Baltic Sea, which is considered >90% eutrophic, leading to ecosystem disruptions and putting livelihoods connected to the Baltic at risk (Barquet et al., 2020). The Baltic Sea, which stretches from the northernmost periphery of Europe to central Europe, provides ecosystem services, products and recreational services to nearly 149 million people in the Baltic Sea region (Storie et al., 2021). A major contributor to the eutrophication of the Baltic is Sweden, who emits 15400 tonnes of nitrogen and 240 tonnes of phosphorus to surrounding water bodies (Trela & Płaza, 2018).

In recent years, the EU has put forth strategies to increase domestic fertiliser production and reduce fertiliser use by 20%, by 2030, through strategies such as the Circular Economy Action Plan, the European Green Deal and the Farm to Fork Strategy (European Commission, 2020). Alternatives to synthetic fertilisers include animal manures and different forms of domestic sewage, such as fertilisers derived from human urine (Menegat et al., 2022). During a year, an individual produces approximately 500 litres of urine which, with a human population of 8 billion, equates to billions of litres combined (Wald, 2022). In tandem, urine alone accounts for 80-90% of nitrogen, 50-65% of phosphorus and 50-80% of potassium found in human excreta (Viskari et al., 2018; Wald, 2022). That is an enormous amount of nutrients that have the potential of being recycled whilst contributing to transforming human waste management into a more sustainable and circular system (Harder et al., 2019).

Sweden uses 870 000 tonnes of fertiliser a year and is import dependent on synthetic fertilisers (Niléhn, 2022). Simultaneously, Swedish municipal wastewater (treated or untreated) is also a big source of nutrient emissions to rivers, lakes and oceans, emphasising the need for recovery of nutrients from sanitation systems instead of releasing them into the environment (Hendriks & Langeveld, 2017). Therefore, Sweden's Agricultural Agency was tasked by the government to map and analyse both Sweden's existing fertiliser production capacity as well as the potential for domestic fertiliser production (Jordbruksverket, 2023c). The results were presented in March 2023 to the Swedish government and identified 18 Swedish initiatives that can support domestic and circular fertiliser production (Jordbruksverket, 2023c). Only four are currently available on the market and the rest aim to be commercialised in upcoming years (Jordbruksverket, 2023c). The initiatives use a wide range of materials such as ashes from waste incineration, waste material from the paper industry and food waste to produce circular fertilisers (Jordbruksverket, 2023c). The only company on the list that recycles urine is Sanitation360, a company based on Gotland. Sanitation360 collects urine from waterless urinals on Gotland and produces a dry-HUF, which is a dehydrated and treated form of HUF, which they are currently trialling (Sanitation360, n.d.). Urine can be used either directly as a liquid fertiliser or be processed into other forms such as Sanitation360's (Zuo et al., 2023).

As farmers are the ones who will need to adopt these new circular fertilisers, they play a vital role in the transition towards a circular nutrient economy (Ekane et al., 2021). Whilst previous studies in India (Simha et al., 2017), South Africa (Wilde et al., 2022), Uganda (Andersson, 2015) and Switzerland (Lienert et al., 2003) have shown that raw HUF has the potential of being adopted by farmers in these regions, they have also highlighted barriers towards its use which could hinder more widespread adoption. Barriers include social and cultural taboos towards handling human excreta, disbelief in its quality as a fertiliser, worries about hazardous substances like pharmaceuticals, preference towards using it to grow non-food crops and concerns regarding consumer acceptance (Andersson, 2015; Lienert et al., 2003; Simha et al., 2017; Wilde et al., 2022). Despite the fact that sufficient treatment methods to remove hazardous substances from urine are still in development, a review study by Martin et al. (2022) found that reducing the presence of heavy metals and pharmaceuticals is possible.

In a European context, few studies have been done regarding both farmer perceptions of HUF, especially dry-HUF, and willingness amongst food retailers and grocery stores to purchase it. Whilst consumer acceptance studies are slightly more common which is shown in a review study by Lienert & Larsen (2010) who found high overall acceptance rates in 7 European countries, the reviewed surveys have small sample sizes and a clear preference is shown towards the use of HUF for non-food crops. In tandem, the review found that only 50% of farmers in Switzerland and Germany thought HUF was a good idea (Lienert & Larsen, 2010). A recent study by McConville et al. (2023) on acceptance by Sweden's biggest grocery stores came to a similar conclusion.

In terms of attitudes towards the use of dry-HUF, there is a lack of research due to its novelty. However, due to Sweden's ongoing sludge debate since the 1980s, attitudes towards sludge are better known and provide some insight into the taboo aspect of reusing human excreta (Ekane et al., 2021; Wallenberg & Eksvärd, 2018). A study by Wallenberg & Eksvärd (2018) found that 85% of Swedish farmers who are offered to use sludge decline, mainly due to worries about hazardous substances. Sludge is rich in organic matter and phosphorus, contains high amounts of pathogens, heavy metals etc. when excreted and comes in the form of slurry (Marin & Rusănescu, 2023). HUF is mainly high in nitrogen and lacks organic matter, is less contaminated by pathogens etc. and comes in either the form of liquid or a dry-from, such as pellets (Senecal, 2020).

1.2 Problem formulation and research questions

The decision to focus on the potential use of a HU dry-fertiliser in Sweden was made due to four main factors. The first is the fact that Sweden has been considered a leader in the field since the 1990s and is the only European country extensively applying urine in agriculture, making Sweden an interesting case study area to learn from (SLU, 2013; Söderholm et al., 2023). Secondly, there has been strong resistance towards the use of sewage sludge in Sweden for decades and as urine is seen as a slightly cleaner source to derive nutrients from, it may have a greater potential to break through as a fertiliser (McConville et al., 2023). Thirdly, HU is a nutrient rich renewable resource that humanity will always have access to, which makes it important to research its potential in creating closed-loop flows that contribute to a sustainable society (Simha et al., 2018b). Lastly, Sanitation360's technology to develop a dry-fertiliser from HU is one of its kind and has the potential to replace currently used pelleted and granular alternatives such as synthetic fertilisers (Daramola & Hatzell, 2023). Combined, these factors pose a unique opportunity to gain deeper knowledge of the role potential adopters of circular nutrient innovations play in their diffusion. Additionally, Lundin et al. (2021) states that a dialogue with farmers about circular nutrient innovations is missing in Sweden.

When developing agricultural innovations, knowledge development amongst potential adopters is a critical factor for success (Aliahmad et al., 2022). With ambitious policies set by the EU and Swedish government to reduce eutrophication and transition to a more circular society, it is vital to take farmer knowledge and demand for innovations that can help achieve that, into consideration (Wilde et al., 2022). This positions the current thesis within the field of sustainability science, by highlighting the importance of including local knowledge in addressing the global need to replace synthetic fertilisers (Kates et al., 2001). As such, this study is built on a dialogue with Sanitation360 and explores Swedish farmer's attitudes towards urine as a fertiliser, with Sanitation360's product as an example. Sanitation360 is located on Gotland, a Swedish island, where pellets derived from urine collected from urinals, are currently being trialled for agricultural use (Sanitation360, n.d.). In tandem, their long term aim is to implement the use of urine diverting toilets on a larger scale on both Gotland and in Sweden (Sanitation360, n.d.). This study therefore aims to answer the following two research questions:

1. What prior knowledge do Gotlandic farmers hold in regards to urine as a fertiliser and have they heard of Sanitaion360's dry-fertiliser?
2. What do farmers see as the barriers and potentials with adopting human urine as a dry-fertiliser?

1.3 Scope

The results of this paper are not representative of Swedish or Gotlandic farmers' perspectives in general, as this paper only showcases the views of 9 out of Gotland's 1200 farmers and Sweden's 58783 (Jordbruksverket, 2020). The results section will therefore focus on descriptive details the farmers discussed about the barriers and potentials. Whilst Gotlandic farmers face unique challenges due to being located on an island dependent on imports from the Swedish mainland, it is still possible to gain valuable insights into the barriers and opportunities faced by Swedish and EU farmers due to similar agricultural regulations set by the EU.

2. Background

2.3 Understanding the ecology of sanitation

Despite the important contribution the flush toilet has had to society in terms of improved hygiene, it is also a prime example of today's throw-away culture (Narain, 2002). The flush toilet has been described as an "ecologically mindless" technology which simply allows us to press a button and forget about what will happen to our waste (Narain, 2002). However, wastewater management hasn't always been this wasteful. In 18th century Japan, human waste was called "shimogoe" meaning "fertiliser from the bottom of a person" and was a highly sought after, and commonly used, fertiliser (Tajima, 2017). Simultaneously, China and France have a long history of making use of both faeces and urine and only a century ago, Paris recycled and made use of half of its urine (Esculier & Barles, 2020; Ferguson, 2014). However, with the improvement of many country's wastewater treatment facilities in the mid 1900s, the recycling of human excreta subsided (Esculier & Barles, 2020).

2.1 Ecological Sanitation

The ecological sanitation approach makes use of source separation sanitation (SSS) with urine diverting toilets (UDTs), composting toilets, wastewater treatment etc., with the aim to create a closed loop system between sanitation and agriculture (Langergraber & Muellegger, 2005). They also require less or no water in comparison to flush toilets which use excessive amounts of drinking water at the same time as many parts of the world are facing water shortages (Boyer & Saetta, 2019). UDTs have been implemented in countries such as Ecuador, China, Zimbabwe, Finland, Sweden and Vietnam but are still not implemented on a larger scale (Karak & Bhattacharyya, 2011). In tandem, 1,9 billion people lack access to basic sanitation globally (WHO, 2021) and the enhanced implementation of EcoSan could contribute to reducing that number by providing people with more hygienic sanitation facilities that aren't dependent on centralised sanitation systems (Dickin et al., 2018; Langergraber & Muellegger, 2005).

2.4 Current circularity goals in Sweden

Despite the fact that Sweden has been a pioneer in developing resource-recovery sanitation solutions since the 1990s, implementation rates of these systems have been at a standstill for decades (Bengtsson & Tillman, 2004; Söderholm, 2023). This, due to increased sanitary regulations such as treatment requirements for wastewater, that the Swedish sanitation system is highly centralised, a lack of acceptance and knowledge of alternative solutions and technical lock-in (Söderholm et al., 2023).

However, Sweden's use of sludge has increased in recent years and in 2020, 34% of treated sewage sludge was recirculated back to agricultural land, largely thanks to the work of Revaq (SOU, 2020). Revaq is the Swedish Water and Sewerage department's own quality insurance system for wastewater treatment. Revaq-certified WWTPs treat approximately half of Sweden's communal wastewater and are built to remove nutrients like nitrogen and phosphorus from the aqueous phase in order to bind them to sludge (eurofins, n.d.). Revaq has set certain limits to the amount of pathogens, such as salmonella, and heavy metals, such as cadmium, that sludge can contain to be allowed as a fertiliser (eurofins, n.d.). However, revaq-certified sludge is only permitted for use in conventional farming (SOU, 2020).

2.3 Gotland and Sanitation360

Gotland is a small island in the Baltic Sea, off the coast of Sweden. The food and agricultural sector is the main employer and the main farming orientations include wheat, carrots, potatoes, rapeseed, beef, lamb and port (Region Gotland, 2023). Gotland is aiming to drastically increase self-sufficiency in terms of food production in upcoming years, as 85% is currently exported (Region Gotland, 2023).

In order to help reduce eutrophication, Sanitation360 is part of a bigger EU project called "P2GreeN", where four different technologies that convert human waste into fertiliser are being trialled in Sweden, Germany and Spain (P2GreeN, 2023). Sanitation360's current technology is able to produce a dry-fertiliser with 8-15% N, 0,7% P, and 2,5% K and recovers >90% of the nutrients from raw urine in their process (Senecal, 2020). The urine is collected from urinals on Gotland, which have been equipped with a stabilising substance to prevent the hydrolysis of urea to ammonia, which otherwise occurs naturally in conventional toilets (Wald, 2022). Reducing this chemical reaction makes the urine both safer to handle and more efficient to store (minimal nitrogen loss to the atmosphere) (Wald, 2022). The urine is then concentrated through a heating process and an additional organic substance is added to form the right dry consistency (Senecal, 2020). In tandem, a pHd candidate is in the process of publishing a paper that analysed the presence of hazardous substances in Sanitation360's fertiliser and found that it is safe to use. So far, the fertiliser is solely being used for field trials and the dry-HUF is not yet available on the market.

After being turned into pellets, it is used to run field trials where barley is grown and later harvested. For two years, a brewery on Gotland has been running brewing trials with the barley to evaluate the quality of the barley for producing beer. By 2026, the goal is to have brewed 150 000 litres of beer from barley fertilised with their dry-HUF. This collaboration is part of a project called N2Brew that is striving to close the nutrient loop in the service chain of beer (Stiftelsen Lantbruksforskning, 2020). In tandem with reducing the need for synthetic fertilisers, Sanitation360's long term goal is to restructure Sweden's WWTPs to recover the nutrients from urine (Sanitation360, n.d.).

3. Theoretical framework

In the past decade, there has been a big rise in research on the adoption of agricultural technology which delves into the application of innovations in the agricultural field (Lowry et al., 2019; Payne-Gifford et al., 2020; Schimmelpfennig & Lowenberg-DeBoer, 2020; Tembo, 2021). A wide range of frameworks have been employed in order to analyse such agritechnology adoptions, such as the theory of Planned Behaviour, the Unified Theory of Use and Acceptance of Technology, and lastly, Diffusion of Innovation theory, which this study utilises (Adnan et al., 2019; Payne-Gifford et al., 2020; Sebuliba et al., 2022).

3.1 Diffusion of innovation theory (DOI)

DOI is a theory developed by Rogers (2003) and aims at examining how innovations spread as well as the process of social change that is involved. The theory builds on the concept of diffusion, which Rogers (2003, p.86) defines as "the process by which an innovation is communicated through certain channels over time among the members of a social system". The diffusion itself is a unique form of communication where new ideas are communicated through information sharing amongst participants, in the hopes of reaching a mutual level of understanding of the innovation in question.

A vital aspect of the communication involved in diffusion is that it should be a two-way process where both participants in the conversation are encouraged to exchange information. The alternative one-way communication, such as when a change agent attempts to persuade potential clients to adopt their innovation, fails to account for the client's needs or concerns. This is an additional reason behind the choice to centre the opinions of farmers in this study, as they have been left out of much of the conversations regarding human waste recycling in Sweden. (Rogers, 2003)

Roger's (2003) notes that despite the main goal of all innovators to have their innovation widely adopted, the same innovation may not be desirable for certain individuals or societal systems whilst it contributes to major advances for others. It may for example be too expensive, require additional changes which the individual is not willing to make, or simply not appeal. No matter how good of a fit someone seems to be as a potential adopter on paper, it is important to steer away from the assumption that the innovation in question will be desired while conducting diffusion research. (Rogers, 2003)

There are four main elements important to a diffusion process; the innovation in question, communication channels, time and the social system. Part of the third step, time, is the innovation-decision process (figure 1), where an individual goes from learning about an innovation for the first time, to deciding whether to adopt or reject it (Rogers, 2003). This process consists of five steps that most often play out in chronological order, knowledge, persuasion, decision, implementation and confirmation. The knowledge stage refers to when an individual "is exposed to an innovation's existence and gains an understanding of how it functions" (Rogers, 2003, p. 309).

Exposure to an innovation often occurs in two main ways; actively by seeking out an innovation due to interest or need, or passively by seeing, hearing or reading about it by accident. The first stage of finding out that an innovation exists is termed "awareness-knowledge" and is crucial in determining whether or not an individual feels determined to learn more about it. The other two forms of knowledge are "how-to-knowledge", an understanding of how to use it, and "principles-knowledge", an understanding of the underlying mechanisms to why an innovation operates as it does. (Rogers, 2003)

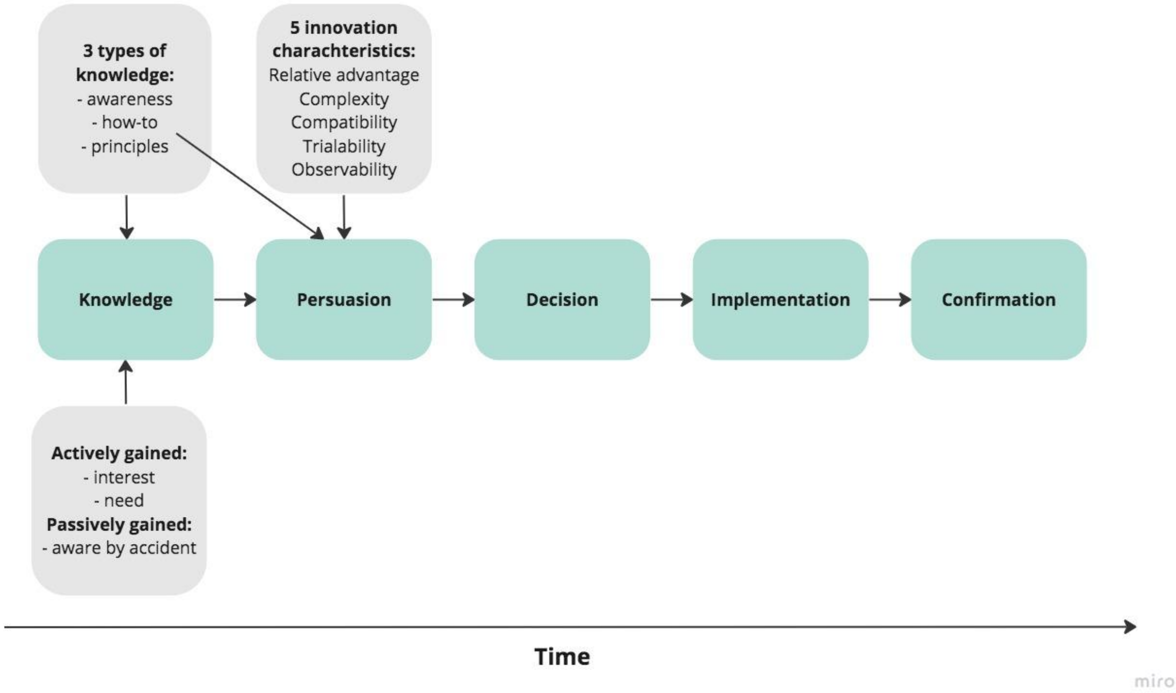

Figure 1. Own illustration focusing on the knowledge and persuasion stage of the innovation-decision making process as described by Roger's (2003). Knowledge is either gained actively or passively and there are three types of knowledge an individual can gain. "How-to" and "principles-knowledge" can also influence the persuasion stage where five main characteristics of an innovation influence whether an innovation is adopted or rejected. Made with miro.

These two latter forms of knowledge can also play important roles in the next stage of persuasion. Here, there are five major characteristics of innovations that influence their adoption rate.

1. Relative advantage – the greater the benefits of the innovation are perceived to be in comparison to what it is replacing, the more rapidly it will be adopted.
2. Compatibility – the more aligned the innovation is with the already existing values, needs and experiences of potential adopters, the more rapidly it will be adopted.
3. Complexity – innovations that are simpler to understand and implement will more likely be adopted faster than innovations perceived as difficult to grasp or implement.
4. Trialability – whether or not the innovation can be used on an experimental and/or partial basis will also determine the rate of adoption. It is also favourable if it can be tried as part of an instalment plan in order to reduce the financial burden of investing in something new.
5. Observability – the more visible the results of the innovation are to others, i.e. to other potential adopters who might notice an adopter using the innovation in

question, the more likely they are to start using it themselves. This factor also contributes to the networking aspect of diffusion where peer discussion amongst neighbours, coworkers, friends and other societal groups can be facilitated. (Rogers, 2003)

These characteristics can also influence each other, such as in cases where the complexity and novelty of an innovation has an impact on the perceived advantage of adopting it (Kaine & Wright, 2022). This is yet another reason behind my choice of centering farmers' opinions on HUFs, as they are the end users and are the ones who will determine the practicality of the dry-HUF. The next stage consists of the decision to adopt or reject the innovation (Rogers, 2003). If adopted, the innovation is implemented and depending on the satisfaction of the adopter, there is another round of deciding whether or not they will continue using it, termed confirmation (Rogers, 2003).

3.2 Operationalisation and application

As this is a study exploring an innovation that will only be available for adoption in upcoming years, there is no way to statistically quantify the rate of adoption dry-HUF will have, which is otherwise commonly done in DOI research (Rogers, 2003). Therefore, this study utilises an approach to DOI that is developed for marketing, where it’s used to help understand which qualities in a product/innovation will garner the attention of potential adopters (Dearing, 2009; Rogers, 2003). Instead of determining the successes and failures of how an innovation has been diffused, the goal of this study is to contribute to the literature on how the theory of diffusion can be used in a qualitative way to inform innovation development.

Different stages of Roger’s (2003) innovation-decision process are used to answer this study’s respective research questions. For RQ1, only the knowledge, persuasion and decision stages of Roger’s (2003) innovation decision process (figure 1) can be assessed in terms of Sanitation360’s dry-HUF. This, as it is not yet available on the fertiliser market which makes it impossible for the farmers to have reached the implementation stage. Even the “decision” stage can only be applied if a farmer has already heard of Sanitation360’s dry-HUF and made the decision to try it once it reaches the market, or not. On the other hand, all 5 steps can be explored in relation to the farmers' adoption or rejection of less novel forms of HUF, such as raw urine or wastewater, as these have been around for longer. To answer the second RQ, the five characteristics important for the persuasion stage, are used to identify the barriers and potentials farmers see with HUFs (relative advantage, compatibility, complexity, trialability and observability). The purpose of using DOI in this study is therefore to discover the strengths and weaknesses with HUFs, in order to better communicate the innovation and facilitate the transition to a circular nutrient economy.

4. Research Design & Methodology

4.1 Exploratory case study & qualitative research

A literature review by Oca Munguia & Llewellyn (2020) on agritech adoption concluded that much of such research views adoption as a binary decision and neglects interacting with farmer attitudes and perceptions towards innovations. Due to this and the open-ended nature of the research questions I sought to investigate, a qualitative research approach was chosen which focuses on obtaining data through communicative methods (Jackson et al., 2007). The data was gathered on Gotland through nine semi-structured interviews with Gotlandic farmers with the help of two key informant interviews with local actors and a dialogue with Sanitation360.

This study aims to help lay the foundation for the potential for future adoption of HUF within Sweden's agricultural setting where little research has been done on farmer attitude towards HUF. For this purpose, this study utilises an exploratory case study approach as the case is not built on any "preliminary propositions and hypotheses" (Streb, 2010, p.3). Exploratory case studies aim to shed light on what's unknown regarding a program, phenomenon or innovation and are used when there is no single or pre-determined or set of outcomes (Streb, 2010, p.372-373).

4.2 Informal discussions & key informant interviews

A literature review of 100 agritech adoption studies concluded that innovations are often poorly understood by researchers and that studies are biassed towards the advantage of the innovation (Fichter & Clausen, 2016). Therefore, since this study is interested in solely exploring farmer perceptions of HUF, the decision was made to prioritise learning about HUF and its context. This was done through informal discussions with the innovation developer, Sanitaion360, and two key informant interviews with a local brewery on Gotland and a local agricultural consultancy agency (Hushållningssällskapet Gotland), who are playing important roles in the transition towards greater circular nutrient management on Gotland (see section 2.3).

From start to finish of this thesis (Oct. 2022- May 2023), a continuous dialogue with the CEO of Sanitation360, Jenna Senecal, has provided invaluable insights into the human waste recycling industry. In addition, being shown the urine drying process on Gotland gave me a deep understanding of their urine converting technology.

4.3 Face to face semi-structured interviews

Face to face semi-structured interviews were conducted with nine Gotlandic farmers at their homes during 13th-17th of March 2023 (see table 1). An essential tool in qualitative research are semi-structured interviews (SSI) which consist of a loose set of interview questions, allowing room for follow up questions (Kakilla, 2021). This helps create a comfortable space for less formal and more in-depth conversations where hidden information that the interviewer might not have expected to be talking about is uncovered (Kakilla, 2021). On the other hand, SSIs can be fatiguing if longer than an hour and it is therefore important to keep them short (Adams, 2015).

The SSIs took place in the farmers' homes and ranged from 30 to 120 minutes, averaging 83 minutes. The key informant interviews took place at the brewery's and HHS's workplaces, and fika was brought to all interviews, which felt like it helped reduce the sense of formality during the interviews. In regards to the farmer interviews, being welcomed to their farms enabled them to show me around whilst telling me about their machinery, crops, soil types etc. which helped give me a better understanding of the scale and operations of the farm.

As SSIs also seek to discover the interviewees' lived experiences prior to being presented with scientific explanations (Kvale & Brinkmann, 2009), the interview guide (see appendix table 3) was structured to start with open-ended background questions about their livelihoods as farmers and their knowledge on urine to date. Prior to the interviews, I developed an illustration (see figure 2) of the circular nutrient process of HUF, inspired by an illustration by Randall & Naidoo (2018), in order to demonstrate Sanitation360's current process and the final details were confirmed by Jenna Senecal. It was shown and explained to the farmers after questions of prior knowledge of HUF had been asked. This was crucial in order to be able to apply the DOI theory as this is where farmers were exposed to the innovation, if they didn't already know of it, which is the first chronological step in the diffusion of an innovation (Rogers, 2003). This enabled the characteristics important for persuasion in DOI theory to be discussed throughout the rest of the interview. Simultaneously, the interview guide was shaped to ensure that the interviews covered the interviewees perceptions of urine as a fertiliser in general and not just within the context of Sanitation360, even though the focus was on a dry-fertiliser version.

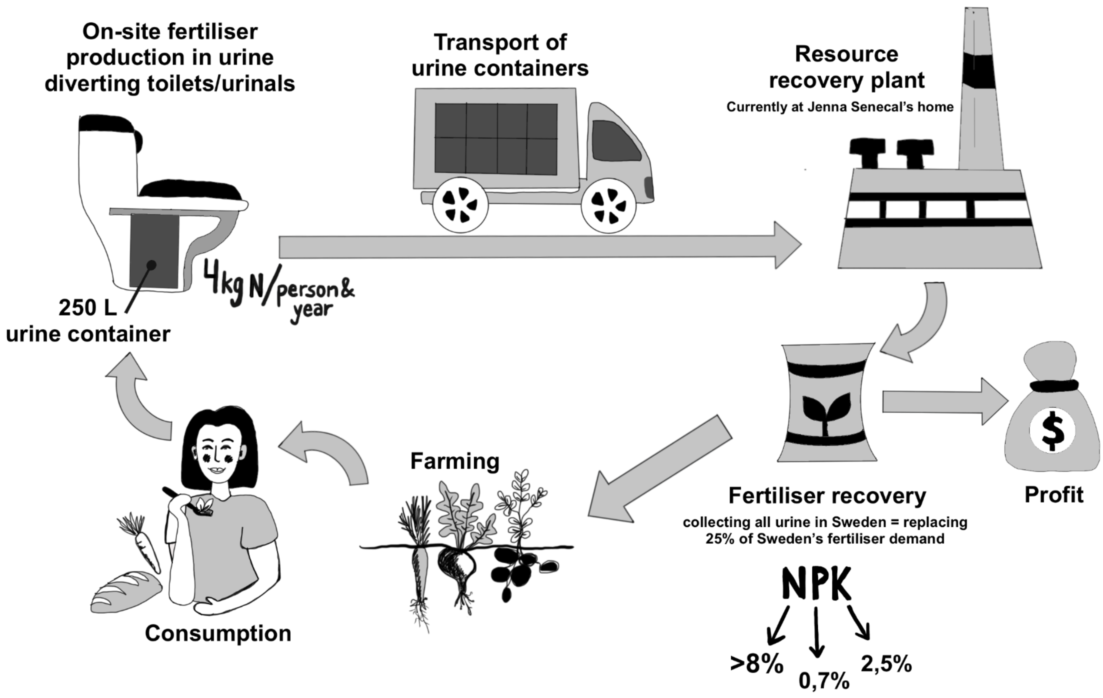

Figure 2. Own illustration inspired by Randall & Naidoo (2018) of the nutrient recycling process between sanitation and agriculture in the case of Sanitation360 on Gotland. For now, urine is collected in urinals during the summer, transported to Senecal's home where it is processed into a fertiliser and can then be used to grow crops for human consumption. If all urine in Sweden is collected, a fourth of current fertiliser demand can be met. During the interviews I made sure to mention that the "resource recovery plant" was for larger scale implementation. Made using Procreate. See figure 1 in the appendix for the printed illustration that I brought with me to the interviews.

4.3.1 Interviewees

The farmer interviews were set up via phone calls or text before my departure to Gotland (see appendix table 1). As Sanitation360's currently part of the N2 Brew project and their goal is to replace synthetic fertilisers, the decision was made to focus on conventional grain farmers as potential adopters. However, despite finding >10 grain farmers via google searches, many were too busy to partake due to timing which coincided with the start of the farming season for some. As the transition to a circular nutrient economy targets all farmers, which Sanitation360 also aims to eventually, the decision was made to expand the production orientation to include vegetable farmers. The finalised list can be seen in table 1 and consists of a mix of conventional, EU-organic and KRAV-certified farmers. KRAV is a Swedish certification that adds additional regulations that need to be followed on top of EU organic ones.

Table 1. Information about the nine Gotlandic farmers (one couple) interviewed for this study.

Farmer	Age	Education	Work load	Farm size (ha)	Farmer since (year)	Production orientation	Certifications	Current fertiliser use
1	43	Agricultural college	100%	250	1998	Dairy, grain & forage grasses (200 cows)	Conventional & Arla (Swedish dairy cooperative)	Own animal manure (cows), synthetic fertiliser
2	40	Course in smallholder organic vegetable farming	Part time	2	2015	Vegetables	Conventional	Bokashi, green manure, old mouldy hay barrels, wool, chicken manure
3	65	Biology and chemistry teacher	100% in tandem with own farm shop & restaurant	19 + 50 forest	1998	Vegetables, berries, fruit, chickens & escargot	Organic & KRAV since 2001	Animal manure (cows at other farm), abattoir waste (biofer)
4	47	Computer technician & economy	Part time	70	2004	Grain	Conventional	Synthetic fertiliser (mainly 21-3-10)
5	29	Construction engineer	Part time	145 + 100 forest	2020	Grain and potatoes	Organic since 2020	Abattoir waste (biofer), pure potassium
6	37 & 35	Garden engineer vs course in smallholder organic vegetable farming	Part time	20	2016	Vegetables	Organic & KRAV	Abattoir waste (biofer), vegetable residue, nettle water
7	68	Agricultural college	100%	44 + 15 forest	1978	Lamb, heritage grain, lentils	Organic since 1986	Biodynamic farming: uses crop rotation with nitrogen fixing crops and straw bedding from sheep
8	56	Agricultural college	100%	58	1989	Vegetables since 2015, dairy prior	Organic & KRAV	Cow manure, Semenko (organic fertiliser based on vegetables and other food produce)
9	59	Agricultural college	100%	400 + 250 forest	1988	Carrots & potatoes	Organic & KRAV	Animal manure (cow), abattoir waste (biofer) for potatoes

4.4 Ethical reflections

As a researcher, it is important to consider one's positionality which “reflects the position that the researcher has chosen to adopt within a given research study” (Darwin Holmes, 2020). My willingness to find solutions to environmental issues as an environmental researcher might garner a need amongst interviewees to withhold views that contradict mine. Therefore, I conducted the interviews with a goal to listen without judgement. However, due to human nature, it is extremely difficult to ever describe something fully objectively which is important to acknowledge (Darwin Holmes, 2020), which makes it likely that I have a biassed interpretation of the findings, despite an attempt to stay objective.

In tandem, the fact that I used a local product as an example might have impacted how comfortable the interviewees felt with saying negative things about it. Especially as Gotland is a small island with tight knit communities. To ensure that my positionality as a researcher was as neutral as possible, it was important to conduct background research on recent policies and geo-political conflicts impacting Swedish farmers, such as the 2023 update of the CAP which included multiple changes in the EU subsidies farmers can apply for (Jordbruksverket, 2023b). Having worked as a farmer during the summer of 2022 was also a beneficial experience as it gave me hands-on experience with many farming practices and regulations. I referenced aspects of my own farming experience when relevant in all the interviews which, I feel, created a sense of mutual understanding between us. At the same time, I was careful about comparing my experiences as a farmer to theirs, as the farmers have years of more experience than me. It also helped that Swedish is my mother tongue which enabled us all to speak our native language. It also entails that I have a good understanding of the interviewee's cultural setting, which has been shown to be an important part of building a good relationship with the interviewee (Kakilla, 2021).

Additionally, all farmers were given a consent form to sign (see appendix table 4) which granted them anonymity and gave me permission to record the interviews. Throughout the results and discussion, the farmers are referenced as "one farmer" and brackets after quotes indicate which farmer in table 1 the quote is from, e.g. "(F5)". In total, 8 male and 2 female farmers were interviewed (one interview consisting of a couple being referred to as one farmer in this study due to having similar responses). In order to ensure anonymity, gender is not mentioned and the farmers will be referred to as "they". Brackets within quotes have been added to explain the topic being referred to.

4.5 Data processing: transcription, coding and analysis

All eleven interviews were transcribed using Word's transcription service. However, the Gotlandic accents were difficult for Word to pick up and I therefore went through them rigorously and transcribed big sections by hand. The transcripts were kept in Swedish and only the quotes mentioned throughout the results and discussion have been translated into English by myself. To analyse recurring patterns, such as barriers and potentials, a thematic analysis was conducted. This process followed many of Kiger & Varpio's (2020) recommended steps when conducting a thematic analysis and was done manually using excel. The final grouping resulted in the creation of 5 themes, each consisting of 3-5 codes (see appendix table 2).

5. Results & discussion

The main objective of this study was to explore farmer knowledge of HUF and the barriers and potentials they see with it as an alternative fertiliser. The following sections include findings covering the interviewed farmer's previous knowledge of HUF as well as factors influencing their perceptions of the relative advantage, compatibility, complexity, trialability and observability of HUF. Important to note is that some factors are specific to Sanitation360's dry-HUF whereas others can be applied to any form of HUF.

5.1 RQ1: Previous knowledge of HUF

All farmers, except one who was aware of revaq's sludge regulations (F4), were surprised when told that Sweden allows the use of urine and sludge in conventional agriculture, suggesting low "awareness-knowledge". The farmer who knew about revaq was also the only farmer who knew about Sanitation360 as they were running an agritech startup and had met Sanitation360's CEO at a startup event. However, they were still debating whether or not to try it depending on its cost and NPK ratio. The remaining eight farmers were positively surprised that there is a dry-HUF being developed on Gotland. In tandem, they were already equipped with large amounts of "how-to" and "principles-knowledge", such as their preferred nutrient content and nutrient release rates of fertilisers thanks to current fertilisers use.

Likewise, all farmers had heard about the use of urine but only in regards to small-scale implementation of treated wastewater or raw urine. Multiple farmers mentioned the sludge debate in Swedish agriculture when asked about previous knowledge of HUF, which has been ongoing since the 1960s and and still hasn't come to an understanding (Bengtsson & Tillman, 2004). In a workshop with Swedish farmers and actors within Swedish water and sanitation, Lundin et al. (2021) noticed a similar trend when discussing wastewater recirculation. Despite the workshop's broad focus on the recirculation of nutrients from all wastewater streams, there was a big focus on discussing the qualities of sludge, suggesting higher awareness of sludge as a fertiliser. This is likely due to Sweden's negative media portrayal of sludge, giving it an unfavourable reputation (Ekane et al., 2021). However, this is also not surprising due to the novelty of HUFs and its recent increase in research attention in comparison to other wastewater research (Aliahmad et al., 2022).

Contrariwise, prior knowledge of sludge could also be favourable for putting HUF on the map as they share many similar characteristics in regards to tabus, regulations etcetera. A previous study on the reuse of untreated wastewater for agricultural irrigation found that detailed farmer knowledge of the properties of such water, was a crucial prerequisite for potential adoption (Mojid et al., 2010). Whilst the role of knowledge in adoption processes is difficult to research due to the methodological challenges with measuring knowledge and attitude, multiple studies have mentioned prior knowledge as a key factor determining adoption (Meijer et al., 2015; Mekoya et al., 2008). In regards to use of HUF, some farmers had used their own urine for gardening but would not use it on their farm crops due to worries about the presence of pathogens, pharmaceuticals and hormones. Many mentioned that the EU or farming cooperatives they're part of, such as Arla and KRAV, forbids reuse of human waste due to the presence of such substances.

However, there were two farmers who stood out in terms of experience with some form of urine fertiliser (F5, F9). Since 1984, one farmer has used fertigation (irrigation with fertiliser) on their family farm from the local municipality's wastewater that has been UV treated in local biological dams (F5). In the case of their parents, who were the ones to adopt the use of wastewater, the awareness process was passive as they were approached by the municipality. When asked if there had been any issues with using it, they replied: *"No, and we've taken continuous soil tests ever since to analyse heavy metal and pharmaceutical concentrations that one can be worried about. But I haven't seen anything."* (F5). Thanks to this, the farmer felt also confident about the use of HUF in general. Another farmer had spread the sewage sludge and wastewater from their own three chamber well on their fields for multiple years before becoming organically and KRAV certified (F9). These were the only two farmers not concerned about the potential presence of hazardous substances. This suggests that the diffusion of HUF will likely be a long process that will require long term practical experience and continuous soil testing to make it evident to farmers that HUF is safe to adopt. To facilitate adoption, it is therefore vital for agricultural advisors to be well informed on the fastly developing new scientific findings regarding the potentials of using HUFs (Aliahmad et al., 2022).

5.2 RQ2

This section presents and discusses the main findings of factors that could impact the adoption of HUF according to Gotlandic farmers. The factors are categorised into the five main characteristics that the DOI theory sees as important when determining the likelihood of adoption. Lastly, each subsection starts with a short summary of the main findings related to the characteristic being discussed.

5.2.1. Relative advantage

The relative advantage concerns if there are aspects of HUFs that are seen as advantageous in comparison to the farmer's current fertilisers. The fact that HUF is a product that recirculates nutrients between cities and agriculture was seen as a major benefit as well as that it would provide Gotland with another domestic fertiliser. For the farmers currently using abattoir waste, the fact that HUF does not cause any animal welfare concerns was also advantageous. Despite this, many farmers are already using fertilisers from waste materials, which makes it important to promote HUF in more detailed terms than "circular".

Circularity & animal ethics

The circular properties of HUF were perceived as an advantage amongst Gotlandic farmers. Multiple farmers mentioned the lack of resource flows between cities and agriculture and showed great enthusiasm towards Sanitation360's work. When asked if they knew about HUF, one farmer said:

> *"Yes, I mean it is so wrong that we have cities and then we've removed ourselves from the cycle. It really can't get worse and then we send it out to the ocean where it does the uttermost harm. So no, it's absolutely terrible that we don't have any recirculation."* (F8).

Additionally, two farmers mentioned the current devastating state of the Baltic Sea and the impact that nutrients from sanitation and agriculture have on it, making circularity even more important for them (F3, F4). One farmer had even installed a circular irrigation system, which collects nutrient runoff into a dam and recirculates it back to the fields, to reduce runoff/leaching (F3). However, some stressed the fact that they were currently using circular fertilisers such as abattoir waste, bokashi and animal manure. Whilst this brought the benefits of the circularity aspect of HUF down slightly, there was a shared consensus about the importance of creating a circular system between cities and agriculture, which their current circular fertilisers do not contribute to. However, the farmers' responses suggest that the kind of circularity HUF contributes to needs to be emphasised in order for it to be more lucrative than current circular fertilisers. Other ways to talk about the circularity of HUF include “closing the metabolic rift”, “closing urban-rural nutrient cycles” and “closing the sanitation loop”.

The latter could be especially beneficial as farmers often feel unfairly blamed by the public and government for contributing to environmental issues, such as eutrophication (Busse et al., 2021; Hansson et al., 2012; Puupponen et al., 2022). One conventional farmer especially described a feeling of their livelihood being seen as unsustainable:

> *“Cities are portrayed as green if there are some plants on the walls and a few flower beds. And then you think the city’s green. But agriculture or rural areas are dirty. It has become some kind of stereotypical image and I find that really sad.”* (F4)

To alleviate this, referring to the circularity of HUF as a sanitation issue shifts the focus and responsibility towards the sanitation sector. This is also emphasised by a previous study which concluded that defining agritech innovations with narrower terms instead of with generic terms like “sustainable” or “circular”, could help assert the advantage of it (Oca Munguia & Llewellyn, 2020).

Whilst the majority of farmers seemed well aware of the impact fertilisers have on the environment, the awareness amongst a few farmers wasn’t necessarily reflected in their practices. Soil mapping, i.e. analysing the nutrient content and soil composition in fields, was seen as more of a necessity to receive EU funding and follow regulations than to inform fertiliser use. This year (2023), many farmers had requested soil tests for the first time in over a decade (which recommend being done every 3 years to prohibit use of excessive fertiliser) to fulfil the subsidy requirements for precision agriculture presented in the new CAP enacted on Jan 1st 2023 (Jordbruksverket, 2023a). In tandem, many expressed not having fully understood their previous mapping results and that it hadn’t made them change their fertiliser choice or application. One KRAV-farmer said:

> *“I choose the one that’s cheap called Spurway which isn’t that precise but it tells me quite a bit and I can do it more often. The other ones are extremely expensive, which I maybe do more like every 10-15 years to really see what the soil balance is like.”* (F3)

This suggests that the diffusion of UDTs or urinals, where the urine is recycled, will contribute to reducing eutrophication as it removes one source of effluent. On the other hand, the use of the resulting innovation, i.e. HUF, will not reduce eutrophication from agricultural land as it is simply another fertiliser that can be used, which if applied without improved nutrient management practices, will still leach or enter waterways through runoff. A promising solution to albeit low rates of soil sampling due to its high costs is the EU's Free Soil Testing scheme which is currently in development (European Commission, 2021). If this could be utilised in tandem with the trialling of HUF, it would likely make farmers feel more confident that it is safe to use them. However, soil sampling also needs to be combined with nutrient management education in order for practices that reduce nutrient runoff and leaching to be properly implemented.

Locality

There was a shared sense of relief amongst all farmers that Sanitation360 was aiming to fully produce its HUF on Gotland, which would reduce their dependence on imported fertilisers. In tandem, locally produced food and ideally self-sufficiency as an island was very important to all farmers and besides urine, other domestically produced fertilisers mentioned include wool, forest debris and recycled batteries. When talking about farm input costs, another said:

> *"When you live on Gotland you're punished twice because you pay for shipping when you order things and there is so much we need to buy but no company on Gotland who produces the things we need."* (F6)

Global geo-political events have caused major fluctuations in fertiliser prices during the past few years (Alexander et al., 2022). Some of the events mentioned by the Gotlandic farmers include COVID-19, the Russia-Ukraine conflict and the Suez canal blockage. Farmers in Iceland, another island, have also expressed a strong willingness to become less dependent on imported fertilisers due to shipping costs (Thorkelsdóttir, 2020).

At the same time, aims to reduce dependency on fertiliser imports are not confined to islands as seen by the EUs aim to increase domestic production in all member states. As part of the EUs work, an Integrated Nutrient Management Action Plan (INMAP) plans to be adopted during the second quarter of 2023 in order to reduce nutrient losses from agriculture by 50% by 2030 (European Commission, 2022). These EU efforts and the willingness amongst Gotlandic farmers to increase domestic production suggests this is a promising time for HUF to gain momentum. It would therefore not be surprising if upcoming future studies on farmer's attitudes towards fertilisers derived from human excreta would find the domestically produced aspect as a commonly mentioned advantage.

However, the local aspect was not seen as favourable amongst the Gotlandic farmers with their own livestock manure (see table 1). This was not surprising as livestock farmers are generally less interested in new fertiliser products as they already have a nutrient surplus from animal manure (Lienert et al. 2003). However, efficient reuse of manure is also an important contributor to the circular nutrient economy (Barquet et al., 2020).

5.2.2 Compatibility

The compatibility concerns how well HUF aligns with the farmers' existing values, needs for the innovation and experiences. Gotlandic farmers' expressed choosing their current fertiliser based mainly on cost, NPK needs, regulations, sustainability and using what's already on their farms. Their prior experiences with consumer scepticism regarding hazardous substances in sludge and disgust towards abattoir waste, were expressed as barriers for HUF adoption. The need for specific NPK ratios could also hinder adoption. However, their need for a dry-fertiliser made Sanitation360's HUF favourable and compatible with their current equipment.

Consumer attitudes

Concerns regarding consumer acceptance of food fertilised with HUF was divided. The farmers who did not worry about consumer acceptance thought consumers don't consider what fertiliser has been used, instead focusing on whether food is locally produced, organic or expensive. The sceptical farmers thought consumers would find it disgusting or unsafe due to potential pathogens and pharmaceutical residue. One farmer would not want to tell their customers if they started using HUF due to previous encounters with customers who were disgusted about their use of abattoir waste (F6). The same farmer felt more okay with HUF if it was used to fertilise non-food crops, such as crops grown for biogas, flowers or livestock feed: *"My thought is that it would first and foremost be good for grain farming because then there is one more step, I mean if it's used for grain farming for animal feed, it results in one more step between us and the fertiliser."* (F6). Another farmer also expressed that it felt "nicer" that the raw urine had been processed into pellets as it sounded less disgusting (F2).

In line with these comments, Segrè Cohen et al.'s (2020) found that U.S. consumers deem HUFs most acceptable if used to fertilise non-food crops as did McConville et al. (2023) who surveyed Sweden's biggest food retailers. Similarly, (Wilde et al., 2019) discovered that the use of nitrified HUFs (a hygienically safe form such as Sanitation360's, which have been treated as opposed to raw urine) have the potential to increase consumer acceptance and therefore reduce concerns about consumer acceptance amongst farmers (Wilde et al., 2019). However, Swedish consumer acceptance of HUF is less well known and if it turns out that many are critical, it could therefore be an idea to at least start using HUF to fertilise non-food crops to contribute to the circular nutrient economy to som degree.

It is difficult to either validate or discredit the scepticism expressed by some of the Gotlandic farmers as previous research on consumer attitudes have low response rates and have come to differing conclusions. A survey conducted by Simha et al. (2018a) at an Indian university, found that 56% of respondents would not be willing to consume food fertilised with urine. Contrariwise, a study by Lienert & Larsen (2010) found positive attitudes towards HUF amongst 85% of respondents in seven Northern and Central European countries, including Sweden. This is likely due to the differing cultural context, as India has high rates of Hinduism, a religion in which bodily fluids are seen as pollution (Dellström Rosenquist, 2005). In terms of cultural beliefs, this suggests that Sweden's predominantly Christian and secular culture does not pose a big barrier towards the potential acceptance of human waste in agriculture (Kasselstrand, 2015). However, the fact that Sweden's current sanitation system has sensitised the public towards the smell and dirtiness of human excreta (Dellström Rosenquist, 2005), could potentially be a barrier.

Hazardous substances & legislation

All farmers expressed worries about the presence of hazardous substances in HUF and sludge, suggesting little information reaches farmers in regards to the current state of scientific knowledge of successful treatments to remove such substances (Häfner et al., 2023; Li et al., 2023; Sharma et al., 2021). Substances mentioned include pathogens, heavy metals, drugs, hormones and microplastics, which they were worried could compromise both human and soil health. One farmer expressed a need for *"conclusive evidence of purity from pharmaceuticals etcetera"* (F3). However, farmers mentioned no health risks with their current fertiliser products, despite research showing that the most common synthetic fertiliser used by EU farmers has up to ten times the cadmium levels that are allowed in sewage sludge for agricultural use in Sweden (Region Gotland, 2019). The maximum cadmium levels allowed in manure are also similar to maximum levels allowed in sludge (Region Gotland, 2019). Therefore, it is not reasonable to hold human excreta derived products to higher standards than the rest of fertilisers on the market (Lundin et al., 2021). Whilst more research is needed to determine the possibility of removing cadmium and pharmaceuticals from urine, recent research has shown that pharmaceutical levels in some HUFs are low and should not pose a barrier to its reuse (Häfner et al., 2023).

The interviews indicate that there is a disconnect between scientific research on the current state of human waste derived fertilisers and farmer knowledge. The majority of farmers mentioned they never, or seldomly, read scientific papers due to their length and detail whereas agricultural newspapers and social media accounts and groups were their preferred sources of innovation information. This implies the importance of translating scientific articles into popular science, and even social media posts, to make scientific findings that can aid sustainable agricultural practices more accessible. Lastly, it is important to keep in mind that today's food trade is global. To guarantee farmers that they can continue their business partnerships with international retailers if they adopt HUF, global consensus on regulations on the use of HUF in agriculture are needed.

In terms of potentially certifying HUF, the majority of farmers wanted it to be incorporated into KRAV so it can be used by anyone. No one saw it as beneficial to introduce yet another certification such as one for a "circular fertiliser". However, applying for such certifications is time consuming and expensive, which small initiatives can struggle to afford to do (Jordbruksverket, 2023c).

Pelleted form

The fact that Sanitation360's fertiliser is dry and comes in the form of pellets was seen as favourable by the majority of farmers, as they already had experience spreading that form of fertiliser or using machines/spreading methods that are capable of spreading it. The farmers who owned tractors and accompanying fertiliser spreading equipment expressed that other forms of urine, such as liquid or slurry, would not be compatible with their machines. One farmer gave an example of when they had decided to try biochar, a carbon rich material used to enrich soils, but ended up not being able to use it due to its moist consistency which got stuck in their spreader (F3). Dehydrating the urine to create the pellets also means that the nutrient concentration increases per unit of weight. This was seen as advantageous storage wise as it occupies less space and due to the fact that it requires less rounds of spreading to apply the same amount of nutrients. The preference of a dry-HUF aligns well with a previous study by Lienert et al. (2003) who surveyed farmers preferences regarding HUFs in Switzerland.

Despite a clear preference towards a dry form, Lienert et al. (2003) also found that the category of farmers who were most interested in a liquid form of urine fertiliser, were those with vegetable production. Similarly, all Gotlandic vegetable farmers expressed that they would appreciate it if Sanitation360 produced a liquid fertiliser that could be used in their drop based irrigation systems. The organic vegetable farmers mentioned that there is currently no good quality organic liquid fertiliser available on the market, as the ones that do exist are too thick and clog their irrigation pipes.

Previous studies have also found that farmers see benefits with a liquid form of urine fertiliser but for other reasons than for drop irrigation (Andersson, 2015; Sutardi et al., 2021). For Ugandan smallholder farmers who produce enough urine in their own households to fertilise their crops, using the raw liquid form of urine means it’s a free and readily available resource (Andersson, 2015). It is therefore important that a wide range of urine based fertilisers are developed to fit differing needs around the world.

Cost & personal values

Many farmers were curious about the cost of the fertiliser, which they expressed would have to lie within the range of their current financial expenditure on fertilisers to be advantageous to adopt. The cost of taking a chance on innovations is a commonly cited barrier amongst agritech adoption literature (Long et al., 2016; Sneddon et al., 2011; Wheeler, 2008). The majority of farmers expressed dependency on EU subsidies and part time jobs to survive financially. Some examples of what farmers answered when asked if they apply for any EU subsidies include:

> *“Yes, I can’t operate without them.”* (F8)
>
> *“Yes, of course! EU subsidies are a big part of my turnover. Say the subsidies stand for 20% of my turnover, somewhere around there. So it’s really important to receive the subsidies and even try to optimise the subsidies a bit.”* (F4)
>
> *“During the past years about 25% of our turnover has come from EU subsidies.”* (F7)

A few Gotlandic farmers worried that the price of HUF would be high due to its novelty and lengthy production process (figure 2) and thought it would be useful if they could apply for an EU subsidy for making the choice to try HUF. One farmer was especially intrigued by the question and replied: *“Yes, if you can get a subsidy for it I would be much more interested in using it, of course.”* (F1). Providing subsidies for adopting organic fertilisers has been found to help influence farmers to switch from synthetic ones (Wang et al., 2018). However, it can also contribute to excessive use of fertilisers, which works against the underlying aim of HUFs to reduce eutrophication (Vondolia et al., 2021). Therefore, it could be beneficial to divide the costs throughout the whole service chain so that farmers don't have to bear the whole cost (Lundin et al., 2021). Whilst there is no current estimation of what Sanitation360's fertiliser will cost, the goal is to make it equivalent to conventional fertilisers.

De Lauwere et al. (2022) found that farmers who practise more circular measures in their farming are motivated by their own social and environmental values whereas those who don't practise that much circularity are motivated more by economic incentives (De Lauwere et al., 2022). However, (Kings & Ilbery, 2012) warns not to make any direct links between farmer values and their agri-environmental choices due to the fact that behaviour is highly complex. In tandem, Marr & Howley (2019) found that farmers often become "accidental environmentalists" by adopting environmental practices for economic reasons or their own health and wellbeing such as in the case of reducing pesticide use, something one Gotlandic farmer mentioned doing (F9). Therefore, whilst an intrinsic drive to adopt sustainable innovations such as HUF could facilitate adoption, economic incentives might be needed to diffuse the innovation amongst farmers who are less driven by sustainability.

Especially three farmers showed much enthusiasm for the topic of HUF as well as their answers, the three farmers most willing to adopt HUF if evidence can show that it's safe to use, were three very different farmers; an EU-organic and KRAV farmer with a wide range of crops (F3), a conventional grain farmer (F4) and lastly, an EU-organic and KRAV-certified vegetable farmer who even offered to trial Sanitation360's product (F8). As this is not a quantitative study, no significant correlations can be drawn between them or their responses. However, there are some visible similarities such as:

1. No livestock, meaning they have to purchase fertiliser (partial or no use of manure)
2. Strong environmental enthusiasm and willingness to farm sustainably
3. No or slight worry about consumer acceptance

Another qualitative study on Swedish farms found that farms that appear different at first, such as conventional and organic farms, can share similar farming strategies and logistics (Marquardt et al., 2022). This was exactly the case with one of the conventional Gotlandic farmers who wanted to prove that conventional farming can be just as sustainable as organic farming through optimising his nutrient management practices, developing a method to minimise pesticide use and eventually purchase a suncell driven tractor (F4). Except for livestock farmers, this suggests that HUF and other human waste derived fertilisers are likely to interest a wide array of farmers depending on their personal mindset towards sustainability and human waste reuse.

Nutrient content

Sanitation360 currently manages to produce a fertiliser with 7,8% nitrogen, 0,7% phosphorus and 2,5% potassium, which was therefore the ratio presented to the farmers (since the interviews, they have achieved 15-1,8-4 NPK). Five of the farmers were pleased (F1, F2, F5, F7, F9) whereas the remaining four had other preferences. Vegetable farmers expressed a need for higher proportions of potassium in comparison to nitrogen, wanting up to double the amount. This, due to the fact that vegetables need large amounts of potassium to grow thick cell walls, making the vegetables both bigger and persistent storage wise, as described by the vegetable farmers. Contrariwise, a conventional grain farmer wanted double or triple the amount of nitrogen for it to be compatible with their current fertiliser (F4). No farmer had an inquiry about phosphorus which they explained is due to the fact that Gotlandic soil is generally rich in phosphorus. However, this will likely therefore vary depending on the geographical location which emphasises the need for HUF to be offered in a variety of NPK ratios.

5.2.3. Complexity

The complexity concerns whether or not dry-HUF is seen as easy to understand and implement into current farming practices. All farmers found that dry-HUF would be easy to adopt but would appreciate transparency regarding the processing of the urine and what implementing UDTs on a larger national scale would look like.

Research to practise

All farmers saw dry-HUF as a simple innovation to adopt. However, many expressed a will to learn about the processes involved in producing dry-HUF. That kind of information is something that Sanitation360 and other urine fertiliser producing companies mainly have available in scientific publications that are often lengthy and involve niche terms and scientific jargon. The farmers expressed that they would appreciate it if it was documented in an accessible way. This could look like including popular scientific summaries of scientific reports on HUF company's websites or including short films showing and explaining the process. In tandem, some felt there was a disconnect between research and implementation of the findings in practice, which one farmer especially reflected on:

> *"It has to, as mentioned, work in practice as well. That's where there's often a bit of an issue with science (...). It can be a really good finding but isn't very simple to practically adopt in the end. Or it might not be that cost effective, which is of course also a big factor."* (F1)

The simplicity of dry-HUF due to its compatibility with current fertilisers, is promising for the diffusion of it (Rogers, 2003). Relatively simple agricultural practices, such as slow release nitrogen fertilisers, have been shown to only take a few months to adopt in comparison to several years for more complex innovations such as digital ones (Kaine & Wright, 2022). However, as sludge is also an innovation of similar simplicity and is still not widely adopted by Swedish farmers, this suggests that the complexity is not a pivotal aspect in the adoption of fertilisers derived from human excreta.

5.2.4 Trialability

The trialability of HUF concerns whether or not it can be used on an experimental and/or partial basis which is supposed to facilitate adoption. The fact that HUF is a divisible product makes experimentation easy. However, legislative and financial aspects might be a barrier for trialling HUF.

Practical aspects

The HUF created by Sanitation360 is a divisible and trialable product that can be trialled on any type of crop, which will likely facilitate adoption as it provides farmers with the possibility to evaluate the benefits of the innovations which can reduce or even fully remove fears of the unknown (Mannan et al., 2017). However, this might not be enough for farmers to seek it out and try it. One farmer expressed a need to be asked to trial a product when in conversation about both sludge and biochar: *"Now they have some type of certification, Revaq or something like that which allows you to use it (sludge) to some extent. However, I've never been asked to use it so it hasn't been topical"* (F4). Similarly, Ekane et al. (2021) found that farmers are not the ones demanding the reuse of sludge in Sweden. One of the Swedish farmers interviewed by Ekane et al. (2021) expressed that farmers would not use sludge on their own incentive. As Ekane et al. (2021) and this study are qualitative ones, this finding can not be generalised to a wider Swedish context. However, it does point to the importance that other actors, such as entrepreneurs and agricultural agencies, monitor, evaluate and promote the use of human waste derived fertilisers.

One farmer wanted to trial dry-HUF for 2-3 years for free, before feeling safe enough to adopt it (F3). They added that they would also require economic compensation in case the HUF didn't live up to its promises. Trying an innovation has been shown by multiple adoption studies to be highly dependent on each individual's interests and willingness and ability to take financial risks (Russi et al., 2016; Sattler & Nagel, 2010). As neither Sanitation360 or HHS offer farmers financial compensation for trialling it, this might slow adoption. In addition, a scoping review of nearly 18 000 studies on payment incentive programs for sustainable agricultural practices, found higher adoption rates when economic benefits were involved as opposed to solely ecological services (Piñeiro et al., 2020). However, Piñeiro et al. (2020) also emphasise the fact that just because economic incentives often lead to adoption amongst farmers, it doesn't mean that they are the best way to go about diffusion of innovations with sustainability aims. This, as such incentives might counteract the strategic aim of the incentive to contribute to sustainable agriculture (Piñeiro et al., 2020). An example would be increasing the adoption of residue mulching which indirectly prohibits the possibility of transitioning to no tillage (Ward et al., 2016). If a subsidy or compensation were to be offered to farmers in order to try HUF, it is important to ensure that its use isn’t crowding out the use of alternative fertilisers (such as using what’s already on ones farm which multiple Gotlandic farmers do, see table 1) or practices that might be more sustainable.

5.2.5 Observability

The observability refers to whether or not HUF is distinguishable from other fertilisers. Due to similar appearance to other pellet shaped fertilisers, the observability is low. However, strong social networks amongst farmers and others within the agricultural sector on Gotland could potentially facilitate adoption.

Visibility & social networks

As any field fertilised with dry-HUF will look similar to any other field, it is vital to make other aspects of the product visible such as the packaging or the marketing of end products. Observability can also be achieved through networking (Rogers, 2003), which is something that all farmers brought up as an important factor that influences their trust in trying new innovations. The most common ways in which the farmers heard about new innovations include agricultural magazines (Land, ATL), facebook groups with other farmers, innovation/machine showing days and by talking to colleagues. This aligns with other pro-environmental adoption literature which presents social incentive as a facilitator (Kuhfuss et al., 2016). Previous agri-adoption studies have emphasised the significant role that interpersonal communication, the mass media and extension services play when an innovation has low visibility (Njenga et al., 2021; Piñeiro et al., 2020). Having strong social networks amongst actors in the agricultural sector is therefore especially important for the diffusion of HUF and other innovations that aren't easily observable.

The Gotlandic farmers mentioned multiple Swedish agricultural actors from whom they would want to learn about HUF from in order to feel safe taking a chance on it. These included LRF, Gotlands Ekologiska Odlare, Lantmännen and Hushållningssällskapet. This suggests that actors within the Swedish sanitary and agricultural industry need to focus on joint action to facilitate the adoption of HUF. Farmer-led or active participation by farmers in the development of innovations has shown promising results in facilitating the adoption of environmentally and socio-economically sustainable agricultural practices (Alomia-Hinojosa et al., 2018; Ensor & De Bruin, 2022; Kraaijvanger et al., 2016). However, collaboration will prove difficult until there is a shared sense of understanding amongst actors in the Swedish sludge controversy, which extends to the use of human excreta in general (Söderholm et al., 2023).

5.3 Future research

With growing demand for Sweden as well as other EU countries to increase domestic fertiliser production in a sustainable way, it is vital that farmers are informed and involved in the process of developing new fertilisers. Therefore, it would be beneficial to conduct continuous focus group studies with stakeholders from relevant industries (agricultural, wastewater treatment, infrastructure and transport sector, policy-makers) in order to create an interdisciplinary space for knowledge exchange and development of HUF. However, due to the global food trade industry, focus groups and workshops would also be needed in international settings to ensure that there is a global consensus on its use. This, in tandem with consumer surveys with bigger sample sizes. It is also important to research the barriers and potentials of a wide range of nutrient sources that can be reused as farmers have different preferences and requirements depending on their production orientation, soil type, financial situation etc. Such examples include leftover wool, forest debris and ashes.

5.4 Limitations & research reflections

Despite the well intention of contributing to the diffusion of awareness and knowledge of Sanitation360's dry-HUF, using a locally produced product as an example for HUF is a limitation to the study. It likely biassed the farmers responses in comparison to if dry-HUF was presented to them without a local company being attached to it. Whilst face to face interviews are said to create a natural encounter, telephone interviews might provide the interviewee with a greater sense of anonymity around sensitive topics which could've been beneficial to counteract this bias (Irvine et al., 2013). At the same time, it provided insight into important potentials of the fertiliser, such as its ability to contribute to domestic production on Gotland, which otherwise could not have been discussed.

Whilst appropriate for gaining an insight into farmers' livelihoods and reasoning behind their attitudes towards HUF, the small sample size and qualitative approach doesn't allow for generalisations to be made. This study can therefore not determine which kind of farmers HUF is likely to be adopted by or how widely it will be adopted. It would therefore have been beneficial to complement the interviews with a survey sent out to as many Gotlandic farmers as possible. In tandem, surveying Swedish consumers' attitudes towards the use of HUF would also have been a useful complementary data source.

In terms of theoretical approach, DOI was useful in providing a structure with which the barriers and potential of HUF could be categorised. However, as it focuses on the adopter, it fails to take into account the barriers and potentials that other relevant stakeholders see with HUF. Therefore, combining DOI with a broader sustainability transition theory such as the multi-level perspective framework developed by Geels (2011), would be beneficial to gain a broader systems perspective.

6. Conclusion

This research identifies the barriers and potentials with dry-HUF from the perspective of nine Gotlandic farmers. As there has been little collaboration between farmers, innovators and the agricultural sector in developing HUFs in Sweden, this research contributes to bridging that gap by using a dry-HUF produced by Sanitation360, a Gotland based company founded in 2019, as an example. In order to do this, the relative advantage, compatibility, complexity, trialability and observability of dry-HUF was investigated as well as farmer's prior knowledge of urine as a fertiliser. Whilst the qualitative nature and small sample size of this study does not make these findings generalizable, it presents valuable insights into farmer attitudes towards HUF.

Farmers were knowledgeable about the potential to recycle nutrients in human excreta but few knew that sludge or urine is allowed in conventional farming and few knew about Sanitation360. Information dissemination of dry-HUF and recent research findings that suggest that some HUFs are safe to use if treated right, needs to become more accessible to farmers. Farmers prefer learning about innovations through popular science publications, social networks and through continuous dialogues between farmers, agricultural advisors, researchers and innovators.

Out of the five characteristics investigated, complexity, trialability and observability seem to pose minimal barriers to potential adoption and farmers do see some major advantages with dry-HUF. On the other hand, bias from knowledge of the Swedish sludge debate, scepticism towards consumer acceptance and legislative barriers might hinder adoption. The use of human excreta did not occur as a possibility to those who were familiar with the controversy surrounding agricultural use of sludge in Sweden. As the mass media has had such a big impact on farmers' attitudes towards sludge and HUFs, it is important to start using it as a tool to create a positive image around human excreta for food production. Lastly, Gotland's dependency on shipping from mainland Sweden, which makes farm imports expensive and uncertain in the case of geopolitical events, made the fact that Sanitation360's fertiliser is produced on Gotland a major advantage.

Consensus on regulations is needed in order for farmers to feel safe using human urine and facilitate an international transition to a circular nutrient economy. The fact that the EU is incentivizing the creation of market places for circular nutrient fertilisers is promising. However, additional measures might be required to reduce the acute situation of eutrophication in the Baltic, if diffusion of circular innovations turn out to be slow due to taboos. In tandem, the use of HUF in itself will likely not contribute to reducing eutrophication and needs to be combined with improved nutrient management practices such as more regular soil mapping.

With the initial aim of dry-HUF to be an alternative for conventional farmers, this study found that many organic farmers are in search of an alternative fertiliser to abattoir waste, which comes with animal welfare concerns. Therefore, it is vital that Arla, KRAV, EU-organic and other certifications start to allow the use of fertilisers derived from human etcetera now that efficient treatment technologies are being developed. This study contributes to insights into qualities of HUF that should be further explored, such as its circular and animal welfare aspects, which could potentially enhance adoption. There is a long way to go to minimise the use of synthetic fertilisers in Sweden as well as secure domestic fertiliser production. However, Sanitation360's technology was positively received which is promising in facilitating a transition to a circular nutrient economy on Gotland, which other regions can likely learn a lot from.

7 References

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8 Appendix

Table 1. Phone/Text contact with potential interviewees. How I approached the farmers on the phone or via text message (translated from Swedish to English).

Hi, my name is Nicola Parfitt and I'm calling as a student from Lund University. Is this (farmer's name) and am I correct to assume that you are a farmer? Hope all is well! I'm calling/writing to you as I'm currently writing my master's thesis in environmental studies and sustainability science which is about including farmers in the conversation about circular nutrient use in agriculture. Therefore, I'm looking for grain and vegetable farmers that would be interested in participating in my study through an interview at

their farm. I'll be coming to Gotland between the 13th and 19th of March and the interviews will take approximately 1-1,5 hours and mainly revolve around your current nutrient use. You will also be anonymous in the study. Is this something you would be interested in participating in?

Table 2. Thematic analysis. The final themes and codes from my thematic analysis of the farmer interviews.

- Theme: Farmer's farm view
    - Climate change and sustainability perspective
    - Soil type
    - EU dependency
- Theme: Current fertiliser use
    - Current choice and factors impacting the choice
    - practices to reduce N leakage
    - Soil mapping
    - Important micronutrients
- Theme: Prior knowledge of HUF
    - Knowledge of Sanitation360
    - Knowledge of HUF in general
    - Previous use of HUF
    - Attitude/personal mindset towards HUF
    - UDT view
- Theme: Barriers with HUF
    - Consumer acceptance
    - Wanted NPK value
    - Potential cost
    - Organic matter
    - legislation/certification
- Theme: Potentials with HUF
    - Circularty
    - Locally produced importance
    - Animal ethics
    - Diffusion/networks

Table 3. The interview guide I developed and brought with me (on paper) to all interviews. The amount of questions that were asked differed depending on the interview and the order in which they were asked depended on the topics that came up. However, the most important ones which I made sure to include are marked with a *.

1. Talk a little about the consent form…Do you work full time as a farmer? If certified, what motivates you to grow under that certification?*
2. I see you have been a farmer since xxxx, have you noticed any differences in the climate/seasons since then and have you done anything to adapt to them?* Is there anything particular on your farm that you think contributes to the benefit of nature? What contributes to the greatest negative environmental impact?
3. Do you use fertiliser your crops? Could you tell me what kind of fertiliser you use and why you chose it?* Are there any extra important factors you look at when choosing a fertiliser*
4. What form do you prefer fertiliser in? Liquid, pellets, etc.*
5. Have you implemented any measures/methods to reduce nutrient leakage specifically from your farm, if so which ones? (to keep in mind: cover crops, mixed crops, no till)*
6. Have you heard about the possibility of using human urine as fertiliser? What have you heard about it? Is this something you've tried?*
7. Have you heard of Sanitation360 who are producing a dry-fertiliser from human urine here on Gotland?*
8. [ask to show them the illustration and discuss any thoughts/questions that come up]*
9. Is there anything you're sceptical about in terms of Sanitation360's fertiliser?*
10. Is there anything you see as an advantage with Sanitation360's fertiliser?*
11. Right now, human urine may not be used in either KRAV or organically certified agriculture, but work is being done to either develop a new certification for it or incorporate it into a certification that already exists such as KRAV or organic, which would you prefer?*
12. What information would you need to know about human urine as fertiliser to feel comfortable adopting it? And would you like to try it?*
13. As a farmer, how do you want to take part in research results that are relevant to you, for example when you have made technology or method changes before in your agriculture?*
14. Consciously being a farmer is often described more as a lifestyle than a job because it is very time consuming, especially during certain seasons. How do you keep up-to-date on agricultural issues and updates to regulations, support to apply for, etc. despite that?
15. Are you part of any networks or advisory organisations that usually update about new regulations regarding plant nutrition/fertiliser issues?*

16. Do you feel that you have the opportunity to influence what research is done on agricultural issues or new strategies and regulations? Do you feel heard to the degree you want to be heard?
17. Do you think it is important to create a more local food industry on Gotland and in Sweden? If so, what do you think can contribute to creating it? Do you think that the use of a locally produced circular fertiliser is something that consumers would have been attracted to if it was included in the marketing of the product?*
18. Do you think that the use of a locally produced circular fertiliser is something that consumers would have been attracted to if it was included in the marketing of the product?
19. What grants can you apply for with the farm/cultivation you have? Are you applying for them? Why/why not?*
20. Has Sweden's food strategy that was adopted in 2017 and extends to 2030 and has it affected you as a farmer/grower such as how much support you receive, how? (that Sweden should increase food production, self-sufficiency, sustainability)
21. What do you think about CAP and other subsidies regarding fertiliser/nutrition? Could you have imagined using urine as a fertiliser if there was a subsidy for it?*
22. Have you ever felt worried about the availability of fertiliser?*
23. How do you feel about your farm's future?
24. Something you wonder or something you think I missed to cover?
25. Do you carry out soil mapping of your fields or any other soil testing? How often? Have they been helpful/have you changed any of your practices after receiving the results?*
26. Do you follow a nutrient management plan? If yes, what does it look like, what nutrients are included, micronutrients, how is it produced and who makes it?*
27. I've heard that the use of seaweed as a fertiliser is quite common on Gotland. Have you tried using it as fertiliser? If so, what did you think? If not, why and what do you think about sorghum as fertiliser?
28. Have you participated in any environmental projects during your time as a farmer? If yes, which one(s) and how was that experience?
29. Is there anything you’re wondering about in terms of human urine as a fertiliser?*

Table 4. Consent form in Swedish explaining that the interviewees participated out of their own free will, would remain anonymous in this thesis and consented to being recorded.

Kontaktuppgifter

Namn: Nicola Parfitt

Telefonnummer: 0708500857

E-post: nicolaparfitt@rocketmail.com

Samtyckesformulär

Om uppsatsen

Det här är en masteruppsats som skrivs av Nicola Parfitt, inom programmet LUMES (International Master's Programme in Environmental Studies and Sustainability Science), på institutionen LUCSUS på Lunds Universitet. Uppsatsen handlar om att centrera lantbrukare/odlare i frågor gällande näringsanvändning inom lantbruket samt att ta reda på lantbrukares/odlares åsikter om en potentiell övergång till en cirkulär näringsanvändning. En stor del av uppsatsen handlar även om att undersöka vilka potentiella hinder och möjligheter det finns för användningen av humanurin som gödsel i Gotland och resten av Sverige. Den här intervjun, tillsammans med andra, utgör en del av den data som kommer att analyseras och användas i uppsatsen.

Vad det innebär att medverka

- Ditt deltagande är frivilligt, och du har alltid möjlighet att dra dig ur studien om du önskar
- Namn, telefonnummer och e-post delas inte med någon, och du förblir anonym i studien

Genom att skriva under detta formulär ger du ditt samtycke till att:

- Intervjuerna spelas in i syfte att jag som intervjuare kan lyssna på, transkribera, och analysera svar. Dessa filer delas inte med någon annan än mig
- Uppsatsen kommer att delas online via Lunds Universitets Bibliotek & potentiellt även publiceras i en vetenskaplig tidskrift
- Resultaten och den färdiga uppsatsen kan komma att delas med samtliga deltagare i studien (inklusive dig själv) om så önskas
- Ta emot en liten gåva som tack för ditt deltagande

Kön

Ålder

Utbildning

Storlek på gård

Årtalet du började odla

Produktionsinriktning

Plats och datum

Underskrift

Namnförtydligande

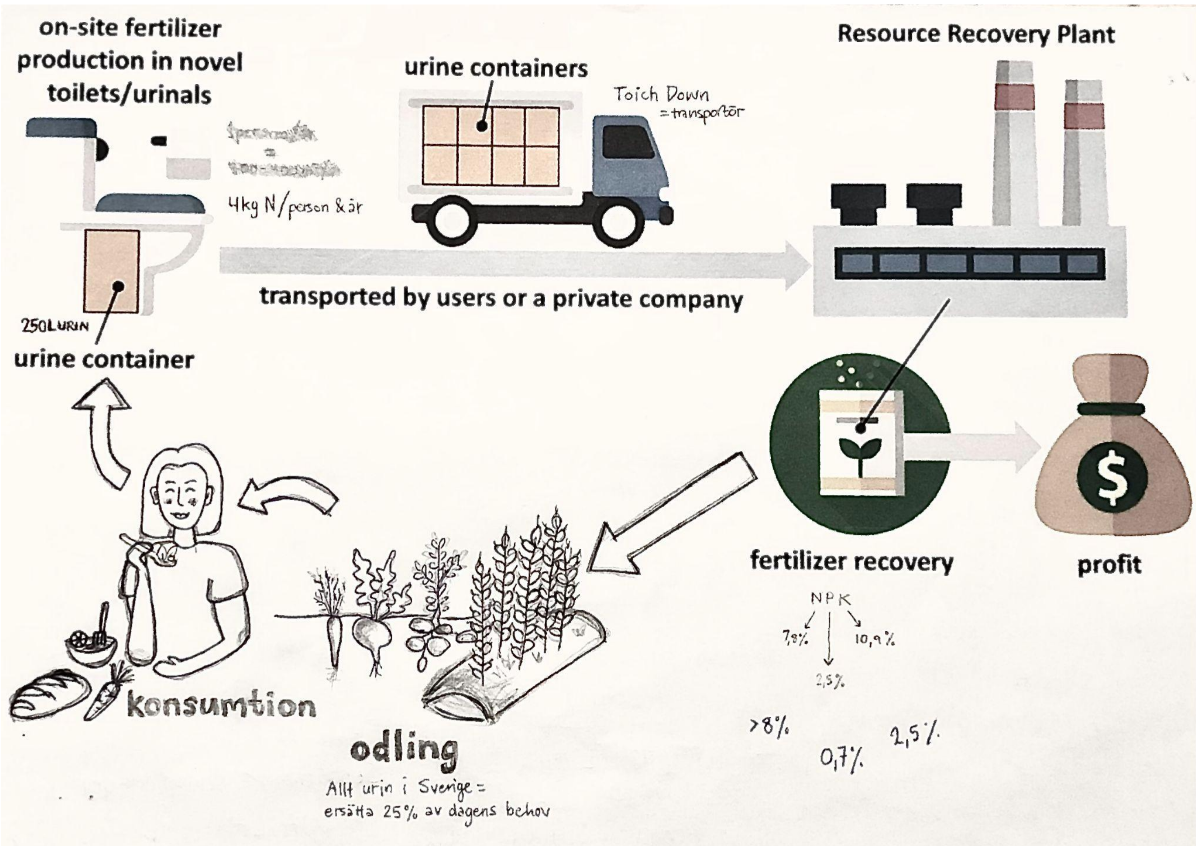

Figure 1. The printed version of Sanitation360's process of creating a human urine fertiliser on Gotland. Illustration inspired by Randall & Naidoo (2018) and own details added by hand.