Separation and acidification of digested animal manure

Properties of the future organic fertilizers

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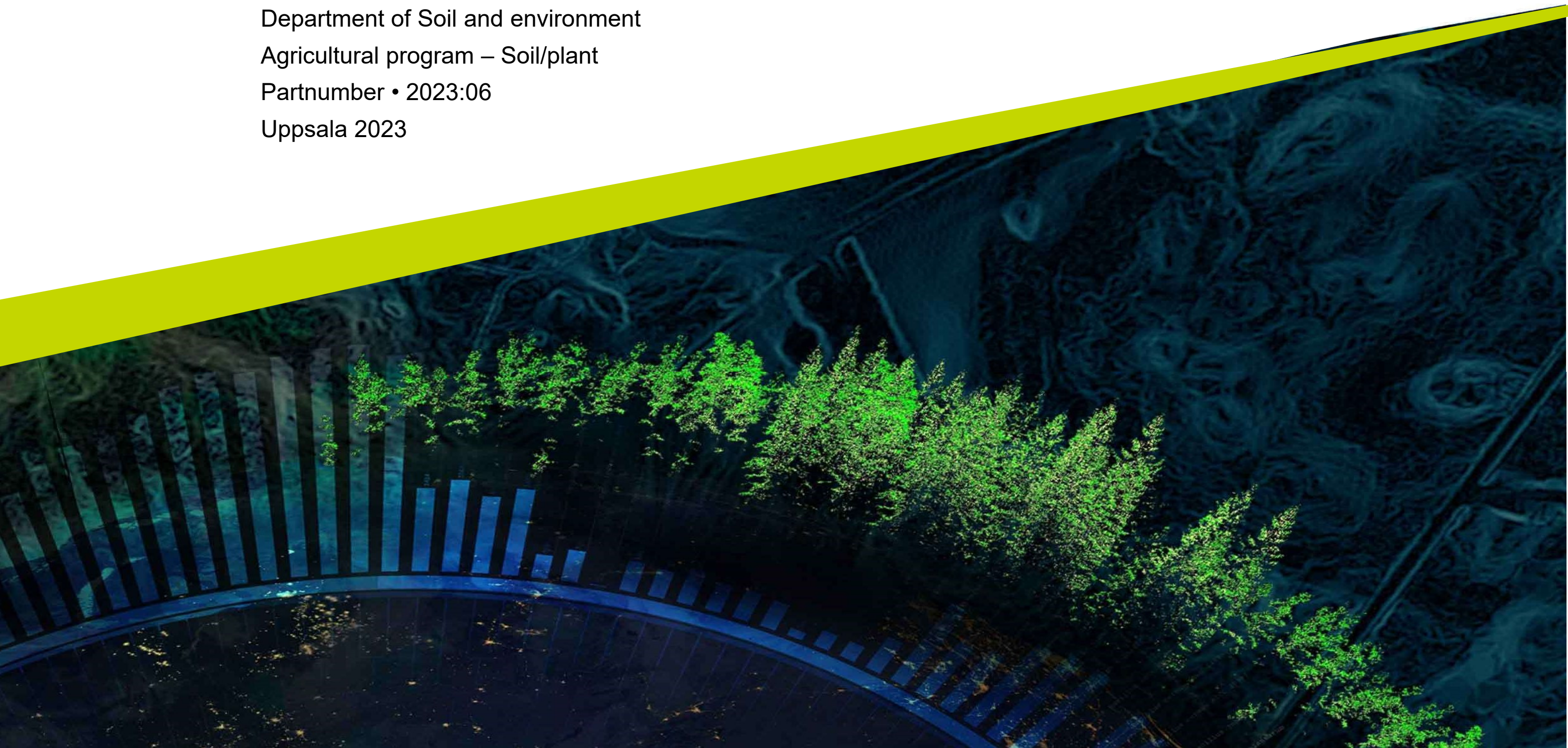

Separation and acidification of digested animal manure – properties of the future organic fertilizers

Separering och surgörning av rötad stallgödsel – egenskaper hos framtidens organiska gödselmedel.

Marie Björs

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Abstract

Agricultural areas with a high animal density contribute to eutrophication in waterbodies and seas worldwide due to accumulation of nutrients around animal farms. Animal manure is heavy and bulky, thus unpractical to transport long distances and new techniques have been developed to refine animal manure and make it easier to transport. In this paper mechanical separation of digested liquid animal manure was investigated, a method where the digestate is separated into a solid and a liquid phase. The solid fraction has a high phosphorus and carbon concentration as well as a high dry matter content, making it a good phosphorus fertilizer and easy to transport. The liquid fraction contains the main part of nitrogen and works well to spread on fields adjacent to the treatment facility. However, ammonium nitrogen in the liquid fraction risks being lost quickly to the atmosphere due to ammonia volatilisation. By lowering the pH of liquid fractions, the ammonia emission can be reduced. Two methods for lowering the ammonia emission were compared to see how lower pH might affect the mineralizing potential of nitrogen and carbon in the digested manure.

To investigate their fertilizer value, an incubation experiment was conducted with different fractions of digestate from a biogas plant in Kalmar Sweden. On the biogas plant, pig, cow, and poultry manure as well as food and slaughterhouse waste were anaerobically digested and the digestate was separated with a screw press. To potentially lower the ammonia emission, a part of the liquid fraction was plasma activated, which lowered the pH from 8.2 to 4.4. All the samples from Kalmar were transported to Uppsala for the incubation experiment. In Uppsala another fraction of the liquid fraction was acidified with sulfuric acids to pH 5.5. The different fractions, raw unseparated digestate, solid fraction, non-acidified liquid fraction, acidified liquid fraction and plasma activated liquid fraction was incubated for 44 days to measure mineral nitrogen concentration, mineralization rate of nitrogen and carbon dioxide emission. The mineral nitrogen concentration was analyzed on several occasions during the experiment by AgriLab in Uppsala. By plotting the change of mineral concentration over time, the mineralization rate could be calculated. In addition to the incubation, additional cups were prepared the same way and placed in glass jars with falcon tubes with 50 ml 0.5 M NaOH. The sodium hydroxide in the falcon tubes captured the emitted CO_2 which in turn could be estimated through titration with H_2SO_4.

In this experiment, the nitrification was delayed when the pH was lowered while a net-mineralization still occurred. The liquid fraction treated with sulfuric acid only had a delay for a few days and the mineralization rate was about the same as for the non-acidified liquid fraction. The plasma activated liquid fraction had a delay during the entire experiment (44 days) and the lowest net mineralization of all treatments. The plasma activated liquid fraction is probably still a good fertilizer due to the high initial nitrite/nitrate concentration compared to the other materials.

A farmers survey was incorporated in the thesis to see if any fertilizers produced might interest Swedish framers. The survey consisted of 22 questions about current and future use of organic fertilizers as well as positive and negative properties of the different organic fertilizers on the market. Most of the farmers in the survey wanted a fast release of nitrogen and phosphorus and considered carbon important in organic fertilizers. According to the incubation experiments, only the liquid materials had a net mineralization during the first 44 days, which gives a positive delivery of nitrogen to crops in addition to the initial content of ammonium nitrogen. However, these materials can contribute to soil compaction due to a higher water content. Soil compaction was an important factor which might hinder farmers to use organic fertilizers according to the survey. The solid fraction on the other hand is at low risk for soil compaction problems and had a high carbon and phosphorus concentrations. However, the solid fraction caused net-immobilization of nitrogen which lowers the nitrogen fertilizing value of this fraction.

Many farmers expresses that an organic fertilizer needs to be price worthy and must compete with easily available untreated manure that already is on the farm. The refined manure needs to have an added value like easily available nutrients, lower environmental impact, and lower contribution to soil compaction. For example, the solid fraction in this experiment might improve soil structure and increase phosphorus concentrations in phosphorus-poor soils. Additionally, the liquid fraction can be a good nitrogen fertilizer while lowering the phosphorus surplus in phosphorus-rich areas given that the solid fraction is transported away (i.e., better for the environment). Finally, this experiment showed that separated manure can be an attractive for farmers depending on the farms nutrient need.

Keywords: Digestate, Eutrophication, Farmers' survey, Plasma activation, Screw press

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Abbreviations

AD	Anaerobic digestion
A-LF	Acidified liquid fraction of digestate
$BaCl_2$	Barium chloride
BSAP	Baltic sea action plan
C	Carbon
Ca	Calcium
CH_4	Methane
CO_2	Carbon dioxide
CO_3^{2-}	Carbonate
Cu	Copper
D	Digestate
DM	Dry matter
EU	European Union
Fe	Iron
H_2CO_3	Carbonic acid
H_2O	Water
H_2SO_4	Sulfuric acid
HCl	Hydrochloric acid
HCO_3^-	Bicarbonate
HNO_2	Nitrous acid
HNO_3	Nitric acid
K	Potassium
LF	Liquid fraction
LRF	The Federation of Swedish Farmers (Lantbrukarnas riksförbund)
Mg	Magnesium
Mn	Manganese
$M_x$digestate	Concentration in digestate
$M_x$solids	Concentration in solid fraction
N	Nitrogen

N_2	Dinitrogen
N_2O	Nitrous oxide
H_2O_2	Hydrogen peroxide
Na	Sodium
NaOH	Sodium hydroxide
NH_3	Ammonia
NH_4^+	Ammonium
O_2	Dioxygen
P	Phosphorus
P-LF	Plasma activated liquid fraction of digestate
S	Sulphide
SEx	Separation index
SF	Solid fraction
SLU	The Swedish university of agriculture (Sveriges lantbruksuniversitet)
T1	Tank 1
T2	Tank 2
T3	Tank 3
T4	Tank 4
T5	Tank 5
VFA	Volatile fatty acid
WC	Water Closet
Zn	Zinc

1. Introduction

Animal manure has favorable properties as fertilizer since it improves soil structure and increases the water holding capacity (Petersen et al. 2007; Eliaspour et al. 2020). The manure contains essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as several micronutrients (Petersen et al. 2007; Akram et al. 2019; Eliaspour et al. 2020). However, the nutrient concentration in the manure does not always match the crop's needs. Manure application to the field can lead to a surplus or deficit of one of the other nutrients depending on the yield, soil characteristics, and manure source (Akram et al. 2019). Through excessive manure application, N surpluses quickly lead to leaching or gaseous emission, which can end up in lakes and rivers (Oenema et al. 2001) and reduce water quality. When P is over-applied, on the other hand, it is mainly accumulating in the soil. If the over-application continues over several years, the risk for P leaching increases due to the saturation of P in the soil. Thus, the P leaching potential depends on the history of the P application (Svanbäck et al. 2019). The Baltic Sea has significant problems with eutrophication due to human activities. Around 97 % of the Baltic Sea has a bad eutrophication status. The situation has improved over the years, but it still poses a big problem in the sea's ecosystem (HELCOME 2018). The eutrophication, coupled with increased temperature and the Baltic Sea's natural tendency for oxygen deficit, enhances the area of hypoxia and has dramatically changed the ecosystem (Carstensen et al. 2014).

An obstacle in reducing the release of nutrients into the Baltic Sea is the specialization of farms. Specialization has led to a division of whole regions where some have very high animal density which results in nutrient surpluses and over-application of nutrients. At the same time, some areas have very few animals and import a large amount of mainly synthetic fertilizers (Oenema et al. 2001). In general, areas with high animal densities often have nutrient surpluses, while crop-producing regions often have nutrient deficits (Gerber et al. 2013; Akram et al. 2019; Svanbäck et al. 2019). The specialization originated in the need to produce more food during the late 19th century for the growing population. Many new techniques were invented to produce more food, and one of the most successful was the Haber Bosch method which was developed in the early 20th century. The Haber Bosch method is a technique that makes mineral N from dinitrogen (N_2) in the air. This method allowed agriculture worldwide to produce more and foremost cheap food. Today about 50 % of the protein supply comes from ammonia-N fertilizers, mainly produced by the Haber Bosh method (Dawson & Hilton 2011). However, the Haber Bosch method requires energy, and N fertilizer production uses around 1-2 % of the world's energy consumption (Dawson & Hilton 2011; Bogaerts & Neyts 2018). At the same time, manure is sometimes disposed of as waste (Oenema et al. 2001; Graves et al. 2019; Svanbäck et al. 2019), meaning that there are nutrients that are not utilized, creating a net nutrient surplus around the world. Indeed, there is a vast potential in recycling the nutrients in organic waste (i.e., animal manure, crop residues, or sewage sludge) to produce more food for the future population (Dawson & Hilton 2011) and lower the nutrient surpluses.

Many new techniques are being developed to be able to reuse and redistribute animal manure to nutrient-poor areas and thus lowering the nutrient surpluses in nutrient-rich areas in a sustainable and environmentally friendly way (e.g., Kai et al. 2008; Flotats et al. 2011; Bogaerts & Neyts 2018; Jardali et al. 2021). In Denmark, manure is acidified to lower the emission of ammonia (NH_3) and thus N loss, in order to maintain manures N fertilizing value and reduce associated environmental risks (Kai et al. 2008; Pantelopoulos et al. 2016). A company based in Norway aims to reduce the N loss and boost the manure with nitrate (NO_3^-) by using plasma activation (Graves et al. 2019). Further, by transporting the manure from farms or areas with nutrient surpluses to regions with nutrient deficits, the nutrient load in the environment can decrease (McCrackin et al. 2018; Akram et al. 2019). But transporting the manure can be expensive, and different types of separations have been suggested to transport the excess manure more easily e.g., in forms where the water has been removed (Hjorth et al. 2010; Flotats et al. 2011). Lastly, it is still important that the manure is spread according to the crop and soil needs (Petersen et al. 2007; Svanbäck et al. 2019).

The interest in using processed manure exists, but there can be a problem for crop producers to get a hold of the fertilizers. The problem is that they live too far away from animal farms or manure processing facilities (e.g., anaerobic digestion plants). To increase the nutrient redistribution and use of processed organic fertilizers, they must be priceworthy, easy to get a hold on, and work with the current machine parks. But only a few studies have investigated these questions, so a lot is unknown about farmers' willingness to use organic fertilizers (Case et al. 2017).

1.1 Aim

This project focused on the separation of manure to be able to redistribute it from nutrient-rich areas to areas with nutrient deficits. An incubation experiment was conducted to investigate nutrient release and concentrations in the soil after applying different organic materials. The focus of the incubation study was on liquid fractions from anaerobically co-digested manure produced at MORE biogas in Kalmar. The liquid fractions were acidified and plasma-activated to decrease the N loss from the materials. Beyond the characteristics of the separated and treated materials, this study aimed to investigate the interest in these types of organic fertilizers among Swedish farmers. This thesis is a part of a bigger project, Circular NP, where the goal is to develop new fertilizers and investigate the market for separated manure and digestate with the hope that it will lower the nutrient surpluses (BalticWaters2030 n.d.). This study aims to answer:

- How is the nitrogen in separated solid and liquid fractions released in soil?
- Does acidification or plasma activation of the liquid fraction change the release N dynamics?
- Does any of the organic fertilizers produced and used in this study match the needs and preferences of Swedish farmers?

2. Background

2.1 Manure as fertilizer

The nutrient concentration of animal manure can often be estimated trough information about the feed intake, water intake and type of animal, it's age and if it's a high performing/producing animal (Jönsson et al. 2004; Perazzolo et al. 2016). However, when handling and storing the manure, many losses occur, mainly through N loss (Graves et al. 2019; Svanbäck et al. 2019). Nitrogen in inorganic forms in the animal manure can very quickly transform into ammonia (NH_3) and nitrous oxide (N_2O), which can vaporize into the atmosphere (Oenema et al. 2001). Manure has a different nutrient composition depending on the feed intake. A fiber-rich, and thus hard digested feed will have a large amount of the nutrients incorporated in the organic material. An easily digestible feed will have higher concentrations of inorganic nutrients. When organic material is used as fertilizers, the inorganic nutrients will be directly available for crop uptake but will also more easily be lost than nutrients bound in organic form (Jönsson et al. 2004).

The loss of NH_3 and N_2O depends on the manure collection and storage system in the animal housing. Often any kind of system that minimizes the manure's contact with oxygen, i.e., anoxic conditions, is good at reducing the N loss (Oenema et al. 2001). During storage, it is essential to cover the manure to maintain the anoxic conditions (Gerber et al. 2013). Further, by injecting or incorporating the manure into the soil shortly after application, the NH_3 loss is reduced (Oenema et al. 2001)

Other nutrients in the manure like P and K are not as easily lost to the environment as N. When P is applied to the field over the crop's needs, it accumulates in the soil. After years of over-application, the soil can become saturated with P, which leads to leaching to the ground- or drainage water. Once a field has reached high P concentrations, it takes several years until it starts to decrease even if no P is applied. Thus, the field can have high P concentrations and an increased risk of P leaching for a long time (Le Noë et al. 2017; Svanbäck et al. 2019).

2.2 Treatment of manure

2.2.1 Anaerobic digestion in biogas plant

During anaerobic digestion (AD), the organic material is degraded in anoxic conditions, and methane (CH_4) is produced, which can be collected and used as energy (Albihn & Vinnerås 2007). Anaerobic digestion is a sensitive system, but because CH_4 can be collected and used as an energy source, its positive environmental qualities outweigh the complexity (Albihn & Vinnerås 2007). In 2020, 191 TWh of biomethane and biogas were produced in Europe. Biogas production is estimated to increase over the following years and is expected to meet 30-40 % of the European gas need by 2050 (European Biogas Association 2022).

Anaerobic digestion effectively mineralizes organic N, increasing the NH_4^+-N content. During degradation, the organic material content decreases, and pH rises partly due to the degradation of fatty acids (Petersen et al. 2007; Möller & Müller 2012). The degraded material is called digestate and can be used as fertilizer and for soil improvement (Insam et al. 2015). Anaerobic digestion effectively lowers the CH_4 losses from the manure handling system. Animal manure has a lower biogas yield when used as feedstock compared to energy crops, especially cattle manure. The methane yield can improve via the cow's diet but never reach the respective yields of energy crops; therefore, AD of solely manures is relatively uncommon, and most AD plants co-digest manures with other materials with high methane potential (Amon et al. 2007).

The mineralization of N and the high pH in digestate can lead to larger N-losses due to NH_3 volatilization compared to raw, undigested manure. The ammonia loss increases eutrophication and lowers the amount of plant-available N. Therefore, it's essential to cover the storage of digestate and incorporate the digestate in the soil shortly after application to reduce N loss (Petersen et al. 2007; Möller & Müller 2012; Styles et al. 2018).

Different temperatures in AD treatments give various levels of sanitation. A higher temperature at 50-55 ˚C is often enough to be able to spread the manure on arable land (according to EU regulations). A mesophilic temperature at 30-37 ˚C is usually insufficient to reach satisfactory sanitation levels. However, mesophilic temperatures can reach adequate sanitation if the NH_4^+-N concentration is high enough. Higher NH_4^+-N concentration is achieved with higher protein content in the material (e.g., pig manure) (Albihn & Vinnerås 2007).

2.2.2 Acidification of manure

Acidification lowers the pH of the manure and can reduce NH_3 volatilization from manure or digestate. When the pH is lower than 7 the equilibrium between NH_4^+ and NH_3 changes, with a higher fraction of NH_4^+. Ammonia opposed to NH_4^+ is volatile and by lowering the pH, less N is lost as NH_3 (Kai et al. 2008; Regueiro et al. 2016). When accounting for the higher N content in the acidified slurry due to lower NH_3 emissions, acidification can give the slurry a higher fertilizing value. Usually, a pH of 5.5 is enough to lower the NH_3 emission significantly (Sørensen & Eriksen 2009), which is the target pH in commercial acidification systems (Fangueiro et al. 2015).

The slurry can be acidified during different steps of the manure handling chain. Firstly, acidification can occur daily or weekly in the animal housing, often seen as long-term acidification. Secondly, acidification can occur in the storage tank, which can be both long-term and short-term depending on the timing. In acidification in the storage tank, there is a lot of foam formation which is one of the main downsides of this process. Lastly, another short-term acidification occurs during field application, where acid is added to the manure shortly before soil application (Fangueiro et al. 2015).

Several acids can be used to lower the pH of manures, and they all differ in how they affect the materials. Sulfuric acid (H_2SO_4) is a strong acid and is not required in large amounts to reach the target pH (Fangueiro et al. 2009; Perazzolo et al. 2016; Regueiro et al. 2016). Sulfuric acid and hydrochloric acid (HCl) are more effective in lowering the NH_3 emission than nitric acid (HNO_3) and lactic acid (Fangueiro et al. 2015). Acidification with HNO_3 has the potential to increase denitrification, i.e., formation and loss of N_2O (Vandré & Clemens 1997). But if the pH is lower than 5.5 in HNO_3 amended slurry the N_2O loss is decreased (Stevens et al. 1997). The slurry pre-treated with AD has a higher buffer capacity than untreated manure and requires more acid. Sigurnjak et al. (2017) added 27 g of H_2SO_4 to 1 liter of digestate to acidify it to pH 5.5, while only 18 g was required to lower the pH of raw pig slurry. The buffer capacity is due to higher concentration of bicarbonates in AD-treated slurry. The higher concentration of bicarbonates is due to the degradation of volatile fatty acid (VFA) in the manure (Masse et al. 2008; Perazzolo et al. 2016).

Acidification can also affect the availability of nutrients in the manure as well as its color and texture. Inorganic compounds in the animal manure like iron (Fe), P, calcium (Ca) and NH_3 are affected by changes in pH. These inorganic compounds could either be dissolved, bound to particulate matter, or precipitated. Precipitates like struvite ($MgPO_4NH_4$) and calcium carbonate ($CaCO_3$) is dissolved at lower pH and releases nutrients like Ca and P (Fangueiro et al. 2015). However no change is expected in K content, organic N and nitrate (NO_3^-) content of acidified slurries compared to untreated slurries (Fangueiro et al. 2009). Further, no changes in composition of organic materials are expected, especially during short term acidification. With long-term acidification, there may be a higher proportion of larger undissolved organic compounds in acidified slurry compared to untreated slurry. Acidified slurry can have a lower viscosity than untreated manure due to particle aggregation as the sludge has higher conductivity and less negative surface charge (Fangueiro et al. 2015). Acidification can have an increase in dry matter (DM) concentration (Fangueiro et al. 2009; Perazzolo et al. 2016; Regueiro et al. 2016) and H_2SO_4 is especially effective in doing so (Regueiro et al. 2016). The increase DM content is believed to be because of the addition of a sulfate ion by H_2SO_4 (Fangueiro et al. 2009).

Acidified slurry in soils

Acidification on-farm can inhibit the turnover of organic material in slurry (Sørensen & Eriksen 2009), which can lower the CO_2 and CH_4 emission (Fangueiro et al. 2015). Higher NH_4^+-N concentrations have been observed in acidified slurries compared to non-acidified, which might be due to nitrification delay, reduction/inhibition of N immobilization, and stimulation of organic N mineralization (Fangueiro et al. 2009). The delayed effects on nitrification is larger with higher NH_4^+ concentration (Sigurnjak et al. 2017). The effect on the microbial community is lower for short-term acidification than long-term, where the slurry is kept at a low pH for extended periods (Fangueiro et al. 2015). The acidified slurry contains acetic and other organic acids in a protonated form, which can cause the inhibition of microorganisms' degradation (Sørensen & Eriksen 2009). The exact effect of acidification on microbial community is still debated (Fangueiro et al. 2015). Additionally, the C/N ratio is often a good indicator on the mineralization potential of N, but because of acidification's inhibitory effect on microorganisms, C/N ratio might not be accurate indicator for acidified treatments (Fangueiro et al. 2009).

The delayed release of N has been shown to affect the yields in a negative way. There is a risk that acidified slurries release nutrients after the crop's peak nutrient uptake and can therefore not be utilized. Lettuce is a crop with a short growth period and have in experiment not been able to utilize N from acidified slurry due to delay in nitrification. If the N release starts after the plants nutrient uptake there is a significant risk of NO_3^- leaching (Sigurnjak et al. 2017). On the other hand, acidification can potentially increase the availability of P in the soil because of higher solubility of inorganic material when pH is decreased (e.g., dissolution of struvite). The higher availability of P can increase yields. Increased yields in winter wheat, spring barley, and maize have been observed after applying acidified slurry (Fangueiro et al. 2015).

2.2.3 Plasma activation of manure

Plasma is ionized gas, and the most recognizable one is the sun. So-called *gas discharge plasmas* can act in ambient temperature with atmospheric pressure. Plasma has grown in interest over the last couple of years because it works well with varying energy production among fossil-free energy sources. Plasma also has the potential to produce CO_2 and convert it to CH_4 for fuel as well as convert N_2 to NH_4^+ and NOx for fertilizers (Bogaerts & Neyts 2018).

With electricity, plasma generates NOx by using N_2, dioxygen (O_2), and water (H_2O) in the air. NOx can react with a material and oxidizes to NO_3^-, nitrite (NO_2^-), and hydrogen peroxide (N_2O_2) (Bogaerts & Neyts 2018; Graves et al. 2019). This process has oxidating and antimicrobial properties and has been shown to reduce the pathogen load in the material. Acidified nitrite can also work as an antimicrobial agent and has been used in food preservation for many years. The extent of pathogen reduction in manure and different temperatures is not fully understood yet and needs more research (Graves et al. 2019).

Beyond the antimicrobial and oxidating effects, the formation of nitric and nitrous acid (HNO_3/HNO_2) through the reaction between water (H_2O) and NO_2^-/NO_3^- will acidify the material and lower the NH_3 emission in the same way as acidification with H_2SO_4. The pH drop in the treated material is mainly due to the accumulation of NO_3^-. Thus, by activating manure with plasma, NH_4^+ can be preserved, and at the same time, the manure gets a higher NO_3^- concentration. The plants usually take up NO_3^- more quickly than NH_4^+, so the plasma-activated manure should have more readily available N to the crops (Graves et al. 2019).

Although, plasma-activated water and acidified nitrate have been used in the food sector for some time, there are a few uncertainties when using the technique in manure, like if the plasma activation can lower the odor of the slurry and if N_2O emission increases or decreases after applying plasma activated manure. According to Graves et al. (2019) plasma activation should lower odor and the overall N emission. Additionally, this technology has not reached its theoretical potential yet. Calculations and computer models show that it has the potential to compete with mineral fertilizer in terms of the required energy to produce N and thus the price, but it's a long way there. For now, it is a more environmentally friendly alternative to mineral fertilizers, because it works well with the varying energy production of solar- and wind power (ibid). Jardali et al. (2021) have investigated a rotary gliding arc plasma resulting in high NOx production and relatively low energy consumption (Lowest at 2.5 MJ mol^{-1}). Depending on the settings and concentration of N_2 and O_2 into the plasma, different levels of NOx were achieved at different energy consumption levels. The more efficient technique is one step towards a more competitive product (ibid).

2.2.4 Separation of manure

Animal manure is heavy and bulky and thus difficult and expensive to transport and often has unbalanced nutrient concentrations relative to the crop's needs. By separating the manure into a solid and a liquid fraction, nutrients in the solid fraction can more easily be exported from areas with nutrient surpluses to regions with nutrient deficits due to less water transportation (Svanbäck et al., 2019). Mechanical separation can give a solid fraction with high P, organic N, and carbon (C) concentration. The liquid fraction from mechanical separation has a lower DM concentration while higher N and K content. A problem with separation is that it can have significant losses of N compared to untreated slurry during handling. Foremost, the liquid fraction has a larger N loss than the solid fraction, due to the lower DM concentration in combination with higher fraction of NH_4^+, which easily can transform to NH_3. The low DM concentration lowers the potential for crust formation, which increases the surface air exchange of the slurry. Thus, acidifying the liquid fraction or covering it during storage is recommended to lower the N loss (Fangueiro et al. 2010; Perazzolo et al. 2016). On the other hand, the solid fraction can have more significant losses of CO_2 and CH_4 due to its higher C concentration. However, the percentage of CO_2 loss of total C was significantly lower in solid fractions compared to liquid fractions. Thus, the solid fraction contributes more to soils C storage than the liquid fraction (Fangueiro et al. 2008).

Several separations techniques can efficiently separate animal slurries or digestate (Møller et al., 2000; Flotats et al., 2011). Two examples are a screw press and decanter centrifuge. The two techniques differ in investment and running cost as well as efficiency. The screw press is cheaper for separating the DM from the liquid fraction, but it is less effective in separating the nutrients. The decanter centrifuge is more expensive to buy, run and maintain, but can more effectively separate DM and P into the solid fraction than the screw press (Møller et al., 2000, 2002). However, mechanical separation cannot effectively separate N from the liquid fraction to the solid fraction independent of separation techniques. Nitrogen can both be organic and inorganic and how much N that will end up in the solid fraction depends on the fraction of organic N. It is mainly organic N that will be transferred to the solid fraction when mechanical separation is used (Møller et al., 2002). According to Jönsson et al. (2004) around 50 % of N in manure is water soluble, i.e., inorganic.

Like P, several heavy metals are more efficiently separated by the decanter centrifuge than by the screw press. Especially zinc (Zn), copper (Cu), and cadmium (Cd) are primarily associated with manure particles smaller than 0.025 mm (i.e., the particles separated by the decanter centrifuge). However, Zn is believed to be bound to particles >0.025 mm in higher degree than Cu and Cd. Mercury, lead, arsenic, and chromium have not been detectible in animal slurries and corresponding investigations have not been made for these heavy metals. In most cases is the heavy metal concentration in manure too low to cause a problem for the environment after separation (Møller et al. 2007).

How effective the separation becomes and how much nutrient that end up in the solid fraction depends on the type of material that is separated. Depending on what kind of animal the manure comes from and possible pre-treatment, the separation efficiency is very different (Møller et al. 2002; Kai et al. 2008). From the same farm, samples taken on different occasions can have a different composition due to the animal's diet, food intake, and water management (Perazzolo et al. 2016).

2.3 Potential effect of optimized redistribution of nutrients

Some studies have shown that redistribution of P-rich manure has a considerable potential to lower nutrient surpluses in regions with high animal densities (e.g., McCrackin et al. 2018; Akram et al. 2019; Svanbäck et al. 2019). With a better redistribution of manure from areas with a surplus to areas with a deficit, less import of mineral fertilizer might be needed (McCrackin et al. 2018; Svanbäck et al. 2019). The nutrient balances in the countries surrounding the Baltic Sea are diverse; some have, for example, high surpluses of P while others do not (Svanbäck et al. 2019). Areas with high animal densities usually have higher nutrient surpluses than areas with low densities (McCrackin et al. 2018). However, regions with better manure handling also have lower surpluses. For example, Denmark is a country that has relatively low surpluses compared to other countries with the same density of animals. On the other hand, Poland and Belarus have relatively high surpluses (Svanbäck et al. 2019).

The potential of lowering the import of mineral fertilizer in Sweden by better utilization of nutrients in manure is significant, according to a study by Akram et al. (2019). If redistribution of all animal and human feces is optimized for the crops' needs, organic fertilizer within a municipality will account for 64 % of N and 63 % of P. If the manure is transported longer stretches, across municipality borders 75 % of N and 81 % of P would be accounted for (Akram et al. 2019). This calculation does not include separation, acidification, or plasma activation of manure which might change the outcome. In this calculation, some areas would have nutrient surpluses or deficits because the manure cannot always meet the crop demand. For example, sites with high P concertation in the soil would have N deficits if only fertilized with manure (Akram et al. 2019). Calculation of Finland's nutrient balance shows that some areas have high concentrations of P and do not need further fertilization of P. In fact, the P content in manure in Finland should be enough for the whole country, provided it is redistributed (Svanbäck et al. 2019).

There's a potential to optimize the nutrient redistribution so that the crops get nutrients without harming the environment. Case et al. (2017) showed exchanges between crop producers and animal farms. But this is happening with unprocessed manure. There is a clear distinction between crop producers in regions with few animal farms, and it is believed to be because it is hard to transport the untreated manure (ibid).

2.4 Potential in lowering the nutrient load in the Baltic Sea

The Baltic Sea has a bad eutrophication status which is not expected to improve soon. There are still areas where the animal density is very high and thus has high P concentrations in the soil. Kalmar County is a region in the southeast part of Sweden with proximity to the Baltic Sea. The Baltic Proper, as the Sea region outside of Kalmar is called, has a relatively bad eutrophication status and is not expected to reach a satisfying level until at least 2200 (i.e., not for another 178 years) (Murray et al. 2019).

The Helsinki commission (HELCOME) has, since 1974, worked to improve the status of the Baltic Sea. The goal is to have a healthy sea by 2030, which is *"unaffected by eutrophication"*. HELCOMs goal is a sea with close to natural nutrient concentrations, oxygen levels, distribution of animals and plants, low levels of algae blooms, and clear water. The biggest reduction potential is from the agricultural sector. Each sub-basin in the sea has P- and N-leaching targets the countries are endorsed to account for. Both the European Union (EU) and the Russian federation have several policies and legislation that is in line with the Baltic Sea Action Plan (BSAP) (HELCOME 2021). Some of these policies and legislation have shown to be effective in lowering the nutrient surpluses and pushing for better manure handling. In addition to, e.g., EUs policies, several countries have their own policies. Both Sweden and Denmark have policies that have caused the farmers to redistribute manure or buy more arable land to spread the animal manure, and thus lowering the surpluses (McCrackin et al. 2018; Svanbäck et al. 2019).

In 2017 the Swedish government came up with a proposition for an action plan for the Swedish food production and food chain. The goal of the new action plan is to increase Sweden's position in the global food market by sustainably increasing food production by 2030 (Näringsdepartementet 2017). In connection with this proposition, Kalmar County decided to create an action plan to develop the food sector in the region. Kalmar County is a large food production area in Sweden and relatively animal dense (Regionförbundet i Kalmar Län 2015); in 2021, around 15 % of Sweden's animal production was located in Kalmar County. The County hopes to increase its global market position and do so economically, environmentally, and socially sustainable with the strategic plan. To reach their goals, they wanted to collaborate with other regions, different parts of the sector, universities, and other education platforms (Regionförbundet i Kalmar Län 2015). In 2020, Kalmar County developed the strategic plan further with more detail about current and future projects to reach their goals. They had installed scientists at Linné University, focusing on food development, and started a platform for small and middle-size farms. They have also participated in national investment projects like MISTRA food futures, KINOVA growth process, and LRF *Mer mat- Mer jobb*.

Further, the region wants to develop collaboration with the Swedish university of agricultural science (SLU) to increase the knowledge in all parts of the sector (Region Kalmar län 2020).

3. Material and methods

This thesis consists of a literature study, an incubation study, and a survey. In the literature study, articles, reports, documents (etc.) have been searched for in multiple search engines. Example of search engines used was SLU: s search service PRIMO, research gate, and Google. Google was used to find government reports and action plans. The documents found were evaluated based on relevance, and for scientific papers, how much it had been referenced by other researchers and if the article was connected to a university. Primary sources were used when it was possible, but when primary sources were not available, secondary sources were used. The literature study is presented in the background section and is connected to the other parts of the study.

The organic materials evaluated in the incubation study, were separated, collected, and treated at a pilot scale facility at MORE biogas in Kalmar. Further treatments and succeeding incubation study was conducted on the SLU campus. Once the materials were prepared, the incubation was set up, monitored, and sampled.

This thesis survey was sent to Swedish farmers in the autumn of 2021. How the survey was developed is presented below and is also discussed in the results and discussion section. As described, this paper aimed to investigate the interest in organic fertilizers like those produced for incubation study.

3.1 Collecting and producing organic fertilizers

3.1.1 Collection of material at MORE biogas plant

Background about MORE biogas

The organic materials were collected for incubation on the MORE biogas plant in Kalmar, Sweden. The biogas plant is owned by the farmers in the area surrounding it. The biogas plant digests several types of animal manure (80 %), e.g., cow, pig, and poultry but also municipal food waste and slaughterhouse waste (20 %). The digestion occurs at thermophilic temperature (i.e., around 50-55˚C), and the biogas produced is used as fuel. The type of material digested in the biogas plant differs from time to time, depending on what comes in. In proximity to the digestion chamber, there was a pilot-scale section for digestate separation and plasma activation (Figure 1). In the separation area, there were five tanks, one screw press (Stallkamp PSS 2.2-400), and one decanter centrifuge (De Laval). Tank 1 (T1) collected the digestate (D) from the digestate chamber (in the other room). T1 was close to the screw press and had a stirrer that ensured that the material was homogonous. Tank 2 was not used in this experiment. Tank 4 (T4) stored the plasma-activated separated liquid fraction (P-LF). Tank 5 (T5) had a scale and weighted the newly separated liquid fraction (LF). After the LF was weighted and sampled in T5, it was pumped to the larger tank 3 (T3). The material was pumped from T5 to T3 because of T5s limited size (1500 m^3). The limited size was practical when weighing the sample to calculate the separation index (see section 3.4). The solid fraction (SF) from the screw press was collected in a container below it. The decanter centrifuge was unfortunately impaired during this experiment and could not be used for a second separation of the liquids after the screw press. The plasma activating machine from N2 Applied was in the same room as the tanks presented above.

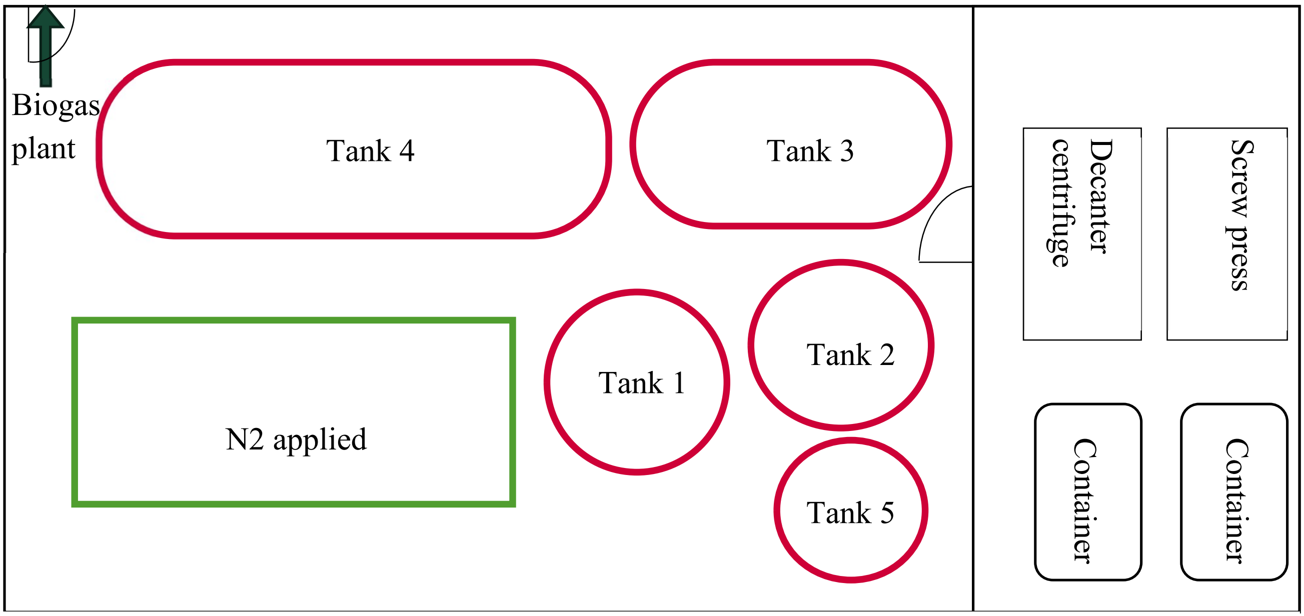

Figure 1. A schematic overview of the pilot-scale separation facility on MORE biogas plant

Collection of organic material

On the day when the samples were collected for this study, most of the organic material in the digestion chamber was pig manure. A small amount of the digestate from the reactor was transferred to T1. Samples were collected from T1 in small plastic tubes and closed to minimize NH_3 volatilization and spillage. From T1, the digestate was pumped into the screw press. The screw press had a hydraulic arm to control how much water was pressed out from the solid material. Three different settings were used for three separation occasions, 7.5 bar, 10 bar, and 12.5 bar. The sieve size of the screw press was 0.75 mm, and the inflow speed was about 7.5 cubic meters per hour. The liquid fraction from the screw press was transferred to T5, which did not have a stirrer. After each separation, the weight of the tank was noted, and samples were collected in tubes like the once used to collect the digestate from T1. The LF in T5 was then transferred to T3 to give room for the subsequent separation batch. The samples from T5 were taken from the top directly after the separation was finished. The solid fraction was collected in a container below the screw press. The container weight with the separated SF was noted, and samples were taken out with a shovel and transferred to large plastic bins. For the incubation study, only the last installation (12.5 bar) was used, and samples taken for the other two installations of the hydraulic arm were stored in the freezer for possible later use. The materials were transported from Kalmar to Uppsala and stored in a freezer (-18 °C). In Uppsala, all materials were sent to AgriLab for analysis (Table 1) see analyze method in section 3.2.3.

Table 1. Properties of materials used in the incubation. The digestate (D) and the separated liquid fraction (LF) had three replicates and the plasma activated liquid fraction (P-LF) had two replicates. The mean values and standard deviation of these three are presented in the table. The separated solid fraction (SF) had only 1 replicate and therefore mean or standard deviation could not be calculated. The standard deviation is presented within the brackets.

	D	LF	P-LF	SF
Dry matter (DM) (%)	5.7 (0.2)	4.4 (0)	2.3 (0)	26.4
Organic N (kg/ton)	1.8 (0.03)	1.7 (0.01)	2.4 (0)	3.8
NH_4^+-N (kg/ton)	2.5 (0.04)	2.5 (0.02)	1.5 (0.03)	2.3
NO_2^-/NO_3^- -N (kg/ton)	<0.001*	<0.001*	2.3 (0)	<0.001*
Total C (Kg/ton)	23.3 (0.7)	16.9 (0.04)	5.7 (0.07)	122.7
Total C/Total N	5.4 (0.1)	4 (0.01)	1.4 (0.03)	19.9
Total P (Kg/ton)	0.7 (0.04)	0.6 (0.01)	0.3 (0)	2.4
Mg (kg/ton)	0.5 (0.03)	0.6 (0.01)	0.2 (0.01)	1.9
K (kg/ton)	2.7 (0.1)	4.3 (0.1)	1.8 (0.05)	2.8
Ca (kg/ton)	1.1 (0.1)	1.6 (0.01)	0.7 (0.01)	2.7
Na (kg/ton)	0.59 (0)	0.62 (0)	0.4 (0)	0.6
S (kg/ton)	0.41 (0)	0.38 (0)	0.1 (0)	1.15
Cu (mg/kg DM)	274 (5.9)	323 (13.6)	181.8 (79.3)	118
Fe (mg/kg DM)	11908 (268.8)	14035 (306)	9254 (4217)	5955
Mn (mg/kg DM)	349 (10)	436 (13)	368 (168)	123
Zn (mg/kg DM)	351 (10)	427 (12)	421 (193)	138
pH	8.1 (0)	8.2 (0)	4.4 (0)	7.8
Volatile solids (% of DM)	73 (0.2)	67.6 (0.16)	75.6 (2.04)	88.3

*Very low standard deviation, <0.00001

3.1.2 Plasma activation of separated liquid fraction

The plasma activation machine installed on MORE biogas was from the Norwegian company *N2 Applied*. The company is relatively new and directed toward farms rather than industrial fertilizer production. They aim to produce a cheap enough product for farms to buy and install to stabilize and boost their slurries with increased NO_3^--N content (Frameworks n.d.). When writing this paper, most of the installations are on a pilot scale, and just a few field experiments have been conducted with similar technologies as *N2 Applied*. The plasma machine installed by *N2 Applied* on MORE biogas was new and had not been running for very long, which contributed to some installation difficulties. The plasma-activated digestate used in this experiment received more NO_3^--N and had a lower pH than the target value (commonly used for applications with the *N2 Applied* method). As a result, there was four times as much NO_3^--N than the initial NH_4^+-N concentration (expected to be two times) and the pH became 4.4 which is noticeably lower than the target of pH 5.5. At the time of the separation and collection of samples, treatment of the LF with *N2 Applied* was not possible; however, some liquid digestate had been separated and treated with *N2 Applied* a few days before and stored in T4. The material in T4 was assumed to be very similar to the one used for separation on the day of sampling. T4 did not have any stirrers, and the samples were collected at the very top of the tank because it was hard to reach further down. The samples were stored in plastic tubes to avoid spillage and NH_3 emission. See table 1 for a presentation of characteristics.

3.1.3 Acidification of separated liquid fraction

As previously stated, acidification can lower the NH_3 emission and thus reduce the loss of N. By acidifying the separated LF before soil application, less N might be lost and may thus be available to the crops and this was tested in the incubation experiment. The goal was to acidify the slurry to pH 5.5, the standard target pH in previously published studies (Kai et al. 2008; Sørensen & Eriksen 2009). A fraction of the LF was acidified at the SLU laboratory with H_2SO_4 (98%). Before acidification, a titration curve was plotted by adding 20 microliters H_2SO_4 to 30 ml of LF, stirring for 2.5 minutes and measuring the pH 30 second after the stirrer was turned off. The acid was applied at a low and controlled rate to avoid foaming and allow adequate time for pH stabilization (Sigurnjak et al. 2017). The titration procedure was repeated twice, and the titration curve was satisfying enough to calculate how much H_2SO_4 was needed to acidify the digestate to pH 5.5 (Figure 2). From the titration curve it was estimated that 1.3 ml H_2SO_4 was needed to acidify 200 g of separated LF to pH 5.5. The acidified LF rested for a few minutes and was added to the soil (see details below).

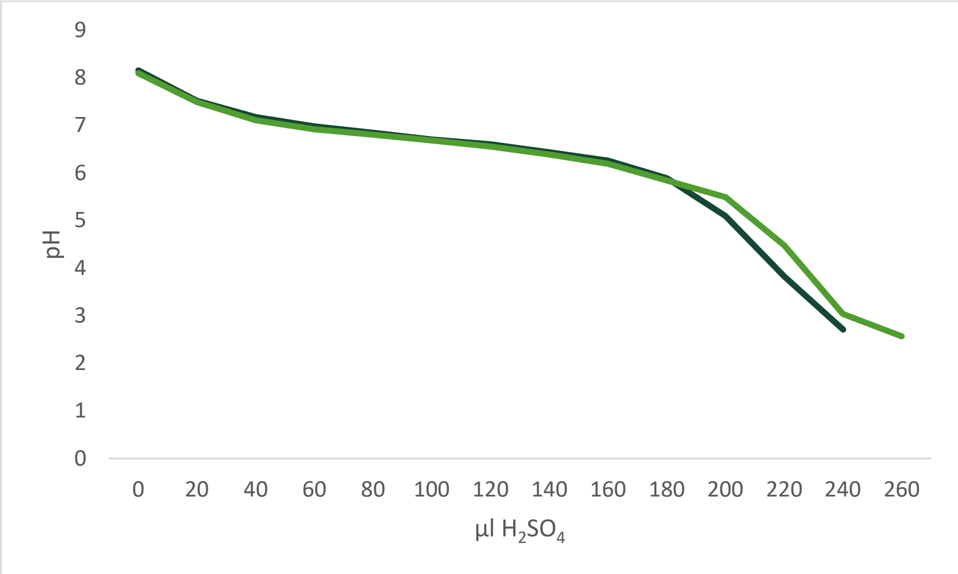

Figure 2. Titration curve for titrations of the separated liquid fraction with H_2SO_4. The two curves represent two titrations with the same standardized method: 20 µl of H_2SO_4 added at a time, mixed for about 2.5 minutes, and rested for 0.5 minutes before the pH was measured with a pH meter. The curves are very similar which indicated a good, standardized method and a reliable result.

3.2 Incubation experiment

3.2.1 Pre-incubation

The purpose of the incubation study was to see how the different types of organic fertilizers described above differ in the soil. To take destructive samples for all the measurements 108 plastic cups with 50 g of soil were prepared. The soil was a sandy loam with a low concentration of organic material (1.5 %) and a density of 1.5 g/cm^3. The soil had a pH of 6.3, an ammonium-lactate extractable P (P-AL) of 4.8 mg/100 g dry soil and NO_2^-/NO_3^--N concentration of 0.2 mg/100 g dry soil. The soil had been prepared before the start of the experiment by air drying it and sieving it through a four-mm sieve. The soil's water holding capacity was checked to be able to add water equal to 65% of the soil's water holding capacity (7.5 ml) and was then pre-incubated at room temperature for two weeks. During the pre-incubation period, the weight was checked to maintain the soil's moisture to 65 % of its water holding capacity.

3.2.2 Incubation

To start the incubation, 1 ml of all LFs and 1.8 g of the SF was added to the soil. The amount of added material was aimed to correspond to a fertilization of 170 kg total N/ha. In total the study included six treatments with three replicates: control (no fertilization), digestate (i.e., not separated), liquid fraction, acidified liquid fraction, plasma activated liquid fraction and solid fraction. The fertilizers were mixed thoroughly into the soil and compressed lightly to return to the soil's natural density. MilliQ water was added again to reach 65 % of the water holding capacity of the soil. To account for the different water concentrations of the material, different amount of water was added to the different treatments. The new weight corresponding to 65% water-holding capacity was noted to maintain the same water content trough the experiment. A lid was placed loosely on the plastic cups to allow air exchange while minimizing water loss. All treatments were incubated at 15˚C and checked every second week to maintain the water concentration. Samples of the six treatments were analyzed on days 3, 7, 14, 21 and 44 and because a destructive sampling method was used three cups from each treatment was removed at each sampling occasion and sent to Agri Lab in Uppsala where they were analyzed for mineral N content within 2 hours for estimation of N mineralization.

Additionally, similar cups as used in the incubation study were placed in sealed 1 liter glass jars to measure the CO_2 emission (degradation of organic matter). The gasses emitted from the samples were collected using falcon tubes with 10 ml of 1 M sodium hydroxide (NaOH) during the first day and 10 ml of 0.5 M NaOH the following days; 3, 5, 7, 15, 21, and 50. At every sampling occasion the jars were aerated to make sure that the samples got enough oxygen. The NaOH traps were titrated to calculate the amount of CO_2 emitted from the samples which later was used to estimate the carbon mineralization. Before titration, the solution was mixed with 1 ml barium chloride ($BaCl_2$) and eight drops of thymolphthalein. The solution was titrated with 0.3 M HCl till the solution changed color from blue to transparent. The amount of HCl added was noted and used to calculate the amount of CO_2 respired, see the calculation below.

3.2.3 Analyzes

All materials and soil samples were sent to Agri Lab, Uppsala, Sweden, for analysis. For the first sampling occasion, all the analyzes mentioned below were carried out. However, for the subsequent sampling occasions the soil was only analyzed for DM, NH_4^+-N and NO_2^-/NO_3^--N. In Agri Lab, all samples were dried at 105˚C for 24 hours and analyzed for DM content. All samples from the first sampling occasion were analyzed for organic-N and total-C after combustion, with LECO CN928. For analyzes of NH_4^+-N and NO_2^-/NO_3^--N wet samples were extracted with 2M KCl and analyzed with flow injection analysis (FOSS TECATOR FIAstar 500 Analyzer). Total P, K, sulfur (S), sodium (Na), magnesium (Mg), and Ca were analyzed with ICP-OES (Spectro Blue ICP) after digestion with 7 M HNO_3. Water-soluble P was analyzed on four occasions with ICP-OES (Spectro Blue ICP) after extraction with water. The soils were also analyzed with the AL method, where ammonium lactate (AL) extracts plant-available P, Mg, Ca, and K from the soil (Ulén & Eriksson 2009).

The fertilizers were analyzed before addition to the soil, and the results were used to calculate the separation index for the screw press (see calculation in section 3.4). The soil samples removed on days 3, 7, 14, 21 and 44 were analyzed based on inorganic N concentration to see the difference in N mineralization between the different fertilizers. On day 3, P, K, Mg, and Fe concentrations were also included in analyzes. These results were used to compare the possible nutrient value of the different fertilizers.

3.3 Survey- Farmer's perspective on organic fertilizers

The survey was conducted from October 2021 to January 2022 (project Circular NP) by SLU and HS konsult AB (a Swedish consult company for farmers in Uppsala and adjacent counties). Before the master's study began, I had the opportunity to be part of the development of the questions as an intern at HS konsult AB in the spring of 2021.The survey aimed to explore the interest among Swedish farmers in organic fertilizers and the reasons for their preferences. The overall objective was to give input for the possible development of organic fertilizers from different sources, such as animal manures, and digestate with different post-treatments. The survey was broadly distributed, and all types of farms were invited. As a result, it could not be ensured that there was a representative selection of farm types, location, farm size, etc. The questionnaire was held online and spread through ads in newspapers for the sector (Jordbruksaktuellt, Land lantbruk, and ATL) through HS Konsult AB's channels (e.g., Facebook) among customers and through other networks like consulting meetings. It was published on the HS Konsult AB's web page and was available as an URL. The questionnaire contained 22 questions (Appendix 1) regarding the farm's background, current use of organic fertilizers, future aspects, and pros and cons of using organic fertilizers. The questions were tested on farmers beforehand and adjusted where needed. Many opened the questionnaire, but only 99 answered all the questions. The background information was compared with the Swedish Board of Agriculture statistics to see how well the response corresponds to Swedish conditions and farmers.

All the answers in the survey were anonymous. The questions in the questionnaire have been examined and compared with each other to see if there are any trends in the response.

3.4 Calculations

3.4.1 Separation index

To calculate the separation index, the weights measured of the SF and LF directly after separation on MORE biogas were used. The weight of untreated digestate (D) was not measured, but by adding the weight of SF and LF, the weight of D could be estimated. It was assumed that the loss during separation was close to zero.

The separation index (SE_X) (eq 1) was calculated as presented in Hjorth et al. (2010), by multiplying the concentration of each parameter in SF (mxSF) by 100 and then dividing it with the corresponding concentration in D (mxD) (equation 1). The purification index (PEx) was calculated by subtracting the nutrient concentration of LF from D and dividing it by the nutrient concentration of D (equation 2).

$$SE_x = m_x SF * 100/m_x D \qquad \text{eq1}$$
$$PE_x = (m_x D - m_x LF)/m_x D * 100 \qquad \text{eq2}$$

3.4.2 CO_2- C in NaOH traps

For each sample, there were three replicates, and the amount of CO_2-C trapped in 4 ml NaOH in each tube was calculated separately. The amount of CO_2-C (respired C) evolved from each tube was measured by titration with HCl to see how much of the NaOH that was consumed. The additional CO_2-C emitted from the fertilized treatments compared to the soil without any added materials (control treatment) was calculated by subtracting the added HCl in the titrations from soil without fertilizers from amount HCl added to the different fertilized treatments. The difference was multiplied with the molar (M) of HCl (0.3) times six.

Next, the percentage of mg C respired the total C content of added fertilizers in 1 kg soil was calculated. The percentage was calculated by dividing the amount of mg CO_2-C in one kg of soil by the added total C of all treatment's times a hundred. Lastly, the percentage of respired CO_2-C from each sampling occasion was summed up to get the accumulated CO_2-C respired per total initial C content in the added fertilizer.

3.4.3 Inorganic N and mineralization

The net-mineralization and net-immobilization were estimated by subtracting the initial inorganic N content, i.e., the sum of NH_4^+-N and NO_3^- -N (day 0), from that of the last sampling occasion (day 44). Values for the control treatment was subtracted to only evaluate N dynamics related to the added fertilizers. The mineralization was later divided with the total added N with the fertilizers to get the net-mineralization and net-immobilization in percentage of N added.

3.4.4 Statistical analyzes

The accumulated CO_2 emission, NO_2^-/NO_3^--N and NH_4^+-N, were analyzed using IBM SPSS statistical software, version 27. One-way ANOVA was used to determine the effect of applied fertilizer. When the significant differences between means were observed, additional post hoc assessment was performed using Tukey's test ($p < 0.05$).

4. Results and discussion

4.1 Characteristics of organic materials

Plasma activated liquid fraction (P-LF)

Based on the analyzes of the materials conducted by AgriLab, P-LF was the material that differed the most from the other liquid materials. Plasma activated LF had higher NO_2^-/NO_3^--N concentration and volatile solid content than LF and A-LF. The high NO_2^-/NO_3^--N concentrations were due to the addition of NO_2^-/NO_3^--N when the material was plasma activated (Graves et al. 2019). However, for the other properties presented in Table 1, such as DM, total C and NH_4^+-N, the concentrations were lower in P-LF compared to LF and A-LF. There is no indication that the pH affects the DM and NH_4^+-N concentration (Fangueiro et al. 2009; Perazzolo et al. 2016; Regueiro et al. 2016) and does not explain why the concentrations is different between P-LF and LF. So, why the DM and the NH_4^+-N concentration is lower for P-LF is unknown, but it might be due to the sampling technique. When sampling P-LF from T2, it had been stored in the tank for a few days and some particles had sedimented to the bottom of the tank. Samples could only be collected from the top of the tank because of its size, and there is a risk that only lighter, smaller particles were collected. Particles that are sensitive to sedimentation are larger particles containing P, and organic material (C). As seen in Table 1, C and P concentrations are the lowest for P-LF.

Nutrients in the separated untreated fractions (LF, SF)

The untreated separated fractions had approximately the same concentration of inorganic N but had different concentrations of organic N. The SF had a higher percentage of organic N compared to LF (Table 1). The separation index confirmed the pattern where most of the N in the SF was organic N while NH_4^+-N had the lower separation index (Table 2). The purification index showed a similar pattern where it was less "pure" for NH_4^+-N. The low separation index for NH_4^+-N is in line with results from Møller et al. (2002). The materials that had not been plasma activated had close to zero concentration of NO_2^-/NO_3^--N (Table 1), but the separation and purification index could still be calculated. The separation index for

NO_2^-/NO_3^--N was the lowest compared to other characteristics examined (Table 2), thus most of the NO_2^-/NO_3^--N from D was transferred to the LF.

The SF had by far the highest concentration of total C, volatile solids, and DM of all materials (Table 1). Furthermore, the separation index was highest for volatile solids, followed by total C (Table 2). The high separation index indicates, as expected, that most organic materials was transferred to the SF (Møller et al., 2000, 2002). The same pattern could again be seen in the purification index, where LF received a smaller fraction of the organic material from the D.

Total P was also higher in the SF (Table 1), but the separation index shows that it was not as effectively separated to the SF as C (Table 2). However, it was separated more efficiently into the SF than water-soluble P. Magnesium (Mg) and Ca were separated more effectively into the SF than P. Phosphorus, however, had a higher separation index than K, Na, and S. In fact, K, Na, and S are either bound to smaller particles than 0.75 mm (sieve size of screw press) or even dissolved in the liquid. On the other hand, Mg, Ca, and P are usually bound to the larger particles in the materials and are therefore more easily separated to the SF. Potassium and Na, which had the lowest purification index, are probably, at least in part, dissolved in the D as the water-soluble P (Møller et al. 2007). The separation index is approximately the same for water-soluble P, K, and Na (Table 2).

Metals in separated untreated fractions

The separation index shows that Cu and iron (Fe) were transferred to a greater degree to the SF while manganese (Mn) and Zn was not. The purification index also shows that the LF was relatively clean from Cu and Fe. The results can be explained by how the metals are bound to particles in the material. As Møller et al. (2007) discovered, some metals are more likely to bind to smaller particles. Zinc is most often bound to particles <0.025 mm while Cu is usually bound to particles >0.025 mm (ibid.). The binding of metals might explain why Cu has a higher separation index than Zn, the screw press cannot effectively separate particles smaller than 0.7 mm (because of the sieve size), and some particles that are 0.025 mm are unlikely to be transferred to the SF. Separation with a decanter centrifuge that is more efficient at separating particles <0.025 mm might have a higher separation index for in this case Zn (Møller et al. 2007; Pantelopoulos & Aronsson 2021).

Table 2. The average separation index and purification index of the screw press. Calculations based on the last separation carried out with 12 bar pressure on the hydraulic arm of the screw press. A high separation index indicates a high concentration of the respective compound in the solid fraction, while a high purification index indicates a low concentration in the liquid fraction

	Separation index (%)	Purification index (%)
DM	25.7	26.8
Organic N	11.6	10.3
NH_4^+-N	5.2	4.8
NO_2^-/NO_3^--N	4.9	4.2
Total C	29.2	31.3
Total P	18.6	17.6
Total S	15.6	12.8
Water soluble P	5.8	8.6
K	5.8	1.9
Mg	21.1	20.4
Ca	13.2	15
Na	5.4	1
Cu	11.3	13.6
Fe	11.9	13.8
Mn	8.2	8.5
Zn	9.4	11
Volatile solids	31	32.3

4.2 Incubation

4.2.1 Soil analyzes

The soil samples from the first day of sampling (i.e., day 3) matched the composition of the materials used. The SF treatment had the highest P concentrations of all materials (Table 1) as well as the highest application rate, which increased the P concentration in the soil and even changed the P-AL class (Table 3). None of the other materials changed the P-AL class of the soil; they simply had the same class as the control. The potassium concentration was highest in soil with SF, but SF did not have the highest concentration of K, the high concentrations were due to higher application rate of SF, since the application rate was based on N content. The other materials also increased the K-AL concentration in the soil. The digestate, LF, and A-LF increased the K concentration to the same K-AL class as SF, i.e., from class I to class III. On the other hand, the soil with P-LF only increased from class I to class II. The solid fraction also had the highest Mg and Ca concentration and thus increased the concentrations of these compounds in the soil. In the soil with D, LF, A-LF, and P-LF the concentration of Mg and Ca was about the same as the control.

Table 3. Mean from the analysis of P-, K-, Mg- and Ca-AL the soil samples removed from incubation on day 3 (first analysis), the standard deviation is presented in the brackets. The control treatment, without additives, presents the soil´s own nutrient concentration.

	Control	D	LF	ALF	P-LF	SF
P-AL (mg/100 g)	4.7 (0.1)	5.6 (0.3)	5.6 (0.3)	5.2 (0.1)	5 (0.1)	16 (0.7)
P-AL class	III	III	III	III	III	IVB
K-AL (mg/100 g)	3.7 (0.1)	10.4 (0.8)	10.7 (0.5)	10 (0.3)	8 (0.1)	16 (0.4)
K-AL class	I	III	III	III	II	III
Mg-AL (mg/100 g)	3 (0.04)	3.9 (0.3)	3.8 (0.3)	4 (0.1)	3 (0.1)	14 (1)
Ca-AL (mg/100 g)	40 (0.8)	41.7 (0.6)	42 (1)	40 (0.8)	40 (0.8)	54 (0.5)

4.2.2 Nitrification

For the rest of the experiment (after day three) the NH_4^+-N concentrations decreased in all the treatments (Figure 3a). While the NH_4^+-N concentration decreased, NO_2^-/NO_3^--N increased in almost all treatments except for P-LF (Figure 3b), this indicates that the NH_4^+-N was nitrified to NO_2^-/NO_3^--N (Gómez-Muñoz et al. 2016). Little, or no NH_3 emissions were expected because the soil and material were carefully mixed and compressed, mimicking the incorporation of slurry into soil, which according to Oenema et al. (2001), significantly decreases NH_3 emission. The initial NH_4^+-N concentrations were highest for SF but declined and reached the same concentration as the control at the end of the experiment on day 44 (Figure 3a). The digestate, A-LF, and LF all had the same initial NH_4^+-N concentration but differed throughout the rest of the experiment. The acidified LF had significantly higher NH_4^+-N concentration from day 7 until day 22. After day 22, the NH_4^+-N concentration decreased in acidified treatment and was the same as the control at the end of the experiment.

Acidified LF (A-LF)

As seen in Figures 3a and b, there appeared to be a delay in nitrification in A-LF compared to the non-acidified LF. The slower decrease of NH_4^+-N in A-LF may be due to the formation of organic acids in combination with low pH, which can inhibit the activity of the microorganism in the soil (Sørensen & Eriksen 2009). The delay of nitrification after applying acidified slurry has been reported in previous experiments (e.g., Fangueiro et al. 2009; Sørensen & Eriksen 2009; Sigurnjak et al. 2017). However, Fangueiro et al. (2016) were able to show that the impact on nitrification as a result of acidification was affected by the properties of the soil, and above all, the soil's own buffer capacity. If the soil has a high buffer capacity, the delay of nitrification can be very low or even non-existent. If the soil on the other hand has a lower buffer capacity and the pH is below 6, the activity of the nitrifying bacteria in the soil can be strongly reduced (Gandhapudi et al., 2006 in Fangueiro et al. 2016). In Figure 3d, the pH of A-LF was on average lower than that of the other treatments, even though the difference was not significant. This might indicate that the buffer capacity of the soils was not high enough to inhibit the effect of acidification.

Acidified digestate, as previously mentioned, can reduce NH_3 emission at times when the digestate might come in contact with O_2 (Kai et al. 2008; Regueiro et al. 2016). Furthermore, the delay in nitrification discussed above can be positive when storing the digestate and in some instances if the digestate is spread before plants starts to take up nitrogen. If NH_4^+-N in the slurry transforms to NH_3 before the plants starts to take up nitrogen or during storage in the digestate lagoon (without cover) N could be lost through NH_3 emission. On the other hand, NO_2^-/NO_3^--N can easily be lost through leaching, especially during heavy rainfall. Thus, it is important to spread the acidified digestate at the right time to take advantage of the positive effect (Sigurnjak et al. 2017).

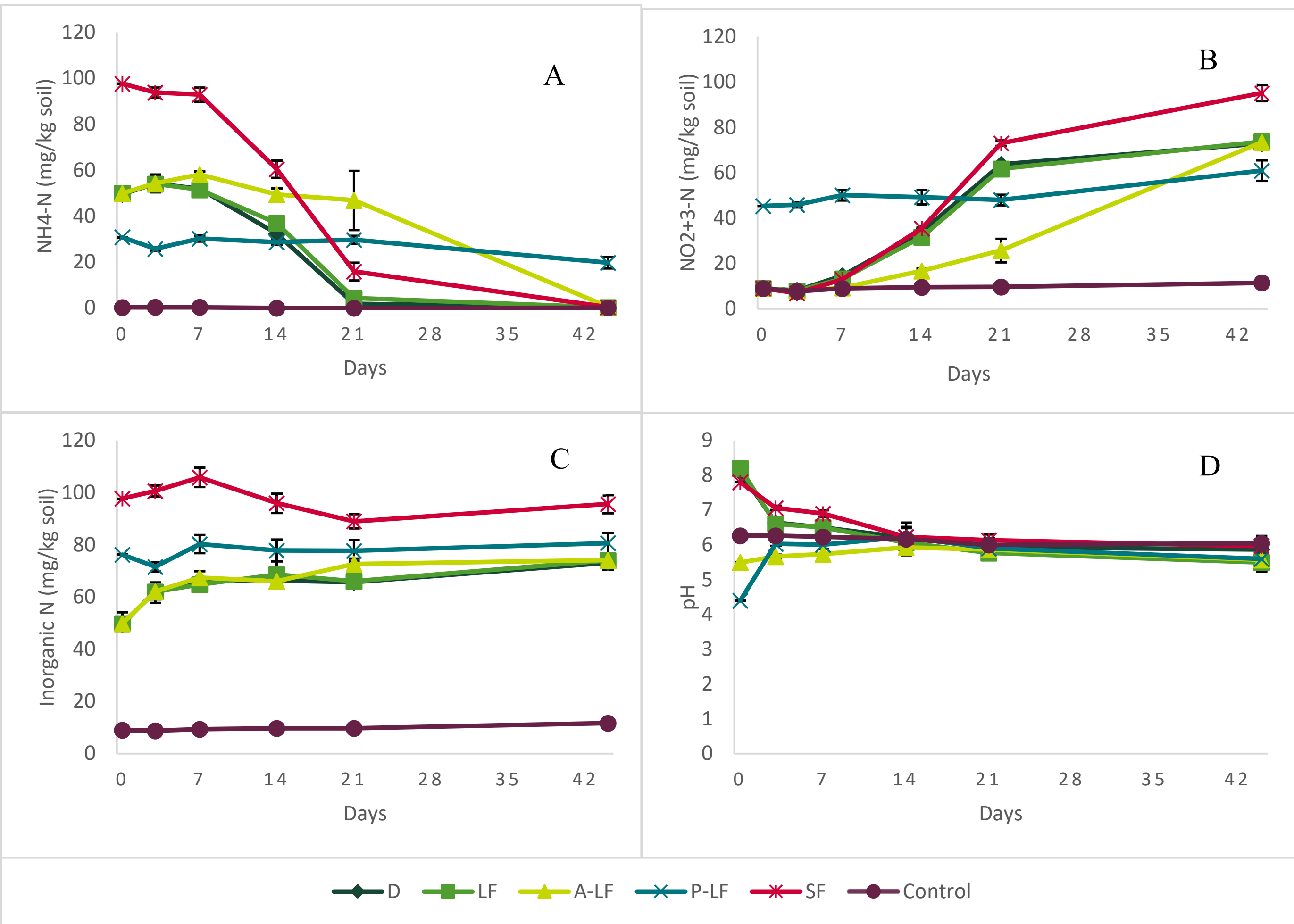

Figure 3. Analyses from the incubation, where the error bars represent the standard deviation with a margin of error of 95%. A and B shows the amount of NH_4^+-N, NO_2^-/NO_3-N in mg/kg soil from samples sent to AgriLab on days *3, 7, 14, 21 and 44*. C shows the combined concentration of inorganic N in mg/kg soil. D. shows the pH during the incubation

Plasma activated LF (P-LF)

Plasma activated LF stood out from the other treatments; the initial NH_4^+-N concentration was lowest at day 0 while the NO_2^-/NO_3^--N concentration was highest (Table 1). At the end of the experiment, the NH_4^+ concentration decreased by 2 mg/kg soil, and NO_2^-/NO_3^--N had increased by 10 mg/kg soil. Thus, the nitrification process seemed to be significantly inhibited by the P-LF.

Why the P-LF had this low nitrification is uncertain, the initial pH was lower than the A-LF treatment but when mixed in the soil, the pH of P-LF was higher than A-LF (Figure 3d). The pH was above 6 in P-LF and should not inhibit the nitrifying bacteria (Gandhapudi et al., 2006 in Fangueiro et al. 2016). Plasma activated LF has a low proportion of CO_2 respired from the soil and Fangueiro et al. (2016) saw that low CO_2 emission correlated with lower nitrification in sandy soils with low organic matter (15.2 g/kg) levels as well as low pH (5.71). The soil in this experiment has similar organic matter (1.5 %) content but higher pH (6.3), which makes this theory uncertain. At the same time, the strongest correlation between NH_3 emission and additives in slurry is related to the slurry's own buffer capacity rather than the CO_2 concentration according to Vandré & Clemens (1997). The buffering capacity of the digestate used in this experiment is unknown so it is difficult to investigate further.

Moreover, it is known that HNO_3 has a lower effect on the buffer capacity of slurry than more potent acids like HCl or H_2SO_4 (Vandré & Clemens 1997). A more thorough analyzis of plasma-activated slurry from *N2 Applied* machine on MORE biogas has shown a higher fraction of NO_2^- than NO_3^- (unpublished data). It is not certain that the material collected for this experiment had the same composition, but if so, it might have affected the rate of nitrification due to inhibition of microbe activity due to toxic levels of nitrite. Additionally, the P-LF can be compared to long-term acidification, which has a more significant effect on the microbial community compared to short-term acidification, i.e., A-LF treatment (Fangueiro et al. 2015).In fact, many factors may have contributed to the delayed nitrification in P-LF but further research is needed to understand the reason behind the results thoroughly.

4.2.3 CO_2 emission

Plasma-activated LF

Plasma activated LF was the material with highest accumulated CO_2 emission during incubation (Figure 4a). Figure 4a shows that it was during the first three days that most of CO_2-C (mg/kg) in the soil respired. However, the amount of CO_2-C respirating in P-LF treatment never exceeded the other materials and dropped rapidly after day three, close to zero (Figure 4b). The respiration top at the beginning of the experiment could be connected to potential high fraction of readily available C that could be converted into CO_2. This theory is strengthened by Peters & Jensen (2011) who have seen that materials containing a higher proportion of lignin can have a lower C mineralization and thereby lower respiration.

By comparing inorganic N seen in figure 3c, with the amount of respired CO_2, a negative correlation was seen in the first three days. Peters & Jensen (2011) were able to see a correlation between the proportion and composition of C compounds and N mineralization. The correlation showed that a low percentage of total C and low concentration of readily degradable C compounds gave a net N mineralization (Ibid.). Thus, the relationship between inorganic N and CO_2 emission may be linked to the fact that before day three there was a high fraction of readily available C which gave N immobilization while after day three there was both lower C content left in the material and probably lower proportion of readily available C which gave an N mineralization.

Digestate, liquid fraction and acidified liquid fraction

There were no significant ($p<0.05$) differences in accumulated CO_2 emissions between LF and D (Figure 4a). Both LF and D had higher total CO_2 emissions than A-LF (Figure 4a), which is expected as acidification inhibits microbial activity and decomposition of organic matter (Gómez-Muñoz et al. 2016). The lower degradation due to lower microbial activity is followed by lower CO_2 emissions (Fangueiro et al. 2015). Additionally, during acidification, a part of the C in the material is lost due to the transformation from HCO_3^-/CO_3^{2-} to CO_2 (Fangueiro et al. 2013). How much CO_2 was emitted during the acidification phase is unknown, but according to measurements made by (Fangueiro et al. 2016), 2.8 % CO_2 could be lost within the first hour after acidification. The calculation of accumulated CO_2 emission with and without 2.8 % loss before application showed no significant difference ($p<0.05$) in accumulated CO_2 emission or inorganic N. Figure 3 (a-d) and figure 4 (a-b) presents graphs of A-LF without an estimated CO_2 loss of 2.8% because the material was mixed into the soil shortly after acidification and it was probably less than 2.8% that had disappeared.

Solid fraction

The solid fraction had the lowest percentage of accumulated CO_2-C emission of total C of all treatments (Figure 4a), indicating that the carbon content was more stable in the SF (Fangueiro et al. 2015). The screw press cannot separate smaller particles from the LF (Hjorth et al. 2010) which gives the SF a coarse material. A finer material is assumed to have a higher proportion of CO_2 emission of total C emission than a coarser material (Fangueiro et al. 2008). If a decanter centrifuge had separated the LF once more to obtain an even finer material, it might have had a higher accumulated CO_2 emission.

The solid fraction had the highest total carbon content of all the other treatments (Table 1), and it should contribute to the highest amount of soil carbon during a crop's growth period. The high C concentration is reflected in Figure 4b where SF has the much higher proportion of respired CO_2 than the other treatments. All liquid fractions had a low carbon concentration compared to SF (Table 1), which partly explains the lower CO_2 respiration.

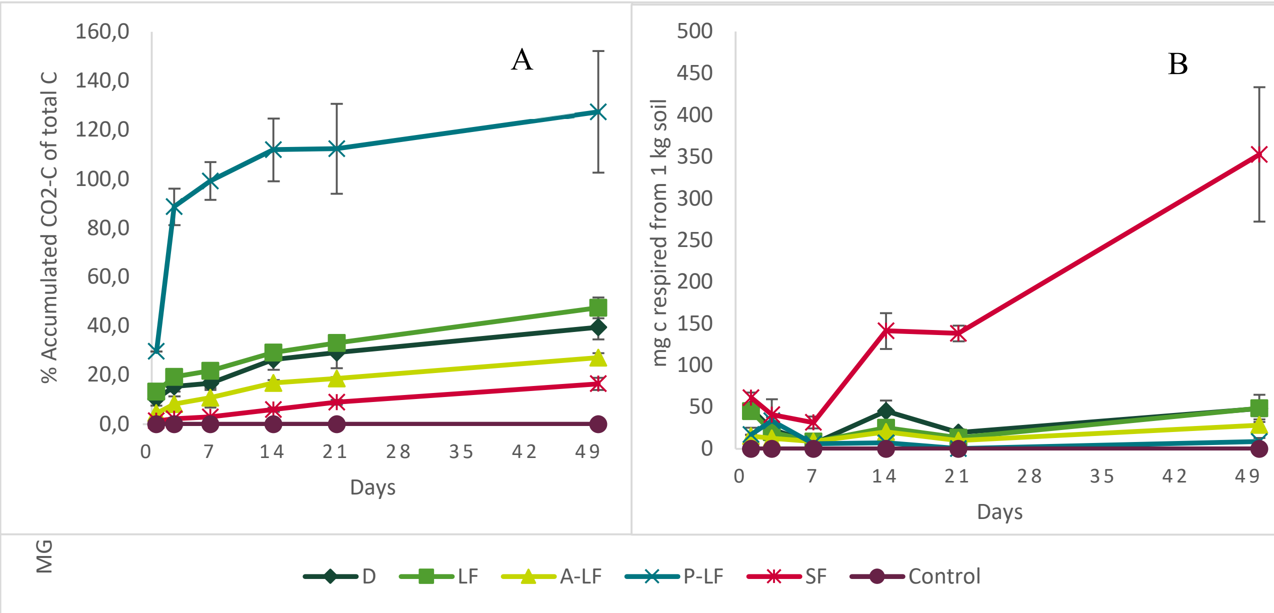

Figure 4. Analyses from the incubation experiment with error bars representing standard deviation with a margin of error of 95%. A and B show the amount of CO_2- respired both in % accumulated by initial Total C and mg CO_2–

4.2.4 N-mineralization

All liquid fractions had a net N mineralization (Figure 5). Different studies have different results regarding net-mineralization for LFs and A-LFs. Gómez-Muñoz et al. (2016) and Fangueiro et al. (2009) had a net-immobilization when soil was mixed with the LF of screw press separated pig slurry. Fangueiro et al. (2016) had a net-immobilization and a net-mineralization depending on the soil's characteristics. A soil with a high C/N ratio would result in a net immobilization independent of the material applied (ibid.). The carbon to nitrogen ratio of the soil used in this experiment is unknown, but since the control (soil only, no additives) had a net-mineralization (results not shown), is it possible that it had a low C/N ratio. The untreated LF had a low C/N ratio (Table 1) and a net-mineralization which further indicates the soil in the experiment had a low C/N ratio which had low effect on the materials mineralization potential (Gómez-Muñoz et al. 2016; Fangueiro et al. 2009; 2016). Since the A-LF was acidified just before addition to soil, there was no analyzis for it, but it is assumed that the C/N ratio is the same as

LF. Despite the short-term acidification, A-LF had slightly higher mineralization than LF, it may be due to higher solubilization of nutrients in A-LF (Gómez-Muñoz et al. 2016; Fangueiro et al. 2009). Further, the D had a slightly lower net mineralization than LF and A-LF, which might be explained by the slightly higher C/N ration of D (Table 1).

Plasma activated LF on the other hand had the lowest C/N ratio of all treatments (Table 1) which should give a higher net mineralization according to the pattern seen above. However, P-LF had a significantly lower net mineralization than the other liquid materials. But, due to the uncertainties in P-LF, it is hard to fully understand the results. As an N fertilizer, it still has a high value because the N concentration and especially the NO_2^-/NO_3^--N concentration is so high that there is a lot of N available despite the relatively low net mineralization (Figure 3c).

The solid fraction had a net immobilization which can be linked to the higher C/N ratio compared to the other materials. The immobilization of the solid fraction due to a higher C/N ratio is in line with previous findings from Fangueiro et al. (2009) and Gómez-Muñoz et al. (2016). In addition to the C/N ratio, the roughness of the material also plays a role where a material with a higher proportion of coarse material can have a net-immobilization compared to material with finer materials (Peters & Jensen 2011). The solid fraction is rich in organic N, however, mineralization into plant-available inorganic N is a requirement for adequate utilization of N by the crops. It is credible that an additional separation with a decanter centrifuge, which gives smaller particles (Hjorth et al. 2010), would have a greater N-plant nutrient value than screw press separated SF, as decanter separated SF would still have a high content of organic N at the same time have a possible net-mineralization.

The estimated N mineralization from a material is crucial when assessing the fertilizing value of the product (Fangueiro et al. 2009). However, previous studies have shown that the potential net-mineralization of organic fertilizers is highly dependent on soil properties (Fangueiro et al. 2016). It is therefore not definite how the material will behave if it is used commercially.

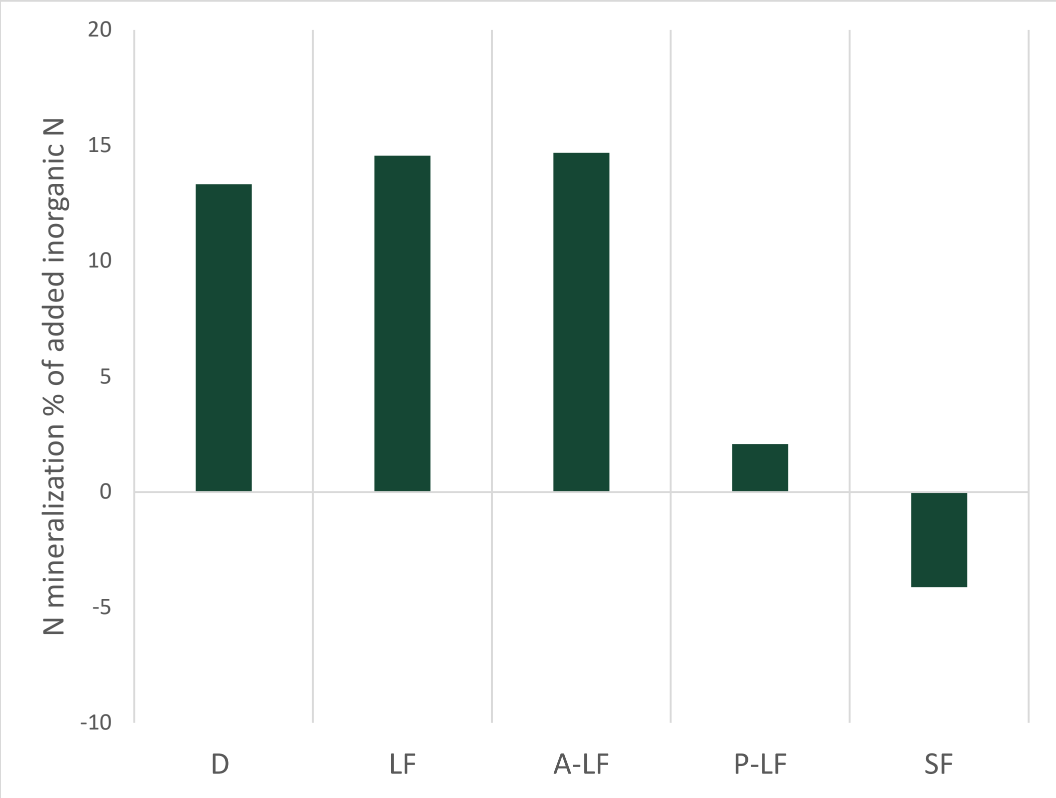

Figure 5. Percentage of mineralization and immobilization of the treatments; the change in inorganic N from the beginning to the end of the incubation study divided by the initial addition of inorganic N. Positive values indicate net mineralization between days 0 and 44, while negative values indicate net immobilization between days 0 and 44

4.3 Farmer's perspective on organic fertilizers

4.3.1 Composition of Swedish farms

There were 99 farmers who responded to this survey from all over Sweden, which corresponds to 0.2 % of all farms in Sweden. In 2020, there were 58'791 farms in Sweden, according to the Swedish Board of agriculture (Jordbruksverket 2020).

Most of the farms in the survey had crop production as their primary production (Table 4), mainly the cultivation of cereals, legumes, or oilseeds. The crop-producing farms in most cases had no secondary production; Only about 20 % had animals in their secondary production. On the other hand, most livestock producing farms had crop production as their secondary production. There were fewer crop-producing farms according to Swedish statistics in 2020 compared to the survey (Jordbruksverket 2020), which indicates an overrepresentation of crop producers in this study.

Table 4. Presentations of the farmers' form of production compared to the statistics from the Swedish board of agriculture. The Swedish board of agriculture's statistics has a mixed production category, which the survey did not have. Mixed farms had several forms of production, with no production part accounting for more than 2/3 of the farm's workload, making it difficult to define a primary production. Because the survey did not ask for workload, it is assumed that the form of production to which the farmer responded accounts for more than 2/3, which makes no farm in the survey considered mixed

	Composition of the farmers in the survey	Agricultural statistics from 2020 (Jordbruksverket 2020)
Crop production	60	28
Animal production	36	27
Mixed*		7
Small farms**		38

*Farms with several production forms, none of which account for 2/3 of the workload, which the survey didn't account for.

**Farms so small that it's not statistically possible to divide into production forms.

Most of the farmers in this survey had larger farms, between 100-200 ha and more than 200 ha. Below 100 ha, the numbers of farmers decreased by hectares, where only a few had between 1-10 ha (Table 5). According to the Swedish Board of Agriculture's statistics, the pattern for Sweden is the opposite, where most farmers have an area between 1-10 ha and the least number have more than 100 ha (Jordbruksverket 2021).

Table 5. Farm size for the farmers who responded to the survey compared to statistics from the Swedish Board of agricultural (Jordbruksverket 2021). There is a slightly different grouping in the survey and the agricultural statistics. For example, the statistics do not have a group for >200 ha. See the "" for a more thorough description.*

	The composition of the farms in the survey (%)	Agricultural statistics from 2020 (Jordbruksverket 2021)
1-10 ha	4	44
10-50 ha	9	26 (+ 9; 30,1-50 ha) *
50 -100 ha	16	10
100- 200 ha	26	11*
>200 ha	28	

**The agricultural statistics divided 10-50 into two groups: 10-30 and 30-50 ha.

*11% have more than 100 ha, thus including ">200 ha."

The farmers in this survey were young compared to the Swedish statistics. Most of the farmers in the survey were between 35 and 60 years old, while most Swedish farmers were between 50-64 years old in 2020 (Jordbruksverket 2021). Note that the age classification in the survey and Swedish statistics differ (Table 6). In future surveys the same age groups as the Swedish statistics should be used to compare more easily.

The age group was compared with the size of the farm to gain a deeper understanding of the composition of the farms. The comparison showed that the youngest age group, i.e., between 18-24 years, had the largest farms and the oldest age group had the smallest farms in the study (Table 6). Additionally, the Swedish board of agriculture's statistics shows that many Swedish farmers do not have an active business, which may explain the young age of those who responded to the survey. It may be that some of the older people included in the Swedish statistics have begun to wind down their operations and are therefore not interested in studies like this. But it may also be the case that the low age in the survey is due to the fact that the survey was held online, older people might be sceptical or not knowing how to conduct these surveys.

Table 6. A presentation of the age of the farmers in the survey (question 21); Two questions were compared to understand the distribution of farm sizes (question 20) between the different age groups. The age distribution in the survey was compared with statistics from the Swedish Board of agriculture (Jordbruksverket 2021).

The composition of the farms in the survey		
	The distribution of age groups (%)	The most common farm size in the different age groups (ha)
18-24	11	>200
25-40	24	100-200
40-60	35	>200
60+	11	50-200
Statistics from the Swedish board of agriculture (Jordbruksverket 2021)		
Age group	Distribution (%)	
<34	5	
35-49	20	
50-64	40	
65+	35	

*Simplification of the results, the same number of farmers over 60 years had 50-100 as the number of farmers over 60 years that had 100-200 ha.

Both organic and conventional farms answered the survey; Most were conventional, 77 % (including all forms of production). Most livestock producers had conventional production, around 70 %. The crop producers were also mostly conventional, with only 18% of crop producers being organic. In 2020, 19 % of arable land in Sweden was in organic production, according to the Swedish Board of agriculture. Thus, the distribution between organic and conventional crop producers is similar to the Swedish statistics. Beef and dairy products were about 85% conventional, thus slightly higher than in the survey (Jordbruksverket 2021).

To conclude, the farmers who responded to the survey did not have the same composition as Swedish statistics. In the study, a more significant fraction of farmers had crop production as their primary production. Furthermore, the farms were larger, and farmers were younger. The share of organic production was about the same as the statistics.

4.3.2 Current use of organic fertilizers

Most of the respondents, 83 %, in this survey used organic fertilizers, although only about half of them had livestock production. This implies that farms that did not have animals purchased organic fertilizers even though it usually is more expensive. Most crop-producers used organic fertilizers such as biofer or ecoväxt (Swedish brands) and Revaq sludge (Swedish certification of sewage sludge). Many crop-producers used manure from animal sources as liquid or solid animal manure. This suggests that a certain redistribution of manure from animal farms to crop-producers is taking place in Sweden today, which Case et al. (2017) found in a 2016 study in Denmark.

Although many farmers used organic fertilizer, only a few were able to meet their requirements for nutrients by applying only organic fertilizers. A big part of farmers needed to apply extra nutrients in the form of mineral fertilizers. Most farmers spread around 136-170 kg total N/ha (both mineral and organic fertilizers), which is the recommended amount for, e.g., wheat production in Sweden (Figure 6a). Only 30 % of 136-170 kg N/ha was applied as organic fertilizers. When looking at farms with lower plant nutrient requirement (31-65 kg total N/ha), almost the entire nutrient requirement (95%) of organic fertilizers (Figure 6b) was achieved. A pattern could be seen in the results, where the fraction of organic fertilizers decreased with increasing total N application. That said, it seems that the farms that grow N demanding crops like wheat needs extra nutrients, like mineral fertilizers. While farms that grow crops with lower N demand such as legumes can more often rely on organic fertilizers.

The farms that spread the lowest amount of P (<5 kgP/ha) also generally spread almost all of it in organic form. However, not all farms that spread <5 kg P in total/ha spread as much in organic form because some responded that they did not know how much they spread in organic form. As with N, most farms applied P in the higher ranges. Most farms spread between 16-20 kg total P/ha (Figure 6c), and about 67 % of this was spread in organic form (Figure 6d). The second most common amount of total P for the farms was 21-25 kg total P/ha, where about 70 % was spread in organic form.

The percentage of nutrients applied in organic form was calculated based on questions 4, 5, 8, and 9 (Appendix 1). Each farmer who applied a certain amount of P and N in organic form (questions 8 and 9) is added together with the respective amount they spread to get a total amount of the 99 who responded to the survey, while keeping apart who had answered which amount. The same was done for the total amount of P and N (question 4 and 5) spread by the farmers. Since the amount that each farmer had replied that they had spread was known, the number of organic fertilizers corresponding to, for example, < 5 kg organic P/ha could be divided by the corresponding amount to <5 kg total P/ha. Since the amount of application had ranges (e.g., 31-65 kg N/ha), an average of the range was used to make the calculations for each range.

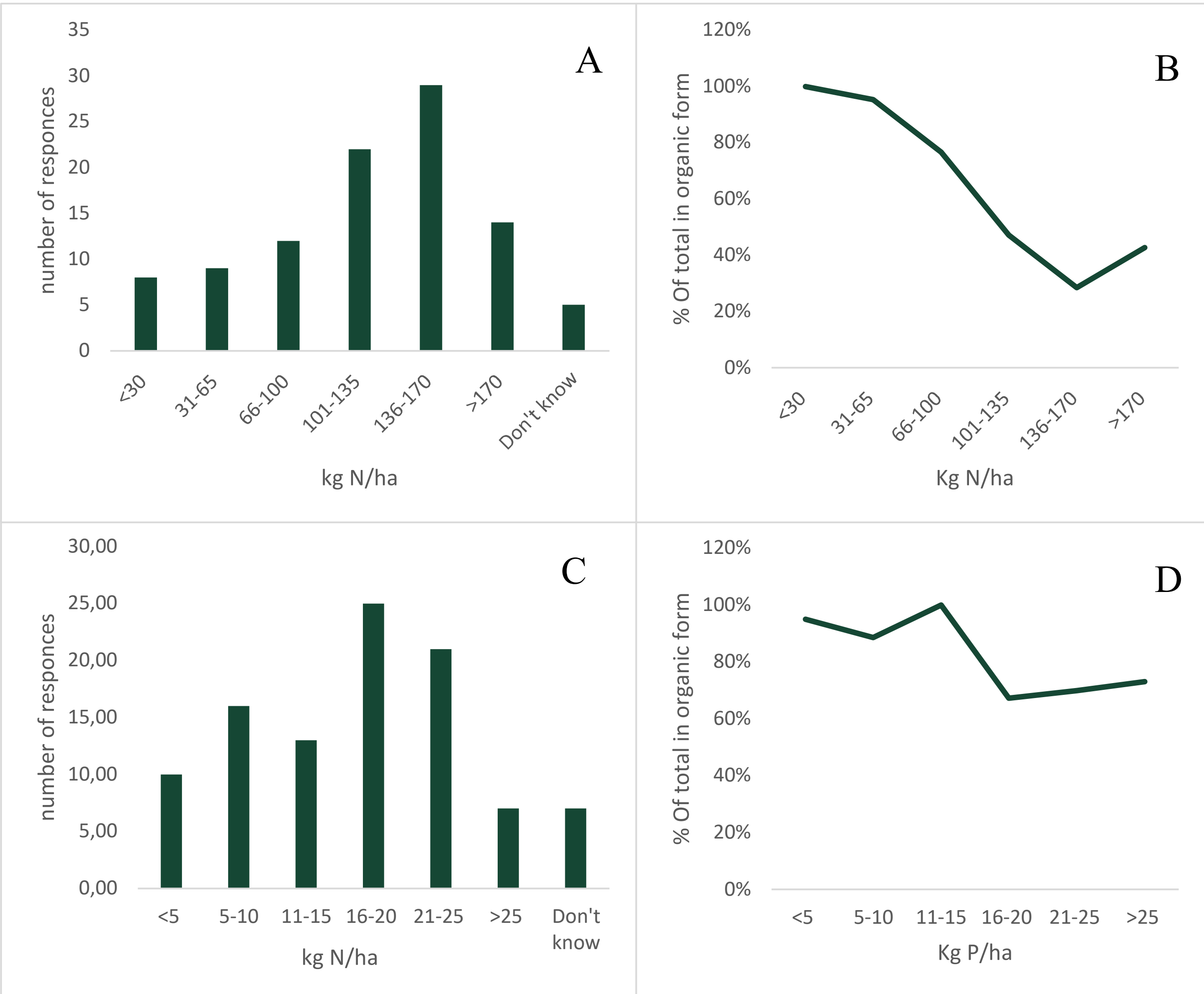

Figure 6. The farmers estimated the total amount of N and P spread on the fields. On the left is estimated nutrient application with mineral and organic fertilizers, with N on top and P on the bottom. On the right is % of total N and P spread as organic fertilizers, with N on top and P on the bottom. See Appendix 1 for more detail

4.3.3 Future use of organic fertilizers

To understand how farmers feel about trying new types of organic fertilizers, they were asked what kind of fertilizers they would consider using within the next five-year period. The most popular organic fertilizers for future use are animal slurry and solid manure; these are also the most widely used today (Table 7).

The current and possible future use were compared to see which organic fertilizer might have the highest potential for future use. The comparison was made by subtracting the current use from the future use to see if someone who does not currently use one of the organic fertilizers might be able to do so in the future. This comparison shows that there are 31 (out of 99) people who are willing to use biofertilizers compared to today's use (11 people), i.e., 20 people who do not use biofertilizers today may consider using them in the future. The solid and liquid fraction of separated animal slurry or digestate are organic fertilizers that several people may consider using in the future but are not commonly used today. Only three people use the LF today while none use the SF (according to this survey). Other organic fertilizers that may be used more in the future are composted animal manure or digestate and sewage fraction from source-separated sewage. Organic fertilizers that are unlikely to be used more than today were animal slurry and solid manure/deep litter, with fewer people using them in the future than currently. That being said, these two organic fertilizers are still the most common.

Table 7. Presentation of current use of organic fertilizers according to the survey (question 7, see appendix 1), compared to preferred future use of organic fertilizers (question 10, see appendix 1). The current use and predicted future use were compared to see if there was any organic fertilizer that is not so common today but is seen as a possible future choice for Swedish farmers

Organic fertilizers	Current use	Future use	Difference
Animal slurry	48	45	**-3**
Solid manure/deep litter	55	54	**-1**
Urine (from animals)	9	10	**1**
Biofertilizers (digestate from biogas production)	11	31	**20**
The liquid fraction of separated animal slurry or digestate	3	15	**12**
Solid fraction of separated animal slurry or digestate	0	15	**15**
Acidified animal slurry or digestate	0	7	**7**
Composted animal manure or digestate	5	17	**12**
Pelleted animal manure or digestate	3	12	**9**
Biochar	1	9	**8**
Organic fertilizers on the market (e.g., biofer/ekoväxt)	8	14	**6**
Source separated closet water	0	4	**4**
Urine from urine separated toilets	1	4	**3**
Sewage fractions from source-separated sewage	0	11	**11**
Sludge (REVAQ)	11	17	**6**
Other organic fertilizers	4	6	**2**

Amount of organic fertilizer in the future

Most farmers in the survey estimate that they would use the same or increase their use of organic fertilizers in the future. Only about 6 % estimated they would reduce their use of organic fertilizers (Figure 7). An attempt was made to compare future use, current organic fertilizers, and production form. The comparison showed no clear difference that a farmer with a particular form of production or current use of organic fertilizer wanted to increase or decrease the use of organic fertilizer in the future.

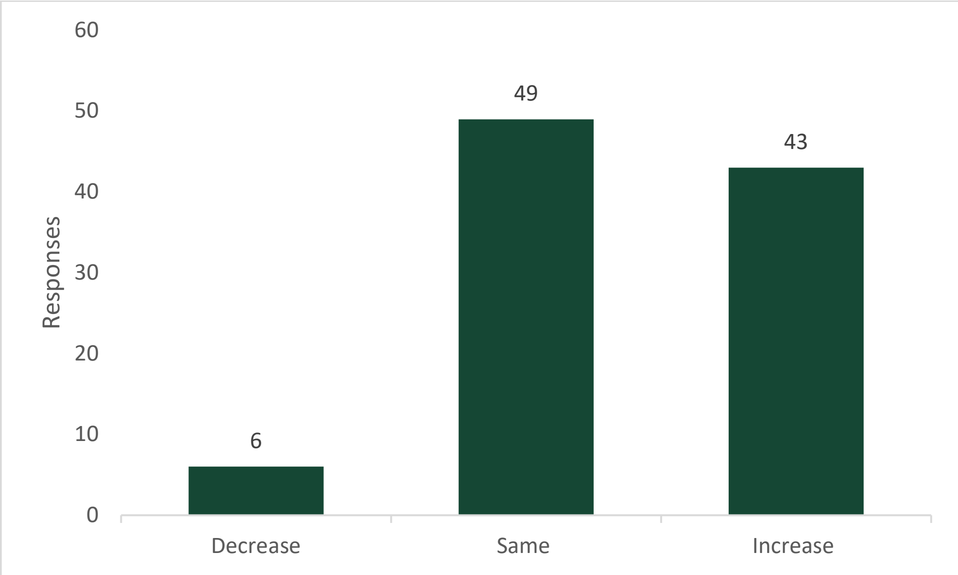

Figure 7. Predictions made by farmers about their future use of organic fertilizers (to increase, decrease or the same amount of organic fertilizer as today.

Properties of future organic fertilizers

The farmers in the survey ranked why they choose to use organic fertilizers but also the biggest obstacles to using them. Moreover, they were asked to answer in what form they would prefer a future organic fertilizer to be. They were also asked about if it is important with a fast release of N and P and about the importance of carbon in the fertilizers.

Table 8. Presentation of the reasons for using organic fertilizers in order of priority. The total number of clicks refers to the sum of the number of farmers who answered that it is a crucial reason, second most important reason, or quite important reason.

Reasons to use organic fertilizers.	Number of clicks
Soil improvements	63
Uses the manure that the farm produces	46
Priceworthy	36
Free or get refunds	36
Carbon sequestration	33
Have organic production	30
Available	23
Known nutrient value	21
Others	20
Environmentally friendly	18
Appropriate plant nutrient composition	16
Easy to handle	13
Not more expensive (than mineral fertilizers)	13
Quality certified	9

Potential answers about the reason to use organic fertilizers were included in the question, e.g., soil improvement, price, environment, and nutrient value. The farmers could respond if they thought it was the most crucial reason, the second most important reason, or quite important but still a relevant reason for using organic fertilizers. In Table 8, answers are presented without ranking, i.e., all responses weighted equally according to number of times they were chosen in total (all levels included). The most important reason for using organic fertilizers was the soil-improving properties that organic fertilizers have. The second-highest ranking was that the farmers have animals and use the manure at hand. The third and fourth highest ranking was the price of the organic fertilizers, both whether it was prize-worthy or even free/gets refunds for using it. The lowest ranking reason for using organic fertilizers was whether it would be quality certificate, “not more expensive” than mineral fertilizers, as well as easy to handle (Table 8).

The highest-ranking reason not to use organic fertilizers is that it contributes to soil compaction. Soil compaction can be a problem with organic fertilizer due to the dilution of nutrients with water, thus less nutrient per kg wet weight. Spreading a material with a low concentration of nutrients per kg wet weight requires a large and heavy tank or several overruns with a smaller tank to reach the target application rate. Thereby, the risk of soil compaction may increase. The second highest-ranking reason is that it is expensive to spread. The third highest ranked reason is unsure nutrient content and fourth is that it is difficult to get a hold of if the farmer would no longer have animals. At the bottom of reasons for not using organic fertilizers is that it is expensive as well as the risk of environmental impact (Table 9).

Table 9. Presentation of reasons for not using organic fertilizers; in order of priority. The total number of clicks refers to the number of framers that answers that it is a crucial reason, second most important reason, or quite important reason.

Reasons not to use organic fertilizers	Number of clicks
Contributes to soil compaction	50
Expensive to spread	30
Uncertain nutrient value	25
Hard to handle practically	20
Hard to conduct a fertilising plan	12
If I stop with animal production	12
Other	12
Non-appropriate plant nutrient composition	12
Risk to not be able to sell my product /my buyer don't allow it (mostly sludge and sewage fraction)	10
Hard to get a hold on	7
Not quality certified	6
Expensive	1
Risk for negative environmental impact	1

Nutrient release and carbon content

Farmers were asked if they would prefer an organic fertilizer that would release N and P to the crops quickly or slowly. Most farmers wanted a quick release of nutrients rather than a slow one, but there were slightly more that wanted a fast release of N than P. This question was compared with the background question: Whether the farmers were conventional or organic. The comparison did not show a clear trend between the different agriculture practices. Both organic and conventional farms found a fast release of nutrients to be better than a slow one. However, more organic farmers than conventional wanted a slow release (Figure 8). So, the number of farmers who wanted a quick release was about the same for organic and conventional but differed for the slow release of nutrients. One reason why the numbers of farmers differ is that several of the conventional farmers did not answer this question.

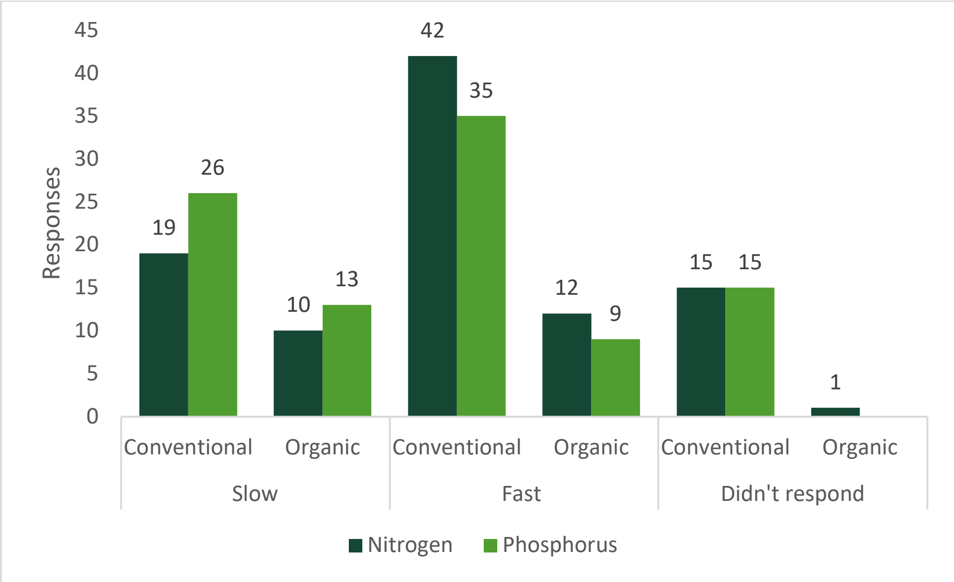

Figure 8. If the farmers want a slow or a fast release. Divided up into if the farms are organic or conventional (i.e., comparison between questions 3, 17, and 18, see appendix 1).

There was also a question about the importance of C content in organic fertilizers. Most farmers thought the C content was somewhat important, and only a few though it was not essential. Almost as many farmers thought C content was essential as the number of farmers who thought it was somewhat important. As with the nutrient release to the crops, this question was compared between organic and conventional farms. Almost as many organic farmers as conventional believed that C content was essential. However, more conventional farmers thought C content was somewhat important than organic farmers. Furthermore, a higher proportion of the organic farmers replied that C content was not crucial in organic fertilizers than the conventional farmers (Table 10).

Table 10. Presentation of the importance of carbon content in organic fertilizers. Additional comparison between conventional and organic farms to see if there is a difference between the interest in carbon depending on on-farm practices.

	Distribution among all respondents (%)	Distribution among organic farmers (%)	Distribution among conventional farmers (%)
Essential	32	36	38
Somewhat important	40	36	52
Not important	12	27	10

Further, the farmers were asked in what form they would like to have the future organic fertilizer. According to this survey, granules were most popular before pellets and liquid. The combined solid and liquid forms were more popular than the semisolid forms but not as popular as granulate, pelleted, and liquid (Figure 9). There was no pattern of preference between the farmer's current use of organic fertilizers, i.e., the farmer that today used liquid manure was as optimistic to pellet as, e.g., farmers that used digestate or composted manure.

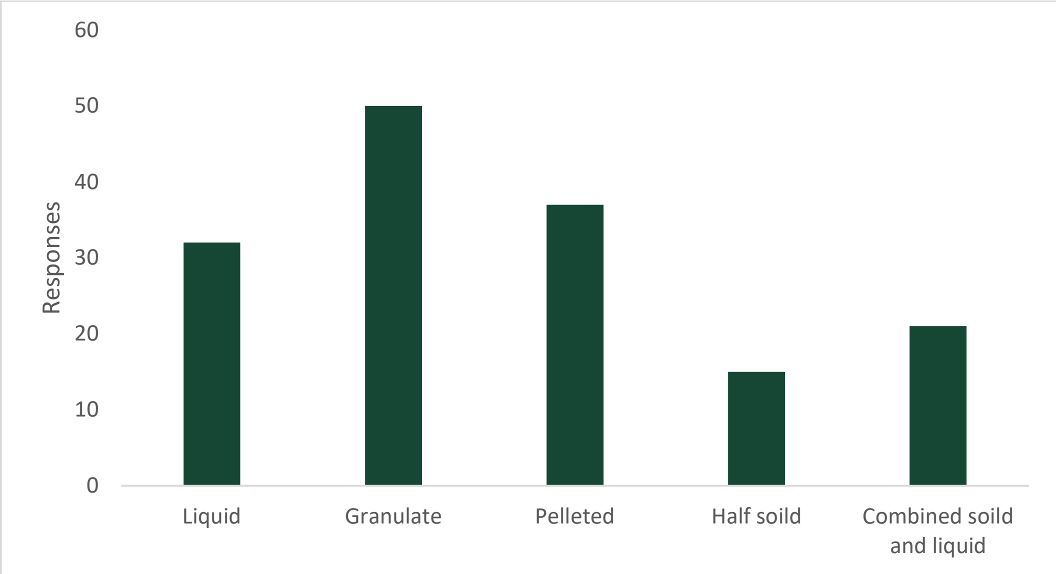

Figure 9. Which form of organic fertilizer is considered more interesting in the next five years according to farmers in the survey.

4.3.4 Alternative organic fertilizers

To see how open farmers are to alternative organic fertilizers, they were given the opportunity to answer if they would *absolutely*-, *possibly*-, *rather not*, or *absolutely* not consider using alternative organic fertilizers in the future. They also had the option to answer that it *did not matter*. The alternative organic fertilizers were urine from urine separating toilets, litter from a dry toilet, water closet (WC) water from closed tanks (i.e., no greywater), REVAQ sludge, household compost, and digestate.

Table 11. Number of farmers that absolutely could consider using alternative organic fertilizers (question 15). The alternative with highest numbers of farmers is estimated to be the most interesting to farmers given it was quality safe and certified

Organic fertilisers with alternative sources	Number of responses
Biodigestate	47
Urine from urine separating toilets	27
Household-compost	20
Latrine from dry toilets	19
WC water from closed tanks (not bath-, dish-, laundry water)	22
Sewage sludge (Revaq)	18

Many farmers were optimistic about using alternative organic fertilizers, with most answers being *absolutely* or *possibly*. The most popular organic fertilizer was bio-digestate, and the second most popular were urine from urine separating toilets and household compost. However, although urine was second most popular, only about half as many could (*absolutely*) consider urine compared to digestate (Figure 10).

Further, almost as many could (*absolutely*) consider using REVAQ sludge compared to urine (Figure 10). Indeed, there was not much difference in how many people could *absolutely* consider using one of the alternative organic sources as fertilizers, except for bio-digestate, which was the positive outlier.

A comparison was made on age and frequency of *absolutely*-, *possibly*-, *rather not*, *absolutely* not, or *did not matter*, to see the variance in how the different age groups in the survey answered the questions. This comparison showed that the younger age group was not *absolutely* positive, and most answered that they would *possibly* use an alternative source for organic fertilizer. The next age group, 25-39, was more optimistic, with the majority *absolutely* being able to consider using an alternative organic fertilizer. The age group, 40-60, was as positive to organic fertilizers as those between the ages 25-39. The oldest age group was somewhat positive, with many *possibly* considering using an alternative organic fertilizer. Nevertheless, there were also many in the oldest age group who would *rather not* and *absolutely* not consider using organic fertilizer (Figure 11). As discussed before, the age in the survey is not representative for Swedish statistics. The positive answers for alternative organic fertilizers may indicate that most of the farmers in the survey answered because they were already interested. The fact that the older ones were less positive than the younger ones might strengthen this theory, since there were few over the age of 60 who responded to the survey.

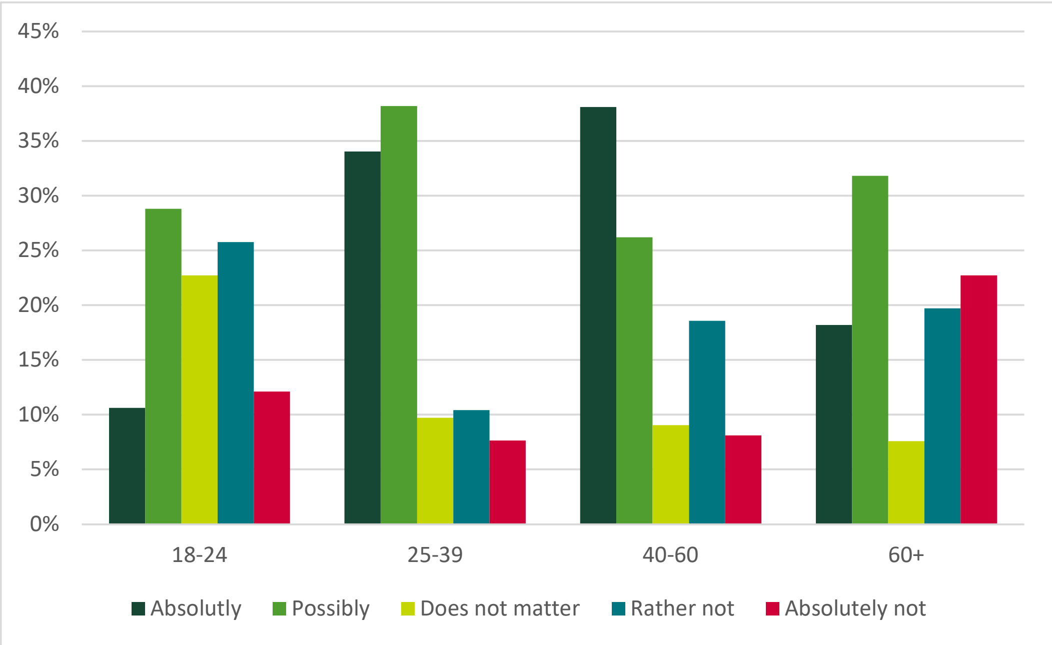

Figure 10. The distribution of positive versus negative responses from question 15 (also seen in figure 10) depended on age group (question 21) in the study. See appendix 1 for more information

4.4 Future potential of the fertilizers examined in the present study

It is important to remember that the incubation study was done under very controlled conditions, and the results would probably differ significantly from field conditions. However, it is still possible to assess the suitability of separated digestate as organic fertilizers. First, the farmers in this survey seemed interested in a future use of organic fertilizers, and several thought they would increase their use which is positive news for a study like this.

An uncertainty in future use is the nutrient content of manure, which can change depending on which feed is used (Jönsson et al. 2004) and thus also which animals are involved, what time of year it is, etc. Additional uncertainty is potential N losses during handling, which can be counteracted by acidification. The stability of the acidified slurries can thus increase the framers' confidence in using slurries as a substitute for mineral fertilizer (Fangueiro et al. 2015). Sigurnjak et al. (2017) discussed that acidified slurries can benefit some crops, especially those with longer growing period. However, as previously mentioned, LFs from separated manure or digestate do not have the same C and P content as the SFs and are not suitable for those farms that have a high need for C and P.

The SF can quite easily be converted into granulated/pelleted form and is easier to transport longer distances than the LF due to the weight/ nutrition ratio. Thus, the SF may be of interest to farmers because of its low weight and high C and P concentration. This study has not gone into more detail about the potential of the SF but see Nissen (2022) for an in-depth discussion around this organic fertilizer.

The organic fertilizer that stood out the most was P-LF and there are great uncertainties in the results around this material. Due to the great uncertainties, future research is necessary to gain more understanding of its nutrient content and how it affects the nutrient supply after application to the soil. Further, a field or a pot experiment with materials like the once used in this experiment would be interesting to understand how the organic fertilizers would affect the crops.

5. Conclusion

All the liquid fractions showed a net N mineralization in contrast to the solid fraction which showed a net immobilization during the incubation period of 44 days. According to the survey, most Swedish farmers wanted a quick release of nutrients; thus, all LFs should be more attractive for farmers. However, it is important to remember that a different soil than the one used in this study might have a different mineralization effect.

The liquid fractions have a downside where it can have a higher risk of soil compaction due to its weight-nutrient ratio. Swedish farmers preferred the granulated and pelleted forms of organic fertilizers probably due to the lower risk of soil compaction compared to liquid materials. But because the screw press removed most of the P from the LF, it should lower the P load on farms where the solid fraction is removed. Acidified LF has the potential to reduce the NO_3^- leaching due to a delayed nitrification process, but how this in turn affects the yield is unsure.

The solid fraction had the highest C concentrations of all materials, which farmers in the survey appreciate. Additionally, the solid fraction can be transformed into pelleted or granulated forms, which is interesting. However, the solid fraction showed a net immobilization, so it does not have beneficial properties as a fast-release N fertilizer, which was valuable to many farmers according to the survey. It could work well as a soil improver and increase C and P concentrations in soils with low concentrations of C and P. As the survey clearly showed, soil improving properties are one of the most important reasons for using organic fertilizers according to Swedish farmers. Indeed, the two different fractions from the screw press separation have interesting properties in themselves, where some farmers may value the slow release of N as well as high C content of the solid fraction while others may prefer the quicker release of N coupled with the low P concentration of the LFs.

Plasma activated LF had a net mineralization but close to no nitrification, which was somewhat unexpected. Although nitrification is strongly inhibited, there is a very high proportion of NO_3^-/NO_2^--N that either can be taken up by plants or be at risk of leaching. However, these results have significant uncertainties, both during collection and when interpretating the results. There are not many published studies on plasma activation; it is therefore difficult to understand how much of the outcome may have been sampling errors and what may have been representative of the plasma activation technique. As more and larger (e.g., field scale) studies are conducted a better idea of how plasma-activated fertilizer might work in practise could be received.

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Populärvetenskaplig sammanfattning

Östersjön står idag inför många utmaningar, bland annat minskande fiskpopulationer och frekventa algblomningar. Ett tydligt exempel på hur övergödningen syns är det tjocka gröna kladdet som ofta ses på stenar nära stränder. Detta är alger som har bildats på grund av de höga fosfor- och kvävekoncentrationerna. Idag kommer stora delar av fosfor och kväve från jordbruket, bland annat från spridning av djurgödsel på åkermark. I markerna runt djurgårdar så ökar fosforhalterna över tid på grund av upprepad spridning av fosfor med stallgödsel samt inköp av fosforrika fodermedel vilket resulterar i ett så kallat fosforöverskott på gårdsnivå. För att minska risken för att näringsämnena från stallgödsel kommer ut i naturen så har flera tekniker utvecklats. Genom att separera gödsel, alltså ta bort vattnet, så går det att få ett relativt torrt material med mycket fosfor i som går att transportera långa sträckor. Den flytande gödseln som blir kvar är i stället rik på kväve och kan spridas runt djurgården där kväveöverskott sällan är ett problem. Men, kvävet i den flytande gödseln kan vara mycket flyktigt och lätt avdunsta till atmosfären i form av ammoniak och vidare ut till vattendrag. För att undvika problematiken med kväveavdunstning undersöks olika sätt att stabilisera kvävet. Ett sätt som undersöktes i denna studie var surgörning av den flytande delen.

I detta experiment testades två tekniker för att surgöra den flytande delen från i detta fall rötad stallgödsel (biogödsel) som separerats mekaniskt. Det ena var att tillsätta syra direkt till vätskan, som vidare kallas surgjord. I den andra tekniken tillsatte en kväveförening (nitrat/nitrit) som producerats med hjälp av plasmateknik. När kväveföreningen tillsattes i den flytande delen omvandlas det till en syra som sin tur sänkte pH i vätskan, vidare kallad plasma-aktiverad. I detta experiment hade det plasma-aktiverade materialet en oväntad effekt att nästan helt hämma den så kallade nitrifikationen (nitrifikation omvandlar det svårrörliga ammoniumet till mer lättrörligt nitrat). I den plasma-aktiverade flytande delen skedde alltså ingen omvandling av ammonium till nitrat. Den hämmade nitrifikationen har både för och nackdelar då hög andel av ammonium också minskar risken för att kväve försvinner ut till sjöar och hav genom grundvattnet (eftersom ammonium är mindre läckagebenäget). Den surgjorda delen hade också en liten minskning av nitrifikationen under de första dagarna av experimentet med nådde sedan samma nivå som den vätska som inte hade surgjorts. Detta innebär att trots att den surgjorda vätskan hade högre halt svårrörligt kväve i början så omvandlades det till mer lättrörligt kväve efter några dagar. Även om det mer lättrörliga kvävet löper större risk att försvinna i naturen så skapar inte det några problem om det finns växter som har möjlighet att ta upp kvävet innan det rinner ut i vattendragen. Alltså, oavsett vilken form av surgjord gödsel som används så är det spridningstidpunkten som avgör om kvävet kommer tas upp av växter eller rinna ut i vattendrag.

De två olika teknikerna för att surgöra den flytande delen gav också två olika så kallade mineraliseringseffekter av kvävet. Mineralisering innebär att kväve som är bundet till organiskt material i marken, frigörs och därmed blir lättillgängligt för växter. Den surgjorda flytande delen hade högre andel tillgängligt kväve i slutet av experimentet än i början, kväve hade alltså mineraliserats. Den plasmaaktiverade flytande delen däremot hade mindre tillgängligt kväve i slutet av experimentet än början så kvävet hade alltså inte mineraliserats. För att få en långvarig gödslingseffekt föredras nettomineralisering eftersom mer organiskt kväve blir tillgängligt. Detta innebär att den surgjorda flytande delen borde fungera som ett effektivt kvävegödselmedel samtidigt som den minskar förlusten av kväve i och med att det inte avdunstar som ammoniak. Värt att nämna är dock att den plasma-aktiverade flytande delen hade mycket hög andel lättillgängligt kväve i början av experimentet så trots att kväve inte mineraliserades fanns hög andel lättillgängligt kväve kvar. För att bedöma effektiviteten som kvävegödselmedel är det alltså viktigt att kontrollera den initiala mängden lättillgängligt kväve likväl som mineraliseringen av kvävet. Det är också viktigt att särskilja på mineralisering och nitrifikation där mineralisering innebär en reell ökning av kväve som är tillgängligt till växten medan nitrifikationen endast påverkar hur snabbrörlig föreningen är i marken.

Den torra delen med högt fosforinnehåll som har möjlighet att transporteras långa sträckor innehåller även mycket kol och organiskt material. Dessa egenskaper gör att det torra materialet kan fungera mycket väl som jordförbättrande medel då kol är känt för att förbättra jordstrukturen och därmed avkastningen. Fosfor är ofta en bristvara på gårdar som inte ha djur och de måste köpa stora mängden från mineralgödsel som har utvunnits från gruvor, oftast i andra länder. Den undersökta tekniken som underlättar förflyttning av fosfor minskar alltså behovet att importera fosfor från andra länder vilket ökar Sveriges självhushållning i stort.

Den största utmaningen med att förädla djurgödsel som beskrivits ovan är jordbrukarnas vilja att köpa produkten. En enkätundersökning genomfördes för att förstå lantbrukarnas syn på förädlat djurgödsel samt andra organiska gödselmedel som avloppsslam och biokol. Enkäten visade att lantbrukare var positiva till att använda organiska gödselmedel och då framför allt från djurgårdar, medan de var lite mer skeptiska om det var gödselmedel från humana källor. Lantbrukarna föredrog lätthanterliga material så som det torra materialet beskrivet ovan, men de ville också ha snabb frigörelse av näring vilket detta material inte hade. Det var vätskedelen i det här experimentet som hade snabbare frigöring av näring, men då är det tyngre och mer svårhanterligt. Men det var även väldigt viktigt med jordförbättrande medel för lantbrukarna, något som den torra delen kan bidra med. Denna studie har alltså visat att separering av djurgödsel kan bidra med två olika typers gödselmedel; ett jordförbättrande medel och ett kvävegödselmedel där lantbrukarna själva kan avgöra vilket gödselmedel som är bäst lämpade till deras gård. Alla produkter i detta experiment har dock en stor utmaning i att de kan ha svårt att konkurrera mot mineralgödsel. Mineralgödsel har ett känt näringsvärde och är lätt att komma åt. Beroende på typ av gödselmedel kan organiskt gödselmedel vara dyrare än mineralgödsel. Kostnaden för transporten av organiska gödselmedel kan bli väldigt höga, speciellt om de är blöta och tunga som den flytande delen diskuterad ovan. Dessutom finns det en del osäkerheter kring studier som denna, så för att bättre förstå hur dessa typer av gödselmedel fungerar i praktiken behöver större studier genomföras på fältnivå.

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Appendix 1

The questions and answers in the questionnaire.

	Question	Alternatives	Distribution of answers
1.1	Post code		
2.1	What is your primary production form?	Crop production (cereal/legumes/oil seeds)	51
		Crop production (forage)	5
		Horticultural production	4
		Pig production	3
		Dairy (Cow)	17
		Poultry	2
		Beef	12
		Sheep/goat	2
		Non active compony	2
		Energy crops	0
		Other	1
2.2	What is your secondary production form?	Crop production (cereal/legumes/oil seeds)	41
		Crop production (forage)	47
		Horticultural production	4
		Pig production	0
		Dairy (Cow)	5
		Poultry	0
		Beef	14
		Sheep/goat	1
		Non active compony	5
		Energy crops	0
		Other	11
3.1	Do you have conventional or ecological farming practises	Conventional	76
		Organic	23
4.1	How many kg phosphorus did you applied to your fields this year per hectare? (In kg/hectare)	<5	10
		5-10	16
		11-15	13
		16-20	25
		21-25	21
		>25	7

		Don’t know	7
5.1	How many kg nitrogen did you applied to your fields this year per hectare? (In kg/hectare)	<30	8
		31-65	9
		66-100	12
		101-135	22
		136-170	29
		>170	14
		Don’t know	5
6.1	Do you use any kind of organic fertilizers today?	Yes	82
		No	17
7.1	Which or what kind of organic fertilizers do you use today? (Multiple options)	Slurry manure	48
		Solid-/Deep litter manure	55
		Urine	9
		Biofertilizers (digestate from biogas production)	11
		Acidified slurry or digestate	0
		Liquid fraction of separated slurry or digestate	3
		Solid fraction of separated slurry or digestate	0
		Composted animal manure or biofertilizers	5
		Pelleted animal manure or biofertilizers	3
		Biochar	1
		Organic fertilizers on the market (e.g. biofer/ecoväxt)	8
		Source separated closet water	0
		Urine from urine separating toilets	1
		Waste fraction from source separated sewage	0
		REVAQ sludge	11

		Other organic fertilizers, specify	4
7.2	Other organic fertilizers, specify		
8.1	How much kg Phosphorus per hectare where from organic fertilizers like animal manure, manure pellet, biofertilizers etc. (kg/hectare)	<5	24
		5-10	16
		11-15	14
		16-23	11
		21-24	8
		>25	4
		Don't know	6
9.1	How much kg nitrogen per hectare where from organic fertilizers like animal manure, manure pellet, biofertilizers etc. (kg/hectare)	<30	30
		31- 36	30
		66-100	12
		101-135	3
		136-170	0
		>170	2
		Don't know	6
10.1	What or which organic fertilizer do you think is most interesting to use in you production within the next coming 5 years (multiple options)	Animal slurry	45
		Solid-/deep litter manure	54
		Urine	10
		Biofertilizers (digestate from biogas production	31
		Acidified animal slurry or biofertilizers	7
		Liquid fraction of separated animal slurry or biofertilizers	15
		Solid fraction of separated animal manure or biofertilizers	15
		Composted animal manure or biofertilizer	17
		Pelleted animal manure or biofertilizers	12
		Biochar	9
		Organic fertilizers on the market e.g. biofer/ecoväxt	14

		Non	2		
		Source separated closet water	4		
		Urine from Urine separating toilets	4		
		Waste fractions from source separate sewage	11		
		REVAQ sludge	17		
		Other organic fertilizers on the market	6		
10.2	Other organic fertilizers, specify				
11.1	Which of the following statements best describes your future (five years and ongoing) need of organic fertilizers)	I'm going to decrease the use of organic fertilizers	6		
		I'm going to use the same number of organic fertilizers as today	48		
		I'm going to increase the use of organic fertilizers	43		
12.1	How much of your future crop nutrient needs do you believe will come from organic fertilizers or fertilizers with organic sources	<25 %	18		
		26-50 %	25		
		51-75 %	9		
		>75 %	21		
		Don't know	7		
13.1	Rank the three most important reasons to why you use organic fertilizers today or would think about using it in the future (Choose three; most important, second most important, or less important but still of relevance)		**Most**	**Second**	**Less**
		Soil improvements	29	21	13
		Prizeworthy	6	18	10
		Is available in my area	6	3	10
		Environmentally friendly	4	5	5
		Known crop nutrient effect	2	8	8

		Appropriate crop nutrient composition	2	6	2
		Easy to handle	8	0	5
		Quality certified	0	1	1
		Not more expensive than spreading than other fertilizers	0	1	3
		Uses the manure that the farm produces	26	8	2
		Have an organic farm and must therefore use organic fertilizers	10	4	5
		Increases carbon sequensation in the soil.	2	10	9
		Get it for free or get subsidies for spreading it	4	6	13
		Other	0	1	5
14.1	Rank the three most important reasons to why you choose to not use organic fertilizers now or in the future (Most important, second most important, or less important but still of relevance)		**Most**	**Second**	**Less**
		Uncertain crop nutrient value	11	2	3
		Unsuitable crop nutrient composition	0	6	5
		Hard to do a fertilizing plan	2	4	6
		Expensive to spread	5	8	7
		Contribute to soil compaction	13	18	19
		Hard to handle practically	5	8	7
		Not quality certified	1	3	2
		Expensive fertilizers	5	4	3
		Risk for negative environmental impact	3	6	4
		Hard to get a hold on	16	5	4

		If I quit with animal production	14		4		7
		Risk to not be able to sell my products/ my buyer won't allow it (mostly sludge and sewage fractions)	9		5		6
		Other	3		4		5
15.1	How do you feel about spreading organic fertilizers with the following source (giving that it is quality safe and certified)? Absolutely (a.) Possibly (b.) Does not matter (c.) Rather not (d.) Absolutely not (e.)		**a.**	**b.**	**c.**	**d.**	**e.**
		Urine from urine separating toilets	27	23	12	14	7
		Latrine from dry toilets	20	25	11	16	11
		Closet water from closed tanks (not bath-, dish-, or laundry water)	19	24	11	21	8
		Sewage sludge (revaq)	18	25	6	17	17
		Household- compost	23	33	8	11	8
		Bio digestate	47	21	5	6	4
16.1	In what form would you like/prefer to use organic fertilizers	Liquid			32		
		Granulate			50		
		Pelleted			37		
		Half solid form			15		
		Combined solid and liquid			21		
17.1	How fast would you like that the nitrogen is released to the crops in an organic fertilizer?	Slow release			29		
		Fast release			55		
18.1	How fast would you like that the phosurus is released to the crops in an organic fertilizer?	Slow release			39		
		Fast release			45		
19.1	How important is it that an organic fertilizer have carbon i.e., gives more hummus	Very important			32		
		Pretty important			40		
		Not important			12		
20.1		0-10			3		

	How much land do you have (in hectare)	10.1-50	7
		50.1-100	12
		100.1-200	23
		>200	23
21.1	In what age group are you?	18-24	5
		25-39	16
		40-60	21
		60+	4
22.1	What is your gender?	Women	12
		Man	65
		Other/don’t want to answer	4

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