Sveriges lantbruksuniversitet
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Faculty of Landscape Architecture, Horticulture and Crop Production Science

The preconditions for increasing phosphorus recycling from sewage systems in Sweden

– A study of factors influencing Swedish farmers' willingness to use phosphorus fertilizers produced from sewage sludge

Förutsättningarna för att öka fosforåtervinningen från svenska avloppssystem

– En studie om faktorer som påverkar svenska lantbrukares vilja att använda fosforgödselmedel framställda av avloppsslam

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Jesper Edholm Widén, July 2019

Foreword

This thesis has been written during my last semester of studying the two-year master´s programme in Agroecology at the Swedish University of Agricultural Sciences. Through a lens of holistic systems thinking, the programme focuses on the social, economic and environmental obstacles and opportunities for creating sustainable food systems on a local, national and international level.

Two years of studying the field of agroecology has taken my understanding of what constitutes a sustainable food system to a whole new level. With an academic background in social sciences, I have deeply appreciated the opportunity to study a multidisciplinary master´s programme with natural science elements. The programme has provided me with basic skills in agronomy and theoretical knowledge of sustainable cultivation practices, which I believe are crucial skills to have for someone whom, like me, would like to eventually work in policy development for the agricultural and rural sector. I will leave the Swedish University of Agriculture with a broader set of analytical skills and tools, for which I will be forever grateful.

Agroecology as a field of research includes a wide range of perspectives and principles of what constitutes sustainable food and farming systems, as well as suggested causes of action for achieving these systems. For instance, many prominent agroecologists argue for the importance of transitioning from conventional farming to more sustainable farming practices, which *inter alia* includes minimizing dependence on external inputs to the agroecosystem. However, some external inputs are acknowledged as valuable. Sewage sludge as fertilizer for arable fields is an example of an external input that is acknowledged as a potential agricultural resource, but it is my personal opinion that it stops with this acknowledgement and that little attention is given to how sewage sludge can be utilized further. Sewage sludge contain nutrients available in societal circulation, which means that it can serve as a valuable and renewable fertilizer for farming systems. With that being said, Sweden is an example of a country which only applies a small portion of its annually produced sludge on arable fields. For this reason, I believe that agroecologist should conduct research on how the sludge could be used as a larger agricultural

resource than it is today, rather than just acknowledging that it is a resource. For example, research investigating the reasons for the low application rates of sewage sludge on arable fields, as well as the attitudes towards sewage sludge prevalent amongst the relevant actors in the food and agricultural sector, could be conducted. This notion has been a motivational factor throughout the process of writing this thesis and the author hopes that this thesis can serve as an inspirational example of how agroecological research can be conducted in the future.

Abstract

The Swedish government (2018) is currently investigating options for prohibiting direct application of sewage sludge on arable fields and replace it with techniques capable of precipitating phosphorus from sewage sludge and turn it into refined phosphorus fertilizing products. The investigation is part of the government´s ambition to increase the recycling rate of phosphorus available in sewage sludge and thus turn the sludge into a greater agricultural resource than it is today (ibid). The success of refined phosphorus fertilizers is primarily contingent on farmers´ willingness to use them, making the factors influencing this willingness crucial to be aware of. However, these factors are not explicitly mentioned as being taken into consideration in the government´s investigation (ibid), and no previous research exists on this topic. For this reason, this thesis has focused on investigating the factors influencing Swedish farmers' willingness to use refined phosphorus fertilizers produced form sewage sludge. It has done so by conducting semi-structured interviews with nine Swedish conventional farmers. Their answers have been analysed using inductive thematic analysis. The analysis identified three themes, or factors, influencing farmers' willingness to use refined phosphorus fertilizers produced from sewage sludge; (1) *Scientific understanding about the products*, (2) *Features of the products*, and (3) *Price of the products.*

The first factor, *Scientific understanding about the products*, is about farmers expressing a need for a widespread scientific understanding about the refined phosphorus fertilizers and the technologies used to produce them. This in order to avoid that phosphorus fertilizers produced from sewage sludge become subjected to the same controversy surrounding the safety of using them as directly applied sewage sludge is perceived as being subjected to today.

The second factor, *Features of the products,* is about phosphorus fertilizers produced from sewage sludge needing to have physical and chemical features similar to the mineral fertilizers farmers use today.

The third factor, *Price of the products,* is that the prices for phosphorus fertilizers produced from sewage sludge should not exceed those for phosphorus mineral fertilizers, and that society has a responsibility to keep prices at a level where phosphorus fertilizers produced from sewage sludge are economically feasible for farmers to obtain.

The thesis concludes that the Swedish government should implement technologies and refined phosphorus fertilizing products that accommodate the identified factors to the extent possible. This in order to improve the preconditions for an increased recycling rate of phosphorus available in sewage sludge.

Sammanfattning

Den svenska regeringen utreder just nu alternativ för att förbjuda direktapplicering av avloppsslam på jordbruksmark och ersätta det med tekniker som kan utvinna fosfor ur slammet och skapa raffinerade fosforgödselprodukter utav det. Utredningen är en del av regeringens ambition att öka återvinningen av fosfor i avloppsslam och på så vis göra slammet till en större resurs för jordbruket än vad det är idag. Genomslaget för raffinerade fosforgödselprodukter är primärt beroende av lantbrukares vilja att använda dem, vilket gör medvetenheten om faktorerna som påverkar denna vilja absolut nödvändig. Med det sagt, ingen uttrycklig hänsyn tas till dessa faktorer i regeringens utredning och ingen tidigare forskning finns på ämnet. Därför har denna uppsats fokuserat på att undersöka de faktorer som påverkar svenska lantbrukares vilja att använda raffinerade fosforgödselprodukter framställda av avloppsslam. Den har gjort så genom att hålla semi-strukturerade intervjuer med nio svenska konventionella lantbrukare. Deras svar har analyserats med induktiv tematisk analys. Analysen identifierade tre teman, eller faktorer, som påverkar lantbrukares vilja att använda raffinerade fosforgödselprodukter framställda av avloppsslam: (1) Vetenskaplig förståelse om produkterna, (2) Produkternas egenskaper, och (3) Produkternas pris.

Den första faktorn, *Vetenskaplig förståelse om produkterna*, handlar om lantbrukares uttryckta behov för en vidsträckt vetenskaplig förståelse om raffinerade fosforgödselmedel och om teknologierna som används för att producera dem. Detta för att undvika att fosforgödselmedel framställda av avloppsslam blir utsatta för samma kontrovers gällande säkerheten att använda dem som direktapplicerat avloppsslam uppfattas vara utsatt för idag.

Den andra faktorn, *Produkternas egenskaper*, handlar om att fosforgödselmedel framställda av avloppsslam behöver ha liknande fysiska och kemiska egenskaper som de mineralgödselmedel som används idag.

Den tredje faktorn, *Produkternas pris*, är att priserna för fosforgödselmedel framställda av avloppsslam inte bör överstiga priserna för mineralgödselfosfor, samt att samhället har ett ansvar att hålla priserna på en nivå där fosforgödselmedel framställda av avloppsslam är ekonomiskt möjliga för bönder att införskaffa.

Uppsatsens slutsats är att den svenska regeringen bör införa tekniker och raffinerade fosforgödselprodukter som tillmötesgår de identifierade faktorerna I största möjliga utsträckning. Detta för att förbättra förutsättningarna för en ökad återvinning av fosfor tillgängligt i avloppsslam.

Abbreviations

SEPA = Swedish Environmental Protection Agency (*Naturvårdsverket* in Swedish)

Chemical abbreviations

Al = Aluminium

Cd = Cadmium

Cr = Chromium

Cu = Copper

Fe = Iron

Hg = Mercury

K = Potassium

N = Nitrogen

Ni = Nickel

P = Phosphorus

Pb = Lead

Zn = Zinc

Table of content

1. Introduction

The element phosphorus (P) is one of the fundamental nutrients required for crop production, along with other macro nutrients such as nitrogen (N) and potassium (K). Crop production systems all over the world are highly dependent on compensating for the phosphorus that leaves the soil during harvest in order to sustain crop productivity and yield. In Sweden, the majority of phosphorus used to fertilize soils comes from livestock manure, while the second largest source is imported phosphate rock-based fertilizers (Naturvårdsverket 2013). As the name indicates, the fertilizers are produced by mined phosphate rock, which is a finite resource that cannot be artificially manufactured. Even though there are different estimations for when it will occur, one can with absolute certainty say that the world will eventually reach a scenario called 'peak phosphorus', i.e. a point in time where the demand for phosphate rock exceeds the supply (Cordell & White 2011; Neset & Cordell 2012; Hansson & Johansson 2012). Thus, ways to become less dependent on phosphate rock-based fertilizers, or phosphorus mineral fertilizers henceforth, for phosphorus fertilization will be crucial to find in order to ensure global food security for future generations.

A substantial amount of phosphorus is available in sewage sludge, an inevitable bi-product generated in wastewater treatment plants. In Sweden, dry matter sewage sludge has been directly applied to arable fields as fertilizer since the 1970´s, due to its content of phosphorus, other macronutrients and mulch building materials. In 2016, 204 232 tons of dry matter sludge was produced in Sweden, containing approximately 5546 tons of phosphorus, i.e. 2.7 per cent of the sludge's total weight (Statistics Sweden 2018a). However, only 34 per cent of the sludge was applied to arable fields that year, which is still the highest application rate in Sweden so far. In other words, a majority of the phosphorus available in sewage sludge could still be used to fertilise arable land in Sweden.

The low demand for sludge in relation to the supply can be explained by an extensive and controversial debate regarding the safety of using directly applied sewage sludge on arable fields. Sewage sludge does not only contain valuable nutrients, but does contain potentially hazardous

substances in the forms of disease pathogens, drug residues and heavy metals as well (Naturvårdsverket 2013; Svenskt Vatten 2013; Hansson & Johansson 2012). For this reason, the Swedish government (2018) is currently investigating options for prohibiting direct application of sewage sludge and replace it with techniques capable of precipitating phosphorus from sewage sludge, while simultaneously removing substances that are hazardous to environmental and human health. The investigation is part of the government´s ambition to turn sewage sludge into a greater agricultural resource than it is today (ibid), which in turn could contribute to Sweden becoming less dependent on phosphorus mineral fertilizers in the future. The results of the investigation will be released in September 2019 (ibid).

However, a prerequisite for a greater recycling rate of phosphorus in sewage sludge when direct application becomes prohibited is that Swedish farmers are willing to use the refined phosphorus fertilizing products generated by the techniques the government deems reasonable to implement. Considering the controversy surrounding sewage sludge, it is imperative to investigate the factors influencing farmers' willingness to use refined phosphorus fertilizers produced from sewage sludge. These factors and the reasoning behind them are crucial aspects to take into consideration when assessing technologies and products that could be relevant options to replace directly applied sewage sludge with. This perspective is not part of the government's investigation (ibid), which is why this thesis will strive to provide such a perspective. Hence, this thesis will investigate the factors influencing farmers' willingness to use phosphorus fertilizers produced from sewage sludge.

1.1 Purpose and research question

The purpose of this thesis is to investigate the factors influencing farmer's willingness to use phosphorus fertilizers produced from sewage sludge, and more importantly, to capture the reasoning behind these factors. It achieves this purpose by taking a qualitative research approach, where semi-structured interviews have been conducted with Swedish conventional farmers in the Scania region. The topic of the interviews was the participants' views on using phosphorus fertilizers produced from sewage sludge. The responses have been analysed using inductive thematic analysis. The research question that this thesis ultimately attempts to answer is:

How do Swedish farmers describe the factors that influence their willingness to use phosphorus fertilizers produced from sewage sludge?

Ultimately, the goal of this thesis is to provide a farmer's perspective to the process of assessing which technologies and products that could be reasonable options to replace directly applied sewage sludge with.

1.2 Research methodology

In order to answer the research question, this thesis has collected data through semi-structured interviews, after which the data have been analysed using inductive thematic analysis. The processes of data collection and analysis will be described further in the two sections below.

1.2.1 Data collection

The data used to answer the research question were collected through interviews with farmers in the Scania region in southern Sweden, which is the second largest agricultural region in the country, both in terms of arable land and number of agricultural businesses (Statistics Sweden 2018b). Interviews were conducted in Swedish with nine conventional farmers from eight different farms. Organic farmers are not included in this study since application of sewage sludge in any form is prohibited in organic farming in Sweden (KRAV 2018), thus making organic farmers currently irrelevant for this study. However, a study with organic farmers could become relevant in the future if a discussion about allowing sewage sludge in organic farming should appear on the political agenda.

The participants were selected using a snowball-sampling strategy, which means that the first recruited participant was asked to recommend other farmers that could potentially be interested to participate in the study. Each new participant was asked to recommend other potential participants, which created a 'snowball effect' which eventually resulted in a sample of nine farmers being interviewed. The interviews took place in the participants' homes or offices and lasted on average 32 minutes. One interview was a joint interview with two farmers managing a farm together. The interviews were semi-structured with open-ended questions, meaning that

the author asked a set of predetermined questions that were formed in a way that encouraged elaborate answers, rather than simple yes/no answers (see question guide in Appendix I). In addition, individual follow-up questions were asked to the respondents depending on their answers, at which the respondents were asked to elaborate or clarify their answers. For example, a follow-up question could be *"Could you please elaborate?"* or *"When you say…, what do you mean?"* or *"So if I understand you correctly, you mean…?".* Semi-structured interviews were chosen as an interview technique because it allows the respondent to give detailed, elaborate and personal reflections on a topic (Leech 2002), which is highly desirable given the purpose of this thesis. The results, i.e. the identified factors influencing farmers' willingness to use phosphorus fertilizers produced from sewage sludge, are essentially an interpretation of the realities and personal convictions of the participants. Hence, semi-structured interviews served as a helpful tool to capture these aspects.

The interviews were audio recorded and transcribed verbatim. The participants were offered copies of the audio recording and the transcript of their interview. An information sheet was sent to the participants prior to the interview with information regarding the purpose of the study and the terms for participation (see Appendix II below). The farmers' own names and the names of their businesses are anonymous throughout this thesis for ethical reasons. In the text, the respondents are referred to as "P" (for Participant) and a number between 1-8, simply depending on the order in which they were interviewed. Thus, the reader should note that the participants will be quoted as e.g. "P.1", although the participants in the dual interview will be quoted as either "P.7.1" or "P.7.2".

1.2.2 Data analysis

The data have been analysed using inductive thematic analysis, which is a method used to identify, analyse and define patterns or *themes*, within data, where themes are meant to "*… capture something important about the data in relation to the research question…*" (ibid, p.79). Themes were identified using an inductive approach, meaning that they were identified based solely on the information in the data themselves, as opposed to a deductive approach, in which the researcher's own theoretical interests drives the themes (Hayes 2000, Braun & Clarke 2006).

As argued by Hayes (2000), deductive research uses data to confirm or challenge an already existing theory, while inductive research uses data to formulate a new one. An inductive approach was chosen since there is no (to the author´s knowledge) previous research on the factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge, which is a research gap that the author of this thesis wishes to fill.

The thematic analysis was conducted in accordance with a six-step process described by Braun & Clarke (2006). **First**, the data (interviews) were transcribed verbatim and read through carefully to get a clear understanding of their content. The transcribed interviews constitute the data set upon which the analysis is based on.

Second, segments that the author perceived as relevant to the research question were extracted from the data and coded into key words.

Third, codes handling the same issue were grouped together to form candidate themes, a process which generated a total of 29 candidate themes (see Appendix III). The candidate themes are phrased in the author´s own words and should thus not be mistaken for direct quotes from the transcribed interviews. The candidate themes are phrased in ways that summarize the essence of the codes, which facilitated further analysis and eventual formulation of refined and final themes.

Fourth, the candidate themes went through a further review process in two stages, in which candidate themes became refined themes in the first stage and final themes in the second stage. In the first stage, the data set was consulted to see if there was sufficient data to support the candidate themes, which lead to five of them being discarded due to lack of supportive data. In other words, candidate themes that initially made sense on a coding level were discarded once it became apparent that they no longer reflected the meanings of the data. The remaining candidate themes were reviewed in order to see if coherent patterns could be found between them, after which they were grouped together to form five refined themes, although still highly provisional (see Appendix IV, discarded candidate themes grouped under ‘Miscellaneous´).

In the second stage, the five refined themes were put in relation to the entire data set in order to verify their validity, i.e. to see if they accurately reflected the story told in the data set as a whole. This stage proved to be the most vital in the whole analytical process in the sense that it clarified the actual relationships between the candidate themes, causing a need for them to be regrouped into new themes. This stage lead to the five refined themes being reduced to three final themes (see Appendix V). The three final themes constitute the results of the analysis and will be elaborated further in Chapter 3 below.

Fifth, the data set was consulted again in order to find quotes representative of the final themes, i.e. quotes that could be used to tell the complicated story of the themes in an illustrative and convincing manner. The quotes were translated *verbum pro verbo* from Swedish into English. This step also included setting suitable names for the themes.

Sixth, the final report, i.e. this thesis, was produced to present and discuss the results of the analysis.

2. Background

2.1 Peak phosphorus and importance of finding alternative sources to phosphorus mineral fertilizers for phosphorus fertilization

Phosphorus mineral fertilizers are produced by mined phosphate rock, which is sedimentary or igneous rock with a phosphorus content of approximately 12-16 per cent and 5 per cent respectively (Steen 2009). Phosphate rock is not considered a renewable resource, seeing that phosphates naturally cycle between the lithosphere and hydrosphere over a period of millions of years (Cordell & White 2011). In essence, it takes millions of years for phosphates to accumulate into concentrated minable phosphate rock, which is why it is considered a finite and unrenewable resource on a human time scale (ibid).

Phosphate rock is mined at a faster rate than it is able to form, which means that the demand for it will eventually exceed the supply. The point in time when this will occur is referred to as 'peak phosphorus' (ibid; Neset & Cordell 2012; Hansson & Johansson 2012), but there is a lack of consensus regarding when the peak will actually occur. For instance, Cordell, Drangert and White (2009) estimate that the peak will occur within 50-100 years, but could potentially occur as early as the year 2030. Meanwhile, Bertilsson (2011) claims that the peak will occur in approximately 2000 years. The timing for peak phosphorus is difficult to predict, considering that estimations of phosphate rock reserves have changed dramatically in recent years. Phosphate rock reserves are the portion of phosphate rock in the earth´s crust that is deemed technically and economically feasible to mine at current standards (Cordell & White 2011). Seeing that estimations of available reserves are contingent on technology and prices, estimations could change drastically from year to year, which in turn complicate estimations of when peak phosphorus will occur. A clear example of how dramatically estimations of phosphate rock reserves can change can be taken from 2010, when the International Fertilizer Development Center released the report *World Phosphate Rock Reserves and Resources*, in which estimations of reserves in Morocco and Western Sahara from the previous year of 5.7 billion tons increased to 51 billion tons, changing the estimations of total global reserves from 16 billion tons to 60 billion tons (Van Kauwenbergh 2010). This example clearly illustrates how estimations of global phosphate rock reserves can

change, but perhaps more importantly, how difficult it is to determine an exact timing for peak phosphorus.

Despite fluctuating estimations of global reserves and the lack of consensus on when peak phosphorus will actually occur, it is an undisputed fact that reserves will eventually be depleted. Hence, Sweden and other countries need to implement measures that ensure what Cordell & White (2011) call a 'soft landing', i.e. finding alternative sources to phosphorus mineral fertilizers for phosphorus fertilization well before the peak actually occurs. However, the sale of phosphorus mineral fertilizers for agricultural and horticultural purposes have increased rather than decreased in Sweden in recent years. For example, sales have increased annually from the fertilizer year 2010/2011 to 2016/2017, from 10 300 tons in the former to 14 400 tons in the latter, with an average sale of approximately 12 000 tons per year during that period (Statistics Sweden 2018c). In order to avoid further dependence on phosphorus mineral fertilizers and eventually be able to phase it out completely, efforts are needed to introduce new sources, or increase the use of already existing sources, of phosphorus to be used on arable fields.

2.2 Current use, views and plans for sewage sludge in Sweden

As previously mentioned, a considerable amount of phosphorus is available in sewage sludge, which is a resource that is not currently used to its full potential. For instance, 204 232 tons of dry matter sludge was produced in Swedish wastewater treatment plants in 2016, containing approximately 5546 tons of phosphorus, i.e. 2.7 per cent of the sludge's total weight (Statistics Sweden 2018a). This amounts to approximately 38 per cent of the phosphorus mineral fertilizers sold in the fertilizer year 2016/2017. However, only 34 per cent (1185 tons of phosphorus) of the sludge was applied to arable fields that year, which is still the highest application rate in Sweden so far. For example, 23-25 per cent was applied annually between 2008-2014 (Statistics Sweden 2016). When looking at the areas of use for sewage sludge in 2016, the largest area was still application on arable fields, as illustrated in Figure 1 below. Moreover, the second largest area of use at 28 per cent was production of topsoil used in *inter alia* golf courses and gardens, while the third largest area of use at 22 per cent was land fill coverage. While sewage sludge has other areas of use, it is difficult to argue that they perform a societal service to the same degree as when

applied to arable fields as fertilizer. Moreover, an increased use of sewage sludge as phosphorus fertilizer on arable fields could help decrease the dependence on phosphorus mineral fertilizers, which for reasons mentioned above, is highly desirable.

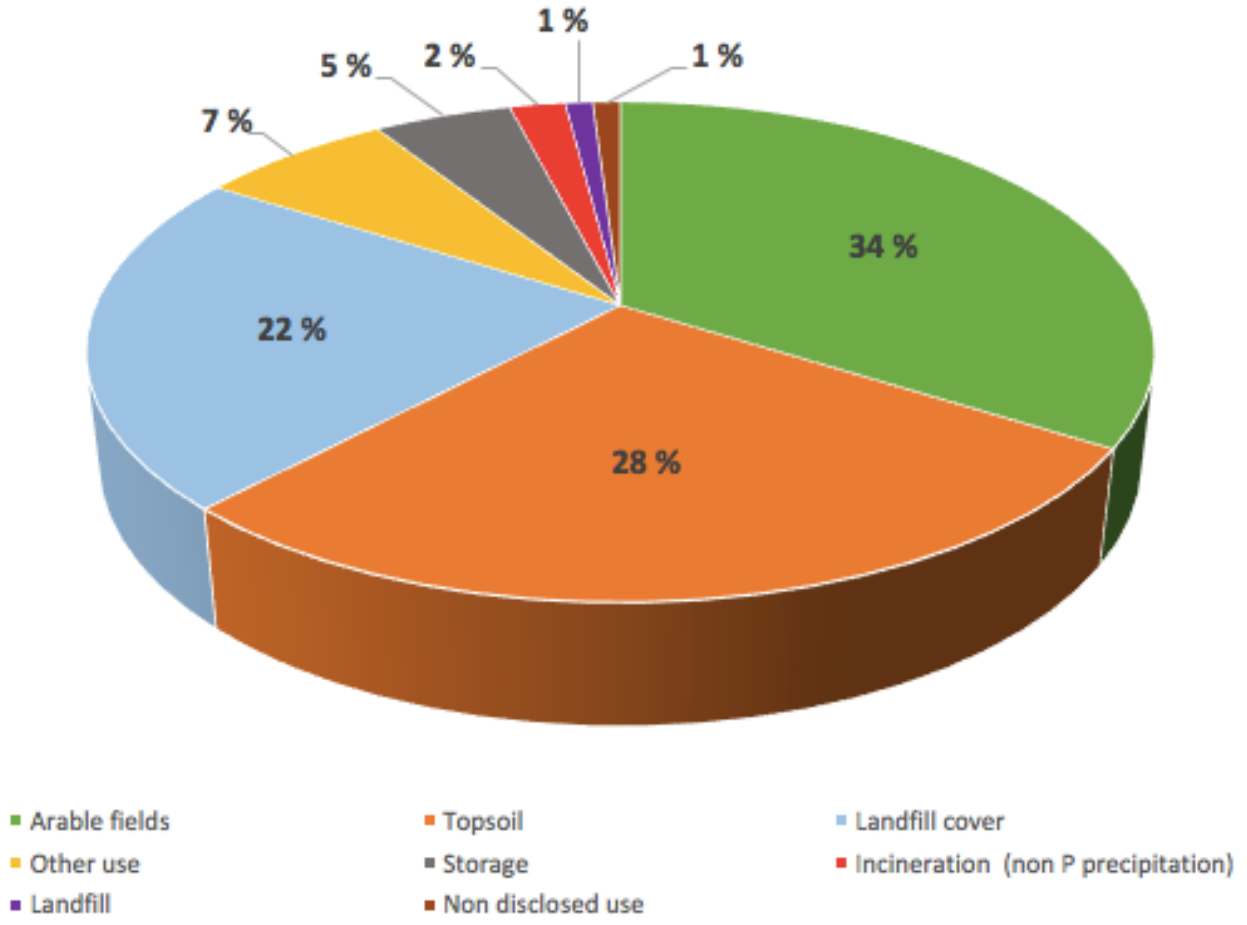

Figure 1: Areas of use for sewage sludge in 2016. Source of statistics: Statistics Sweden (2018a)

To be able to increase the use of sewage sludge as a fertilizer, one must first understand the reasons behind the historically low demand for it. According to the Swedish government (2018), the low demand can be explained by the food sector considering sewage sludge to contain too high levels of substances that are hazardous to environmental and human health. Previous research made on the subject confirms this notion. For instance, Berglund (2001) has presented an article with extensive data on the attitudes and policies that some of the major food companies

in Sweden have regarding the use of sewage sludge as fertilizer. The article finds that food companies generally do not accept sewage sludge as fertilizer for the produce they purchase because of its content of heavy metals, e.g. cadmium (Cd), and organic pollutants, such as brominated flame retardants. The concern is the harmful effects that these substances could have on plants, animals and humans, as well as for these substances accumulating in the soil. Carlsson (2003) reaches the same conclusion in her research conducted on the subject on behalf of the Swedish Environmental Protection Agency (SEPA). In their respective articles, Berglund and Carlsson reaches the conclusion that the hazardous substances must be removed from the sludge in order for food companies to accept it as fertilizer in the future.

Important to acknowledge here is that sewage sludge used for field application must adhere to regulated thresholds for seven different metals; cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), mercury (Hg), nickel (Ni) and zinc (Zn) (SFS 1998:944). The average metal content in sewage sludge produced in 2016 was below the thresholds for all seven metals (Statistics Sweden 2018a). For instance, the average content of Cd in sewage sludge in 2016 was 0.8 mg Cd/kg dry matter sewage sludge, while the threshold is 2 mg Cd/kg dry matter sewage sludge (ibid). To put this in relation to phosphorus content, the sludge contained on average 28.9 mg Cd/kg P (ibid), which is significantly higher than the average Cd-content in phosphorus mineral fertilizers sold in Sweden that year, which was 6.1 mg Cd/kg P (Statistics Sweden 2018c). Even though the metal content in sewage sludge is below the regulated thresholds and thus approved for field application, a partial explanation for the food sector´s reluctance to use it could be that phosphorus mineral fertilizers are considered a cleaner option. With that being said, SEPA has suggested to successively lower the thresholds for metals in sewage sludge in three stages over the years 2015, 2023 and 2030 (Naturvårdsverket 2013). However, the government has decided to go one step further and is currently investigating options for prohibiting direct application of sewage sludge and replace it with techniques capable of precipitating phosphorus from sewage sludge, while simultaneously removing substances that are hazardous to environmental and human health (Swedish government 2018). More specifically, the investigation has three objectives:

1. To suggest how a prohibition for direct application of sewage sludge can be designed, while still being able to recycle the phosphorus available in sewage sludge;
2. To investigate the technologies available for precipitating phosphorus from sewage sludge and the need for investment and establishment support for these technologies, and;
3. To suggest how upstream measures could proceed (Swedish government 2018)

In essence, it is the government´s intention to find technical solutions for precipitating phosphorus from sewage sludge and thus create cleaner phosphorus products that is more accepted by food companies. The hope is that these measures will help increase the recycling rate of phosphorus in sewage sludge and eventually decrease Sweden´s dependence on phosphorus mineral fertilizers, while simultaneously minimizing the spreading of hazardous substances to the environment (ibid). The results of the investigation will be presented in September 2019.

However, a prerequisite for a greater recycling rate of phosphorus in sewage sludge when direct application becomes prohibited is that Swedish farmers are willing to use the phosphorus fertilizing products generated by the techniques the government deems reasonable to implement. While the success of these products is partially dependent on food companies´ willingness to purchase produce that have been fertilized by these products, farmers are the actors who will actually use them in practice, which means that the success of these products are primarily contingent on farmers willingness to use them. In the description of the government´s investigation, the factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge is not articulated as being part of the investigation (ibid), and attempts by the author to contact the government to inquire about such a perspective have been unsuccessful. Moreover, previous reports issued on the technologies available for phosphorus precipitation from sewage sludge on behalf of the Swedish government or other governmental agencies have not included such a perspective either. Examples of such investigations have been conducted by SEPA (see Naturvårdsverket 2013) and Sweco (see Tideström et al. 2009). Another example is a report produced by Levlin et al. (2014), in which reference is made to farmers' preferences of technical features in fertilizers in general, but no reference is made to factors

relevant for farmers when considering using a phosphorus fertilizer produced from sewage sludge in particular. Considering the previously mentioned controversy surrounding sewage sludge, it is imperative to investigate the factors influencing farmers' willingness to use new phosphorus fertilizers produced from sewage sludge. These factors and the reasoning behind them are crucial aspects to take into consideration when assessing technologies and products that could be relevant options to replace directly applied sewage sludge with.

Against this background, the author of this thesis has strived to provide a farmer´s perspective to the process of determining which technologies and products that could be relevant options to replace directly applied sewage sludge with. This has been done by investigating the factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge, which will be demonstrated in Chapter 3 below.

3. Results

This chapter will elaborate the three themes identified during the thematic analysis, i.e. the three factors identified to influence farmers´ willingness to use phosphorus fertilizers produced from sewage sludge, illustrated in Figure 2 below: (1) Scientific knowledge about the products; (2) Features of the products; and (3) Price of the products.

Figure 2: The three themes identified during the thematic analysis

3.1 Scientific understanding about the products

In order for phosphorus fertilizers produced from sewage sludge to become relevant options, farmers expressed a need for an early and widespread scientific understanding about the implications and effects of the products and the technologies used to produce them. This is to avoid that the products become politicized in a way that directly applied sewage sludge is perceived as being today. References were made to a shifting debate regarding the safety of using sewage sludge as fertilizer on arable fields, a debate that is perceived as being built on the opinions of the great masses rather than on scientific knowledge.

> "*We have a lot of ways to inform ourselves today that are not always built on science, but on what some people say about certain things at the right time or the wrong time and then that's what applies. There must not be like politics in, that build on what the great masses think but rather that we build those things on a scientific foundation, so to speak.*"

When asked to give an example of a situation where opinions of the great masses precede scientific knowledge, P.8 explained:

> *"Well, there are people, or companies, that are going to buy my grain that no longer want to do so because they have heard that you shouldn't put sludge on the field. There should be no sludge used in some say three years, some say two years, some say six years and some say not to use it at all. What do they base that on? On nothing else than that they are afraid that those who are going to buy their products think that they have a dirty flour. And I sometimes talk to buyers here that back in the days had seen the wheat plants before they were buying the wheat, but now they hardly know anything. There are people who put together long lists of demands on what I must do, there must be traceability on all the stuff I put in because they have learned that that's the way it should be, well, what do you mean by that? Well, I don´t know but I'll just take the list of demands that they have here and they have there. Do you see? It's completely separated from scientific grounds. They just put up a list of demands, the bigger it is, the better product they think they'll get."*

Through depictions like this, it became clear that the participants are frustrated about the fact that their customers, in particular, base their opinions of sewage sludge on the popular opinion rather than on scientific knowledge. Due to a shifting debate and volatile opinions regarding the safety of using sewage sludge on arable fields, some farmers expressed a sense of insecurity and fear of not being able to sell their produce. For instance, P.1 contended that:

> *"Well, I believe that this whole debate, it has been going up and down. That the country side shall receive the shit from the city and this goes up and down all the time and then you're terrified that you won't be able to sell your products and that you're like poisoning your farm or however you want to put it".*

At a later stage of the interview, P.1 further explained that: *"Many farmers are afraid of doing wrong today. You know, they are afraid of like ending up on the black list. And there have been such violent shifts regarding sludge, that it's like, well, it's fine and then it's really dangerous all of*

a sudden". Similar concerns were expressed by P.4, who explained that: "*Sometimes new issues appear regarding fertilizers that have been used five years prior, and you want to minimize the risks for that. It could happen that you use this now and then the customer changes its mind after three, four years and that field could potentially become blacklisted".*

In essence, farmers are frustrated that customers base their attitudes towards sewage sludge as fertilizer on the popular opinion rather than on scientific knowledge. This is perceived as contributing to often shifting opinions, which in turn contributes to an insecurity on the market and a fear amongst farmers of not being able to sell their produce when opinions change. For this reason, all participants expressed a need for new phosphorus fertilizers produced from sewage sludge entering the market not to be subjected to volatile and shifting opinions regarding the safety of using them, in a way that directly applied sewage sludge has been. In order to help prevent doubts and shifting attitudes towards phosphorus fertilizers produced from sewage sludge, the participants argued for the importance of conducting extensive scientific research on the implications and effects of the products, both in terms of production and field application. For instance, P. 5 argued that: *"Well it's really, you know knowledge and communication of, like the content of the product, its effect, production, impact, everything, so there is an openness around how the product is produced, what it contains, almost for educational purposes, both for the user and for society".* When asked why this knowledge and information is important, P.5 explained:

> *"Because if you can communicate that knowledge from the start of using a new product, then I think you can get society with you instead of against you. You know, if there are knowledge gaps somewhere, then there's a larger risk of wrong information and preconceptions about the products. You know, if you can have an openness from the beginning, then the preconditions for having an acknowledgement of good product management increase".*

It is thus important for farmers that not only information and knowledge about the impacts and effects of the products themselves become available, but also about how the products are

produced and the implications of the production processes. Information about all aspects are considered important to get a full and objective picture of the benefits and issues with the products. As argued by P.8:

> "*It's like, the production of this, well I don't know if you know how this will industrially work, is it local or will it be in two places in the country or are there many transportations and everything, you know, we must start like any other industry by looking at the footprint we make and how much energy that can really be used".*

P.1 made a similar argument in stating that:

> *"And then it can't be like you'll like incinerate sludge or purify it so that you'll get a problem with an energy use that is unrealistic and maybe emissions through the air when you incinerate and so on, so that the process itself can't be too, what can I say, harmful to the environment, you know, so that harm is done in another way instead".*

Essentially, an important factor for farmers is that phosphorus fertilizers produced from sewage sludge are not subjected to the controversial and often shifting opinions regarding the safety of using them in a way that directly applied sewage sludge has been. The current opinions and attitudes towards sewage sludge are perceived as lacking scientific foundation, which should be avoided when it comes to new phosphorus fertilizers produced from sewage sludge. Therefore, a request is that extensive scientific research is conducted and that information is made available about the products and the technologies used to produce them. This in order for the farmers' customers in particular to be able to form scientifically based opinions and positions on phosphorus fertilizers produced from sewage sludge.

3.2 Features of the products

A crucial factor that farmers take into consideration when choosing a fertilizer is how it is composed, i.e. what features it possesses. it is therefore important that phosphorus fertilizers

produced from sewage sludge possess similar features to the fertilizers farmers use today. As argued by P.5:

> *"You always come back to pretty basic, like management, user-friendliness. Because if you're going to switch from a product that many have used for many years to a new product, then it can't be too cumbersome to do that switch. So, if you can compose it in a way that resembles the products used today, then it´s much easier".*

Most farmers articulated a wish for new phosphorus fertilizers to have similar features to the mineral fertilizers they currently use. As argued by P.4: *"Most machines are built for mineral fertilizers today, so it should preferably be something that can be handled just as easy."* P.3 articulated the same preference when stating that: "*I wish that it would be a product that resembles mineral fertilizers so I could spread it with my own fertilizer spreader, that's the wish from my part".* One of the most valued features with mineral fertilizers is what P.7.1 referred to as *"good spreading quality"*, i.e. that the fertilizer comes in a form that is possible to spread on the fields using a preferred technique and with equipment farmers already possess. This was clearly articulated by P.5: "*Well, today we use band application for a lot of the phosphorus we use and we control the different fertilizers so that a lot of the phosphorus is band applied in connection with sowing and less phosphorus is spread widely* [through broad spreading] *…".* At a later stage of the interview, P.5 elaborated on the desired form a fertilizer should have:

> "*So, if you speculate that it could have any form, that is granular or liquid or whatever it is, can I use it then you come back to the technique again but for the actual phosphorus, can I place* [paus for reflection]. *Is it a fertilizer that I with a granulate or in liquid form can place in connection with sowing in the soil close to the core, then it's a brilliant area of use, in many crops. So, in the best of worlds, then granulate, granulated form is the best, that's like option one".*

A product in liquid form was also articulated as a possibility by P.7.2, who explained that: *"We have started using liquid fertilizers with nitrogen this year … but if you can get it* [read phosphorus] *in a liquid product, then you spray it and it also becomes available for the plant".*

As illustrated above, it is important for farmers that the products are composed in a way that is easy to spread, preferably with currently used techniques and machinery. Moreover, as touched upon by P.7.2 above, another important feature is that the phosphorus comes in a form that is plant available, i.e. that the phosphorus is not bound to other components in the product that makes it difficult for the plant to access the phosphorus. As explained by P.8: *"Yes, and then of course, the phosphorus must come in a form that is plant available. Because it's like I said before, I know that other substances have been added to, like, precipitate the phosphorus and it must not be too difficult to dissolve later".* By "*substances"*, P.8 refers to substances that wastewater treatment plants add to the passing sewage water in order to capture the phosphorus. The most commonly used substances contain iron (Fe) and aluminium (Al), which bind the phosphorus into iron- and aluminium phosphates that are mineralized slowly or not at all in the soil (Cohen & Kirchmann 2013; Linderholm 2011). As explained by Linderholm (2011), depending on a soil's microbial features and the plants' ability to exude acids from its roots, the soil has varying abilities to convert phosphorus that is organically or chemically bound to e.g. Fe and Al into phosphate ions available to the plant in the soil solution. It is thus difficult to assess how much of the phosphorus in directly applied sewage sludge that is plant available, which is an insecurity that farmers wish to avoid to the extent possible. As argued by P.5: *"Well it must not be like it fixates in the ground first and it takes time before it, that might on the other hand be good for the next crop, but I would like that the actions I take now are beneficial there and then".* A similar request was expressed by P.2 when responding to the first interview question (see Appendix I) '*could you as detailed as possible describe your thinking when choosing a phosphorus fertilizer?*': *"Well, it must be water soluble so that it's available to the plant, so that it doesn't lie to the following year or something. That it's plant available, you know".*

In short, farmers expressed a need for phosphorus fertilizers produced from sewage sludge to have similar physical and chemical features to phosphorus mineral fertilizers, so that they can be spread with the same techniques and machinery used today. This in order to avoid that the process of switching to a new product becomes too cumbersome. Moreover, the phosphorus must be plant available, since farmers wish to avoid that the phosphorus comes in a form that is

difficult for the soil to dissolve, as could be the case for phosphorus in directly applied sewage sludge.

3.3 Price of the products

The price of phosphorus fertilizers produced from sewage sludge was a central topic in most interviews with the participating farmers. Some farmers referred to the price as the most important factor when considering purchasing a fertilizer. For example, P.6 argued that:

> *"Well, the price is always inevitable. And that's the first thing that the farmer will ask, how much does it cost? Then the next question will be if it fits in his machine, if it's possible to use. I believe that for a new product, it seems as if one thinks in a reversed way. And then when you have like, is it even economically feasible to use it? And can I use it then you perhaps start thinking, well, how plant available is it?"*

A similar argument was made by P.4: "*Well, since we have such a tight economy, a competitive price is a must. Unfortunately, we don't have the margins for higher prices compared to today's prices".* When asked to clarify what *"today´s prices"* mean, P.4 explained that: "*Well, it's always in relation to mineral fertilizers, that's basically what sets the price level*". P.6 made a similar statement:

> *"So far, the majority of my phosphorus, that is fifty percent or more, comes from mineral fertilizers, so you could say that that's what I consider being the most expensive, I probably won't buy anything more expensive than that. So that is probably the biggest on the market and is hence comparable".*

Through statements like those presented above, it became clear that the price is a determinant factor when considering a new phosphorus fertilizer. Moreover, phosphorus mineral fertilizers are considered as setting the price ceiling on the market, which is why farmers would not be willing to pay more for a phosphorus fertilizer produced from sewage sludge than for a phosphorus mineral fertilizer. As argued by P.1: "*Phosphorus today costs about twenty crowns*

[read SEK] *per kilo and I would then be willing to pay twenty crowns per kilo for phosphorus that is extracted* [from sewage sludge]. *And if there is an extraction cost that is higher, then that will have to fall on society".* Much like P.1's argument, some participants argued passionately about society having a common responsibility to keep phosphorus fertilizers produced from sewage sludge at a price level that makes them economically feasible for farmers to obtain. These arguments are based on the notion that society as a whole is responsible for the existence of sewage sludge and therefore has a collective responsibility to turn it into something useful. Some farmers argued that they do society a favour by using sewage sludge as a fertilizer on their fields, since there is no other use for it in its current form. For this reason, it is their opinion that the sewage fees that companies and households pay for sewage waste water treatment should be used to contribute to keep phosphorus fertilizers produced from sewage sludge at an acceptable price level. As argued by P.8:

> "*I don´t want to end up in a situation where agriculture has to pay for this, you know, there is so much money involved in sewage sludge. We all pay sewage fees so it should kind of be covered by that. … it must not become like a gold mine of what they are going to do with the sludge in any way, because the sludge is not agriculture´s problem, but the problem of the whole society, damn it!*".

When asked to clarify the argument about agriculture not having to pay for it, P.8 explained*:*

> *"Well of course we should pay for the phosphorus, but it must not be like the price they want to take is like* [paus for reflection]. *If it's a clean phosphorus fertilizer then it has a value, the same value as any other phosphorus that is really a bit too expensive, you know? So that we´ll get something for free is perhaps a bit stupid to think, but if we* [read agriculture] *in the end is a place that has to take care of it* |read sewage sludge] *because it needs to go into the soil, then we're doing society a favour, that´s what it's like today, we're doing society a favour when we receive it".*

P.7.2 made a similar argument when stating that:

> "*To be blunt, today we don´t pay for the sludge and we pay nothing for the delivery. So, it must not be like society makes money out of selling a phosphorus fertilizer to us, but it should be practically free. Because it's more work for us, we take care of a phosphorus that, where else should we put it?".*

When asked to clarify what is meant by society not making money out of selling a phosphorus fertilizer, P.7.2 responded*:*

> *"Well, I don't think it should, today they're just happy to get rid of it* [read sewage sludge]. *You could say that we, the waste that society contributes with has already been payed for, so to speak. Today you pay your taxes or I don´t know where you pay but probably with taxes you pay for the waste you have".*

As illustrated by the arguments made by P.8 and P.7.2 above, some farmers feel that society should not turn a substantial profit from the same sewage sludge it was previously eager to get rid of because it now has found a way to turn it into a new product that potentially has a commercial value. Although not explicitly articulated, yet implicitly evident, "society" in this scenario refers to the municipal governments, which are the principals in charge of waste water treatment in Sweden, and thus the collector of sewage fees. In other words, some farmers suggest that the fees payed to municipal governments for sewage treatment should be used to help keep the price for phosphorus fertilizers produced from sewage sludge at an acceptable level, i.e. below that of phosphorus mineral fertilizers.

To summarize, farmers consider the price to be a determinant factor when purchasing a fertilizer. Phosphorus mineral fertilizers are considered as setting the price ceiling on the market, meaning that farmers are not willing to purchase phosphorus fertilizers produced from sewage sludge if they exceed the price of phosphorus mineral fertilizers. Moreover, due to the societal service that farmers provide by using sewage sludge in its current form, society has a responsibility to repay that service by keeping prices for refined phosphorus fertilizers produced from sewage sludge at a level where they are economically feasible for farmers to obtain.

4. Discussion

The inductive thematic analysis revealed three factors influencing farmers willingness to use phosphorus fertilizers produced from sewage sludge: (1) Scientific knowledge about the products; (2) Features of the products; and (3) Price of the products, as illustrated in Chapter 3 above. The purpose of this chapter is to put the identified factors, as well as the reasoning behind them, into a larger perspective by discussing how the government could take these into consideration during its assessment of technologies and products that could replace directly applied sewage sludge. It will do so by initially discussing the three factors individually, after which a collective recommendation on how the government could take these factors into consideration will be formulated.

4.1 Discussion about the three factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge

Starting with the first identified factor, *Scientific understanding about the products,* the participating farmers articulated frustrations about their customers basing their opinions on directly applied sewage sludge on the popular opinion rather than on scientific facts. This is perceived as contributing to customers´ often shifting opinions regarding the safety of using sewage sludge as fertilizer, which make farmers fear that they might not be able to sell their produce when customers change their opinions. Thus, in order for refined phosphorus fertilizers produced from sewage sludge to become relevant options, it is imperative for farmers that these products do not become subjected to the same controversy as to the safety of using them as directly applied sewage sludge has been. Farmers believe that the best way to avoid such controversy is that extensive scientific research is conducted and that information is made available about the products and the technologies used to produce them.

The perception that farmers´ customers, i.e. food companies, lack scientific foundation for their opinions regarding the safety of using sewage sludge as fertilizer is a crucial factor for the government to consider during the process of turning sewage sludge into refined phosphorus fertilizers. As previously mentioned, food companies are concerned about the content of

potentially hazardous substances in the forms of *inter alia* heavy metals and organic pollutants in sewage sludge, and the consequences these could have for soils, plants and humans (see Berglund 2001; Carlsson 2003). While there is no secret that sludge contain these substances, research made to measure the effects and consequences of sewage sludge when applied to arable fields contradict the legitimacy of food companies' concerns in some respects. For example, an extensive research project was conducted between 1981 and 2014, measuring the prevalence of metals in crops and soils fertilized with sewage sludge (see Andersson 2015). The results of 33 years of field tests showed no difference in metal uptake between crops that had been fertilized with sewage sludge and crops that had not. Moreover, no statistically significant differences of Cd-rates were detected in soils, while slightly higher rates of Cu, Zn and Hg were detected in soils fertilized with sewage sludge. However, these rates have fluctuated over the years and has stayed well below the regulated thresholds for metals being allowed to be added to soils via sewage sludge application (see SNFS 1994:2 for thresholds). Moreover, in an article compiling results of eleven field studies made on the prevalence of organic substances and drug residues in crops and soils fertilized with sewage sludge, Hörsing (2018) reaches the conclusion that the rates measured in soils and plants pose no danger to humans or the environment.

Based on these findings, it appears as if farmers´ perceptions about their customers' opinions are warranted to some degree. Considering this tendency for food companies to overlook scientific results about the safety of using directly applied sewage sludge, extensive scientific research and information made available on the effects and implications of the refined phosphorus fertilizers produced from sewage sludge and the processes used to produce them, as suggested by farmers, might not be sufficient measures for ensuring that the products do not become subjected to the same controversy and volatile opinions as directly applied sewage sludge has been. For this reason, the government should consider taking a more active role advocating for the safety of using the products it deems relevant to replace directly applied sewage sludge with, and use scientific research results to support this advocacy. In order to minimize the risks of preconceptions forming about the products, efforts should be made to convince food companies that refined phosphorus fertilizers produced from sewage sludge are not simply repackaged

versions of directly applied sewage sludge, but safe fertilising products produced by phosphorus available in the societal circulation.

The second identified factor, *Features of the products*, is about farmers expressing a need for phosphorus fertilizers produced from sewage sludge to be composed in a way that resembles mineral fertilizers, so that they can be spread with the same techniques and machinery used today. A product in granulate- or liquid form was requested for this purpose. Resemblance to currently used mineral fertilizers was requested in order to avoid that the process of switching to a new product becomes too cumbersome. Moreover, the phosphorus must be plant available, since farmers wish to avoid that the phosphorus comes in a form that is difficult for the soil to dissolve and thus for the plant to access, as could be the case for phosphorus in directly applied sewage sludge.

Farmers requesting that phosphorus fertilizers produced from sewage sludge possess the same features as mineral fertilizers is not surprising. As stated by Wittgren et al. (2017), mineral fertilizers have physical and chemical features designed to accommodate the requests of the market, making it quite self-explanatory why participants would request these features. For this reason, it is reasonable to assume that the governmental investigation will have no issue finding technologies capable of producing refined phosphorus fertilizers from sewage sludge that possess these features. In fact, previous investigations and research made on the subject has found technologies capable of producing, *inter alia,* granulated products with plant available phosphorus from incinerated sludge ash (Tideström et al. 2009; Jonsson 2015), meaning that products accommodating to farmer´s requests on psychical and chemical features already exist on the market.

When it comes to the third identified factor, *Price of the products*, farmers consider the price to be a determinant factor when purchasing a fertilizer. Phosphorus mineral fertilizers are considered as setting the price ceiling on the market, meaning that farmers are not willing to purchase phosphorus fertilizers produced from sewage sludge if they exceed the price of phosphorus mineral fertilizers. Moreover, due to the societal service that farmers consider

themselves providing by using sewage sludge in its current form, farmers feel like society has a responsibility to repay that service by keeping prices for refined phosphorus fertilizers produced from sewage sludge at an acceptable level, and suggest that sewage fees payed to municipal governments for sewage waste treatment could be used to do so.

It is thus imperative for the government to ensure that the implemented technologies for precipitating phosphorus from sewage sludge generate products that can be sold on the market for prices below that of phosphorus mineral fertilizers. If production costs result in refined phosphorus fertilizers having to be sold at higher prices, the government should consider implementing a subsidization scheme for these products. SEPA concluded in a report from 2013 that refined phosphorus fertilizers produced from sewage sludge generally are more expensive than imported phosphorus mineral fertilizers (Naturvårdsverket 2013), which suggest that subsidies might have to be implemented in order to make refined phosphorus fertilizers produced from sewage sludge attractive for farmers. However, the current governmental investigation will have to be used as grounds to determine such a necessity, seeing that technological advancements made in the six years since SEPA released its report could have changed conditions on the market. If subsidies should become necessary, it is reasonable to assume that they will be financed by state funds in the same way as e.g. pharmaceuticals are, rather than through municipal sewage fees, as suggested by some farmers. However, as stated by The Swedish Water and Wastewater Association, sewage fees are likely to be increased to be able to finance the operating costs for technologies used to produce the products (Svenskt Vatten 2013).

4.2 Recommendations to the Swedish government

Based on the three identified factors influencing farmers willingness to use phosphorus fertilizers produced from sewage sludge, this thesis recommends the Swedish government to take the following into consideration while assessing products and technologies that could replace directly applied sewage sludge:

- A prerequisite for a greater recycling rate of phosphorus in sewage sludge when direct application becomes prohibited is that Swedish farmers are willing to use the phosphorus

fertilizing products generated by the techniques the government decides to implement. For this reason, the government should take the factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge into serious consideration when assessing technologies and products to replace directly applied sewage sludge with.

- In order to avoid that phosphorus fertilizers produced from sewage sludge become subjected to the same controversy surrounding the safety of using them as directly applied sewage sludge has been, the government should advocate for the safety of using these products. It should support its claims with extensive scientific research results on the implications and effects of the products and the processes used to produce them. Moreover, in order to encourage a climate in which opinions on these products are formed on a scientific foundation, efforts should be made to make scientifically based information available about the products and the processes used to produce them.

- Considering farmers requesting phosphorus fertilizers produced from sewage sludge to possess physical and chemical features similar to mineral fertilizers, the government should to the extent possible strive to implement technologies capable of producing products that accommodate these requests.

- Due to farmers expressing a reluctance to purchase phosphorus fertilizers produced from sewage sludge that exceed the price for phosphorus mineral fertilizers, the government should implement technologies that can produce products that can be sold on the market at a price level below that of phosphorus mineral fertilizers. If production costs or other factors should cause a need for these products to be sold at a higher price, the government should consider implementing a subsidization scheme for these products.

5. Critical discussion about research methodology

This chapter will discuss the research methodology used in this thesis in a self-critical manner. It will first discuss the process of data collection, followed by a discussion about the analysis of data.

5.1 Data collection

As previously mentioned, data has been collected through semi-structured interviews with nine Swedish conventional farmers from eight different farms. The question guide was carefully designed to not include leading questions, in order to avoid that any preconceptions the author might have would influence the participants' answers. With that being said, in the second interview question (*Which impact do you consider society's opinions having on your choice of phosphorus fertilizers?)*, the respondents were asked to reflect over a factor (society´s opinions) they might not have thought of as a factor if not asked the question, which is why it potentially could be interpreted as a leading question. However, the question is phrased so that the participants themselves can determine which actors to include in the term *society*, as well as what the opinions of those actors might be. After having identified these opinions, the participants could then reflect on how, if at all, they impact their choice of phosphorus fertilizers.

5.2 Data analysis

Seeing that the data have been analysed using an inductive approach, something should be mentioned about the author´s ability to ignore its preunderstandings about the topic during the thematic analysis. As argued by Alvehus (2013), it is difficult to claim that a strictly inductive analysis has been made, simply because it is hard to imagine that interpretations of data can be made independently of theoretical preunderstandings. With that being said, it is equally difficult to claim having conducted a strictly deductive analysis, because it is highly unlikely that interpretations of data can be made independently of the researcher (ibid). Thus, it cannot be asserted that the thematic analysis has been conducted in a strictly inductive manner. However, efforts were made to identify themes that truly reflect the data, without influences from the author´s theoretical preunderstandings. For example, conclusions from previously mentioned research by Berglund (2001) and Carlsson (2003) led to the expectation that customers accepting

phosphorus fertilizers produced from sewage sludge would be an important factor for farmers, which might have contributed to the identification of the refined theme *Acceptance of the products* (see Appendix IV) during the first stage of the fourth step in the analytical process (see section 1.2.2 above). However, after further review of the data, it became apparent that acceptance is not as important for farmers as scientific understanding about the products and absence of controversy regarding the safety of using them, which led to the identification of the final theme *Scientific understanding about the products* instead.

In essence, the author recognises that theoretical preunderstandings could have influenced the results of the inductive thematic analysis to some degree, despite efforts to exclude them.

Within this context, something should also be mentioned about the credibility of the results, i.e. if the identified themes truly reflect the story told in the data. A common approach for increasing credibility is to allow other researchers to analyse the data and identify themes as well, after which the level of agreement between all the identified themes are analysed (see Frith & Gleeson (2004) for an example). Due to time constraints, this approach has not been applied to this thesis, and the author recognises that this could negatively affect the credibility of the results to some degree, and would urge that more research is made on this topic in order to get a better understanding of the factors influencing farmers´ willingness to use phosphorus fertilizers produced from sewage sludge.

6. Conclusion

This thesis has focused on investigating the factors influencing Swedish farmers' willingness to use refined phosphorus fertilizers produced from sewage sludge. It has collected data through semi-structured interviews and analysed the data using inductive thematic analysis. The analysis identified three factors influencing farmers willingness to use phosphorus fertilizers produced from sewage sludge.

The first factor, *Scientific understanding about the products*, is based on the participating farmers´ expressed frustrations about their customers basing their opinions on directly applied sewage sludge on the popular opinion rather than on scientific facts. This is perceived as contributing to customers´ often shifting opinions regarding the safety of using sewage sludge as fertilizer, which make farmers fear that they might not be able to sell their produce when customers change their opinions. Thus, in order for refined phosphorus fertilizers produced from sewage sludge to become relevant options, it is imperative for farmers that these products do not become subjected to the same controversy as to the safety of using them as directly applied sewage sludge has been. Farmers believe that the best way to avoid such controversy is that extensive scientific research is conducted and that information is made available about the products and the technologies used to produce them.

The second factor, *Features of the products,* was identified since farmers expressed a need for phosphorus fertilizers produced from sewage sludge to be physically and chemically composed in a way that resembles mineral fertilizers, so that they can be spread with the same techniques and machinery used today. A product in granulate- or liquid form was expressed as a preference for this purpose. Moreover, the phosphorus must be plant available, since farmers wish to avoid that the phosphorus comes in a form that is difficult for the soil to dissolve and thus for the plant to access, as could be the case for phosphorus in directly applied sewage sludge. Similar features to mineral fertilizers was requested in order to avoid that the process of switching to a new product becomes too cumbersome.

The third identified factor, *Price of the products,* is about farmers considering the price to be a determinant factor when purchasing a fertilizer. Phosphorus mineral fertilizers are considered as setting the price ceiling on the market, meaning that farmers are not willing to purchase phosphorus fertilizers produced from sewage sludge if they exceed the price of phosphorus mineral fertilizers. Moreover, due to the societal service that farmers consider themselves providing by using sewage sludge in its current form, society has a responsibility to repay that service by keeping prices for refined phosphorus fertilizers produced from sewage sludge at a level where they are economically feasible for farmers to obtain.

The thesis recommends the Swedish government to implement technologies and refined phosphorus fertilizing products that accommodate these identified factors to the extent possible. This in order to improve the preconditions for an increased recycling rate of phosphorus available in sewage sludge.

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Appendix I: Question guide

The interviews were conducted in Swedish. See English translation of the interview questions in brackets.

1. Kan du så detaljerat som möjligt beskriva hur du tänker du kring valet av fosforgödselmedel?
   (*Could you as detailed as possible describe your thinking when choosing a phosphorus fertilizer?*)

2. Vilken betydelse anser du att samhällets åsikter har på ditt val av fosforgödselmedel?
   (*Which impact do you consider society's opinions having on your choice of phosphorus fertilizers?*)

3. Kan du så detaljerat som möjligt beskriva en situation där du kan tänka dig att använda fosforgödselmedel framställda av avloppsslam?
   (*Could you as detailed as possible describe a situation where you would consider using a phosphorus fertilizer produced from sewage sludge?)*

4. Hur tror du att andra personer som är i din situation skulle tänka kring användningen av fosforgödselmedel framställda av avloppsslam?
   (*How do you think other people that are in a similar situation as yourself would think regarding the use of phosphorus fertilizers produced from sewage sludge?)*

5. Är det något du vill tillägga eller något du anser att jag har missat i min frågeställning?
   (*Is there anything you would like to add or is there anything you consider that I should have asked but didn´t?*)

Appendix II: Information sheet to participants in interview study (in Swedish)

Som del utav min masterexamen i Agroekologi vid Sveriges lantbruksuniversitet (SLU) i Alnarp skriver jag en masteruppsats med titeln: *The preconditions for increasing phosphorus recycling from sewage systems in Sweden. A study of Swedish farmers' attitudes towards phosphorus fertilizers produced from sewage sludge.*

Bakgrund till studien

Sveriges regering undersöker just nu förutsättningarna för att införa ett förbud mot direkt-applicerat avloppsslam och ersätta det med tekniker som kan utvinna fosforgödselmedel ur slam utan att sprida miljö-och hälsofarliga ämnen (Dir 2018:67). En förutsättning för att den fosfor som finns tillgänglig i svenska avloppssystem ska kunna återvinnas genom fosforgödselmedel framställda av avloppsslam är att svenska lantbrukare är villiga att använda dessa produkter. Syftet med denna studie är således att undersöka vad svenska lantbrukare anser behövas, både av de slutgiltiga produkterna själva och på ett samhälleligt plan, för att fosforgödselmedel framställda av avloppsslam ska bli relevanta gödselalternativ.

Studiens preliminära forskningsfråga är: *Under which circumstances would Swedish farmers consider using phosphorus fertilizers produced from sewage sludge?*

För att besvara forskningsfrågan utförs intervjuer med lantbrukare i Skåneregionen för att undersöka vad dessa anser behövas, både av produkterna själva och på ett samhälleligt plan, för att fosforgödselmedel framställda av avloppsslam ska bli relevanta gödselalternativ.

Intervjuns upplägg

Författaren till uppsatsen kommer att ställa öppna frågor till deltagaren om hur denna tänker kring användningen av gödselmedel. Frågorna är utformade på ett sådant sätt att deltagaren uppmuntras till att utförligt beskriva sina tankar kring fosforgödselmedel i allmänhet och

fosforgödselmedel framställda av avloppsslam i synnerhet. Författaren kommer att utgå ifrån ett frågeformulär, men intervjun kommer till stor del bestå av följdfrågor till deltagaren baserade på vad denna berättar under intervjuns gång. Intervjun beräknas pågå ca 30–45 minuter.

Villkor för deltagande i studien

Deltagande i studien är frivillig och kompensation, monetär eller annan, utdelas inte. Deltagaren kommer att intervjuas av författaren till studien. Intervjun kommer att spelas in och transkriberas ordagrant. Den information som kommer fram under intervjun kommer ligga till grund för studiens resultat. Deltagaren förblir anonym då varken dennes eget namn eller dennes verksamhets namn kommer nämnas i studien. Detta för att den information som framkommer under intervjun inte ska kunna spåras tillbaka till deltagaren. Deltagaren har rätt till att innan, under eller efter intervjun välja att avbryta sitt deltagande, oavsett anledning. Deltagaren har vid förfrågan rätt till en kopia av både ljudinspelningen och transkriberingen av intervjun, liksom en kopia av den färdiga studien.

Den färdiga studien kommer att publiceras på *Epsilon*, SLU:s arkiv för studentarbeten, och på så sätt bli tillgänglig för allmänheten.

Kontaktuppgifter till studiens författare

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Appendix III: Candidate themes

Candidate themes
1. The product must be sustainable
2. The product must not be too contaminated
3. The phosphorus should be part of a closed-loop system
4. Low energy important in manufacturing process
5. Emissions from manufacturing process needs to be reasonable
6. The price of the product should be equal to phosphorus mineral fertilizers
7. The price of the product should be less than the price for phosphorus mineral fertilizers
8. There must be scientific certainty about the effects and side effects of using the product
9. The society should share the costs of phosphorus precipitation from sewage sludge
10. The product should have a low heavy metal content
11. The product should be easy to spread onto the fields
12. The phosphorus must be plant available
13. The use of the product must be approved by the custumers purchasing the crop
14. The prosphorus must be water-soluble
15. Society must be informed about phoshphorus recycling from sewage sludge
16. The product should be free from flame retardants
17. A supervisory body for the product/s should be implemented
18. The price must correspond to the potential risks with using the product
19. The product must be possible to store
20. The kadmium content should be as low as possible
21. The product must be free from drug residues
22. The product needs to be compatible with current machinery
23. The product should be odorless
24. The product should be free from microplastic
25. it is an advantage if the product comes in liquid or granulated form
26. The product must be stable and not crumble
27. It must not be cumbersome to change from currently used products
28. The price must compensate for the potential loss of buyers not accepting use of the product
29. There should be no risk that the use of the product can become politicized

Appendix IV: Refined themes

Refined themes	Candidate themes	Miscellaneous
Price of the products	6. The price of the product should be equal to phosphorus mineral fertilizers	28. The price must compensate for the potential loss of buyers not accepting use of the product
	7. The price of the product should be less than the price for phosphorus mineral fertilizers	18. The price must correspond to the potential risks with using the product
	9. The society should share the costs of phosphorus precipitation from sewage sludge	13. The use of the product must be approved by the custumers purchasing the crop
		17. A supervisory body for the product/s should be implemented
Content of the products	2. The product must not be too contaminated	23. The product should be odorless
	10. The product should have a low heavy metal content	
	12. The phosphorus must be plant available	
	14. The prosphorus must be water-soluble	
	16. The product should be free from flame retardants	
	20. The kadmium content should be as low as possible	
	21. The product must be free from drug residues	
	24. The product should be free from microplastic	
Usage of the products		
	11. The product should be easy to spread onto the fields	
	19. The product must be possible to store	
	22. The product needs to be compatible with current machinery	
	25. it is an advantage if the product comes in liquid or granulated form	
	26. The product must be stable and not crumble	
	27. It must not be cumbersome to change from currently used products	
Production of the products		
	1. The product must be sustainable	
	3. The phosphorus should be part of a closed-loop system	
	4. Low energy important in manufacturing process	
	5. Emissions from manufacturing process needs to be reasonable	
Acceptance of the products		
	8. There must be scientific certainty about the effects and side effects of using the product	
	15. Society must be informed about phoshphorus recycling from sewage sludge	
	29. There should be no risk that the use of the product can become politicized	

Appendix V: Final themes

Final themes	Candidate themes	Miscellaneous
Scientific understanding of the products	2. The product must not be too contaminated	28. The price must compensate for the potential loss of buyers not accepting use of the product
	10. The product should have a low heavy metal content	18. The price must correspond to the potential risks with using the product
	16. The product should be free from flame retardants	13. The use of the product must be approved by the custumers purchasing the crop
	20. The kadmium content should be as low as possible	17. A supervisory body for the product/s should be implemented
	21. The product must be free from drug residues	23. The product should be odorless
	24. The product should be free from microplastic	
	8. There must be scientific certainty about the effects and side effects of using the product	
	15. Society must be informed about phoshphorus recycling from sewage sludge	
	29. There should be no risk that the use of the product can become politicized	
	1. The product must be sustainable	
	3. The phosphorus should be part of a closed-loop system	
	4. Low energy important in manufacturing process	
	5. Emissions from manufacturing process needs to be reasonable	
Features of the products	11. The product should be easy to spread onto the fields	
	19. The product must be possible to store	
	22. The product needs to be compatible with current machinery	
	25. it is an advantage if the product comes in liquid or granulated form	
	26. The product must be stable and not crumble	
	27. It must not be cumbersome to change from currently used products	
	12. The phosphorus must be plant available	
	14. The prosphorus must be water-soluble	
Price of the products	6. The price of the product should be equal to phosphorus mineral fertilizers	
	7. The price of the product should be less than the price for phosphorus mineral fertilizers	
	9. The society should share the costs of phosphorus precipitation from sewage sludge	