AGRICULTURE AND FOOD

Technologies and management practices for sustainable manure use in the Baltic Sea Region

Erik Sindhöj, Marek Krysztoforski, Katrin Kuka, Sari Luostarinen, Zanda Melnalksne, Kristina Mjöfors, Kaisa Riiko, Kalvi Tamm, Kari Ylivainio, Minna Sarvi

RISE Report 2020:77

Interreg Baltic Sea Region

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

Technologies and management practices for sustainable manure use in the Baltic Sea Region

Erik Sindhöj[1*], Marek Krysztoforski[2], Katrin Kuka[3], Sari Luostarinen[4], Zanda Melnalksne[5], Kristina Mjöfors[1], Kaisa Riiko[6], Kalvi Tamm[7], Kari Ylivainio[4], Minna Sarvi[4]

[1] RISE – Research Institutes of Sweden, Uppsala
[2] CDR – Agricultural Advisory Centre in Radon, Poland
[3] JKI – Julius Kühn Institute, Germany
[4] Luke – Natural Resources Institute Finland
[5] ZSA - Farmers' Parliament, Riga, Latvia
[6] HELCOM – Baltic Marine Environment Protection Commission, Helsinki, Finland
[7] ECRI – Estonian Crop Research Institute, Saku

***Corresponding author:** erik.sindhoj@ri.se

Report from WP2 of SuMaNu Interreg BSR platform project

RISE Research Institutes of Sweden AB

RISE Report 2020:77
ISBN : 978-91-89167-62-9

A reference to this report can be written as following:

Sindhöj, E., M. Krysztoforski, K. Kuka, S. Luostarinen, S. Melnalksne, K. Mjöfors, Kaisa Riiko, K. Tamm, K. Ylivainio, M. Sarvi. 2020. Technologies and management practices for sustainable manure use in the Baltic Sea Region. Report from WP2 of SuMaNu Interreg BSR platform project. RISE Report 2020:77, Uppsala.

Preface

This report was produced in the Interreg Baltic Sea Region platform project SuMaNu (Sustainable Manure and Nutrient Management for reduction of nutrient loss in the Baltic Sea Region; www.balticsumanu.eu). The project aims to formulate and promote recommendations for more sustainable manure and nutrient management practices in agriculture and thus decrease agricultural nutrient loads to the Baltic Sea. The recommendations are specified to a wide range of target groups from farmers to policy makers. SuMaNu promotes the value of manure as a resource for nutrients and organic matter for crop production. Increased manure nutrient use efficiency will decrease the need for mineral fertilizers and reduce nutrient loss to air and waters.

Work package 2 (led by RISE) synthesized knowledge on sustainable manure nutrient management practices at farm and regional level from the projects that have built the SuMaNu platform. These projects include recent Manure Standards, Baltic Slurry Acidification, GreenAgri and BONUS PROMISE as well as previous Interreg BSR funded projects (Baltic Manure, Baltic Deal and Baltic Compass). WP2 also analyzed manure processing as a pathway to enhance nutrient recycling in the Baltic Sea Region and conducted an analysis of the potential gaps between original project objectives and eventual project outcomes and effects.

All the platform projects have resulted in various recommendations for improving manure nutrient use. This report is an attempt to compile and synthesize these recommendations and to put them in the perspective of where along the manure handling chain they should be implemented to achieve sustainable manure nutrient use in the Baltic Sea Region.

September 2020

Minna Sarvi, SuMaNu Platform Coordinator
Natural Resources Institute Finland (Luke)

Content

Summary

Livestock production in the Baltic Sea Region (BSR) is often geographically concentrated in certain areas, which creates greater livestock density in those areas. The intensification of livestock production seen in recent decades has compounded this problem by generating large amounts of manure to use in a local area. Poor manure management results in loss of nutrients to the air through gaseous emissions and to water though leaching and runoff. These nutrient losses are responsible for considerable negative impacts to the environment, climate and society.

During the past decade, there have been multiple BSR projects addressing sustainable manure use. Most projects have focused on one or a few aspects of sustainable manure use, such as reducing ammonia emissions, or reducing leaching and runoff problems, or increasing nutrient use efficiency from manure. Some projects have focused on specific technologies while others focused more on management practices that can improve sustainability.

The objective of this report was to synthesize relevant results and recommendations from the previous BSR projects to create a comprehensive list of their recommendations for improving the sustainability of manure use in the BSR. This was done within the context of various aspects of sustainability that have been dealt with in previous projects, and in terms of where along the manure handling chain the measures are to be applied.

Aspects of sustainability that were addressed here are decreasing ammonia emissions, reducing greenhouse gas emissions, reducing runoff and leaching, increasing on farm nutrient use, increasing regional nutrient recycling and addressing odors, pathogens, heavy metals and other risks. Possible measures for improving these aspects of sustainable manure nutrient use recommended in the previous projects were summarized and synthesized in relation to where along the manure handling chain the measures should be implemented. These were presented in a matrix of best practices and techniques for sustainable manure nutrient use in the BSR. Aspects of economic sustainability of manure handling and use were discussed as well as how various governance actions can be used in order to help promote the implementation of these best practices.

1. The need for sustainable manure use

During past decades, there has been a trend towards consolidation of livestock farms to increase profitability, which has led to an intensification of livestock production in the Baltic Sea Region (BSR). Larger herds are kept on fewer farms. Industrialization of livestock production has promoted agricultural specialization which in many cases has separated animal production units from feed resources, disrupting the natural cycle of manure use. Larger animal herds produce larger quantities of manure to be handled on nearby fields, and this can also increase the risk for nutrient loss. Alongside specialization, livestock production is often geographically concentrated in certain areas, which has led to regions that have become hot spots of nutrient surplus, further driving nutrient loss from agriculture.

The main consequence of poor manure management is that nutrients are not utilized but instead wasted and lost causing negative environmental, climate, economic and social impacts. The main pathways for nutrient loss from manure are ammonia emissions, runoff and leaching, and to some degree nitrous oxide emissions. These losses are major contributors to air pollution, acidification and eutrophication which threatens both terrestrial and aquatic ecosystem health and biodiversity. Manure also contributes to the emission of greenhouse gases which is driving climate change. Nutrient loss from poor manure management represents a direct economic loss for farmers and will either lead to reduced yields or the need to replace lost nutrients with purchased fertilizers. Poor manure management can also lead to sanitation and odor nuisance issues and can cause negative attitudes towards farming from neighbors and society.

The first step towards sustainable manure use is considering manure as a resource and a by-product of livestock production, not a waste. Manure is rich in plant nutrients, has soil enrichment properties and energy potential. Promoting sustainable manure use focuses on utilizing the resource potential of manure, minimizing the negative environmental and climate impacts and increasing profitability of manure handling.

During the past decade, there has been several BSR projects addressing sustainable manure use. Most projects have focused on one or a few aspects of sustainable manure use, such as reducing ammonia emissions, or reducing leaching and runoff problems, or increasing nutrient use efficiency from manure. Some projects have focused on specific technologies, while others focused more on management practices that can improve sustainability.

In general, solutions for sustainable manure use need to consider both environmental, economic and social sustainability. Most of the past projects, however, have focused mainly on improving environmental sustainability while only touching on the economic and social aspects of sustainability. Environmentally, sustainable manure management entails maximizing manure nutrient use efficiency, utilizing its soil enhancing properties and minimizing environmental and climate impacts. Sustainable manure management must also ensure the economic viability of using the resource potential in manure, otherwise measures will not likely be maintained. Socially, sustainable manure management should remove risks to health, happiness and our way of life.

The objective of this report was to synthesize relevant results and recommendations from previous BSR projects to create a comprehensive matrix of solutions relevant for improving the sustainability of manure use in the BSR. This was done within the context of various aspects of sustainability that have been dealt with in previous projects, and in terms of where along the manure handling chain the practices are applied. The aspects of sustainability and the relevant parts of the manure handling chain are described below. See the Appendix for a brief description of the projects included in this synthesis.

Nutrient utilization (field and farm)

Increasing nutrient utilization from manure implies that a greater percentage of nutrients in manure will be taken up by crops instead of being lost to the environment. There are several factors that affect manure nutrient utilization. Loss of manure nutrients through gaseous emissions, runoff or leaching automatically reduces nutrient utilization potential of manure, since less nutrients will be available for crop uptake. Practices and techniques for manure handling and use can greatly affect these types of losses. Applying too much manure results in over fertilization which increases the risk for nutrient losses and reduces potential nutrient utilization since more nutrients were applied than the crop can take up. Some nutrients, such as nitrogen, are found in both organic and inorganic forms. Organic nitrogen must first be decomposed, e.g. mineralized by soil biota and converted to ammonium nitrogen, before it is available for plant uptake. Since the timing of this process is difficult to steer, mineralization of nitrogen may not coincide with crop needs and further increasing the risk for losses through gaseous emissions, runoff or leaching and thereby also reducing nutrient utilization.

Since manure contains both nitrogen and phosphorus, nutrient utilization needs to address both nutrients at the same time, and this can be a problem. As the nitrogen to phosphorus ratio in manure is lower than optimal for most crops, manure application rates based on crops nitrogen needs will lead to an overapplication of phosphorus. Application rates based on phosphorus requirements of crops will not meet nitrogen needs and supplemental nitrogen fertilization will be necessary to maintain optimal yields.

Increasing manure nutrient utilization at the field and farm level is the cornerstone of sustainable manure nutrient use by ensuring higher utilization rates of nutrients by the crop and ultimately leading to decreased nutrient losses to the environment.

Ammonia emissions

Between 55-95% of the nitrogen in livestock feed is excreted from the animals as urea and organically bound nitrogen in their urine and feces. Once urine and feces are mixed, the urea nitrogen is rapidly transformed to ammoniacal nitrogen (i.e. the sum of NH_3 and NH_4^+). Ammonia (NH_3) is a gas that easily dissolves in water but dissipates from the surface to the surrounding air, until an equilibrium is reached with the air at the surface. Ammonium (NH_4^+) is a positively charged ion that is more stable in solution and not easily lost. The equilibrium between NH_3 and NH_4^+ is pH and temperature dependent. As NH_3 is lost to the surface air, more NH_4^+ will be converted to NH_3 which can then continue to dissipated to the air and rather quickly lead to a loss of the total nitrogen from the manure.

Manure is the greatest source of ammonia emissions in the BSR (EEA, 2020). Nitrogen lost through ammonia emissions is responsible for airborne eutrophication of surface waters, soil acidification, decrease of biodiversity in natural areas, and the formation of fine particulate matter ($PM_{2.5}$) and photochemical smog in urban areas. Ammonia emissions also represent a direct economic loss of nitrogen for the farmer.

Ammonia can be lost from manure soon after feces and urine land on the floor and are mixed in the housing system, and losses can continue to occur until the manure is eventually mixed into the soil after being spread. So essentially, ammonia losses from manure can occur from the livestock housing, from the manure storage and when spreading on fields. Therefore, efforts to reduce ammonia emissions should consider the whole manure handling chain to make the greatest impact.

Sustainable use of manure entails implementation of practices and techniques that reduce ammonia emissions to maintain the nitrogen content and fertilizer value of the manure. Furthermore, nitrogen lost through ammonia emissions represent direct economic loss for farmers.

Greenhouse gas emissions

The livestock sector is responsible for approximately 15% of human-induced greenhouse gas (GHG) emissions globally and is thus a major contributor to climate change (Gerber et al., 2013). Methane emitted during enteric fermentation by ruminant animals and carbon dioxide emissions from deforestation for producing feed crops account for a large portion of livestock related GHG emissions, however, manure and manure handling are also a significant source of methane and nitrous oxide emissions.

Methane is produced when methanogenic bacteria break down organic matter in manure under oxygen-free conditions, and the microbial activity is largely temperature dependent. Under ambient conditions, this means that methane emissions from manure are generally greater during summer months than winter. The anaerobic conditions needed for methane production occur largely when manure is stored. Thus, storage is therefore the portion of the manure handling chain that is mostly responsible for methane emissions. The storage of digested manure has a greater potential for methane emissions because the methanogenic bacteria are already present in large quantity, and temperature may be higher directly after anaerobic digestion. Manure related methane emissions from the animal housing system are generally very low unless manure is temporarily stored in pits under slatted floors. Similarly, little methane is emitted during spreading due to aeration of the manure as it is spread.

Livestock manure is one of the main sources of anthropogenic nitrous oxide emissions. Nitrous oxide is produced from manure by an incomplete nitrification - denitrification process. First in nitrification, bacteria oxidize ammonia (NH_3) to nitric oxide (NO), nitrite (NO_2^-) and finally to nitrate (NO_3^-). Then in denitrification, facultative anaerobic bacteria use NO_3^- as an oxygen source when decomposing organic matter and reduce it back down to NO, then to nitrous oxide (N_2O) and finally to nitrogen gas (N_2). Depending on conditions, some of the nitrous oxide gas can escape before the final step. Because the denitrification bacteria are facultative anaerobic, this nitrous oxide production generally occurs in the boundary area between anaerobic and aerobic zones of manure, such as the floating natural crust on slurry and urine storage, or in the soil once spread.

Manure is also responsible for indirect nitrous oxide emissions through ammonia emissions. When emitted, some ammonia falls on terrestrial soils and there nitrification - denitrification bacteria convert it to nitrogen gas where a small portion is lost as nitrous oxide. According to the IPCC (Intergovernmental Panel on Climate Change), 1% of ammonia nitrogen emissions converts to nitrous oxide. Since nitrous oxide has 298 times the Global Warming Potential than carbon dioxide has on a 100-year perspective, even 1% creates a significant climate impact. Therefore, reducing ammonia emissions will also indirectly reduce the climate impact of animal production.

Practices for sustainable manure handling and use must consider measures to reduce GHG emissions to reduce the climate impact of animal production.

Runoff and leaching

Leaching in agriculture is the loss of water-soluble plant nutrients down through the soil profile. Precipitation or snowmelt moves water-soluble nutrients below the root system to the groundwater or drainage system. The amount of nutrients lost through leaching depends on the soil type, soil structure, crop type, fertilizer type, application rate, and the timing, amount and rate of precipitation. Nitrate nitrogen fertilizers are water-soluble and particularly susceptible to leaching. Phosphorous, on the other hand, generally binds with soil particles through adsorption which hinders leaching. However, depending on the availability of adsorption sites, soil pH and the soil phosphorus status, phosphorus can also be leached below the root zone into groundwater or the drainage system. This is particularly an issue in soils that have long received more phosphorus than crops demand, which accumulates phosphorus in the soil and increases the risk for phosphorus leaching. This is often the case for fields on farms with intensive animal production where spreading rates are determined according to nitrogen application rates, leading to over application of phosphorus.

Runoff is the loss of nutrients and soil particles over the soil surface and off the fields during rainfall events. The rate of runoff is determined by the amount and rate of precipitation, soil water content and infiltration capacity, slope and crop cover of the site. Nutrient loss through runoff is generally associated with particulate phosphorus, but there may also be significant dissolved phosphorus and nitrates in runoff as well. Runoff and leaching of manure nutrients are primarily related to the timing of spreading, application rates, and the spreading techniques used. Runoff and leaching can also occur from improperly built or maintained manure storage sites, as well as from outside animal confinement areas and passageways.

Leaching and runoff have direct negative impacts on ground and surface water quality and are a major contributor to eutrophication.

Manure nutrient recycling (between farms and regions)

Agricultural production in the BSR, like the rest of the EU, has become more specialized focusing on either animal or crop production to improve production efficiency and profitability. Farms with intensive animal production often import more nutrients in feed and fertilizers than they export in product, which leads to a local surplus of nutrients. When many such animal farms are found close together, this creates areas and regions with nutrient surplus. In other areas and regions with more farms specializing in crop production, fertilizers need to be imported and, in many cases, there are deficits in their phosphorus balances.

The surplus nutrients on animal farms are largely found in the manure. These regional differences, with areas having a surplus of manure nutrients and others having to import mineral fertilizers, are driving the idea of nutrient recycling from manure, i.e. finding circular solutions for more sustainable nutrient management. Using the surplus manure nutrients to replace the need for mineral fertilizers will decrease the negative environmental impact of surplus nutrients as well as reduce dependency on limited phosphorus reserves and reduce the need for fossil fuels to manufacture nitrogen fertilizers.

Livestock manure has a relatively low concentration of nutrients, compared to mineral fertilizers, and contains between 85-95% water. This makes it difficult and expensive to transport and limits the distance that recycling manure is economically viable. If crop and animal farms are situated close by, collaboration between farms could benefit both partners and lead to more sustainable manure management. Otherwise, the use of processing technologies to lower the water content, separate and concentrate nutrients from manure will be necessary to make transportation economically viable to areas and regions with nutrient deficits.

Integrating strategies and practices to decrease local and regional areas with nutrient surplus is a necessary part of a larger more holistic approach to sustainable manure nutrient management.

Risks of odor nuisance, pathogens, heavy metals and other contaminants

Odors from manure are considered a nuisance when the smell is perceived as offensive and prolonged enough to significantly interfere with neighbors use and enjoyment of their property. In legal terms this problem is referred to as a statutory nuisance. Many things can affect whether odors are considered a statutory nuisance, the time of day the odor occurs, how long the odor is a problem, the type of smell and its effects. Odor nuisances from manure can arise from the animal housing, manure storage and during spreading of manure.

Manures can also contain various pathogens such as bacteria, viruses and parasites. Most pathogens in manure, however, do not necessarily pose a risk to humans or livestock, since they can rarely survive in the soil for long. Their persistence in the natural environment depends on the properties and quantities of the pathogen and environmental factors such as temperature, pH, moisture, sunlight and competition between other microbes (Bloem et al. 2017). Most risks with pathogens in manure for humans and livestock are related to contamination of surface and ground waters through runoff and leaching.

Heavy metal concentrations in manures are generally low, although variation can be large, and peak concentrations of certain heavy metals can occur (Bloem et al., 2017). Heavy metals in manure mainly originate from feed, since, for example, arsenic, copper and zinc are used as feed additives (Bolan et al., 2015, Poulsen, 1998). Therefore, zinc and copper concentrations in pig and arsenic concentrations in pig and poultry manures can be higher than in mineral P fertilizers, and excessive applications increase the risk for their accumulation in soils. Heavy metals taken up by the crops poses risks to humans and possibly livestock health. However, plant uptake is dependent on the solubility of the heavy metals in soils, which is dictated by several soil properties.

Manure can contain many different organic contaminants that can end up in soils after grazing by livestock or after manure spreading. Among these contaminants antibiotics and their metabolites are considered the most problematic (Bloem et al., 2017). They can accumulate in the soil or be taken up by plants depending on soil properties, chemical structure of the compound and the crop species. This means there is a potential that low concentrations of these organic compounds can enter the food chain and pose a risk for humans. In addition, repeated applications of manures containing antibiotics may increase the risk for the development of antibiotic resistant microbes (Bloem et al., 2017).

Taking into account issues relating to odors and contaminants addresses some of the more societal aspects of sustainable manure management.

2. Managing the entire manure handling chain

Most of the environmental and nuisance issues associated with large-scale livestock farms are directly related to large volumes of manure generated by large herds. Good manure management techniques and practices are essential to ensure high utilization efficiency of nutrients and to meet the growing regulatory scrutiny on intensive animal production.

Generally, the more nutrients from manure that are utilized by crops, the lower the environmental impact of the manure will be. Many methods, techniques and practices can be implemented to increase the manure nutrient utilization. It starts with practices that decrease nutrient losses in all forms during the handling of the manure from when the feces and urine leave the animal until it is applied to the soil and can potentially be taken up by the crops. From there it becomes dependent on the timing and placement of the manure and other field level management practices that can further reduce nutrient losses.

Sustainable manure nutrient management needs to incorporate all aspects of manure handling on the farm. The manure handling chain starts with the livestock and ends with field application of the manure. A description of the basic components in the manure handling chain can be seen in Figure 1. Details of the manure handling chain can vary on different farms and in different regions and depend largely on livestock type, local conditions, regulations (regional and local) and even traditions. Each part of the manure handling chain can affect manure and its characteristics and therefore can also have a significant impact on the environment.

Feeding

Livestock and feeding are included in the manure handling chain because this is the start of nutrient excretion. Manure characteristics and nutrient contents are largely a factor of input and output. Nutrient input is feed and feedstuff and output is the nutrients found in the milk, eggs and meat that are produced. The difference between input and output ends up in the manure as a fertilizer byproduct.

Optimization of diets and feeding regimes to increase production and profitability has long been the focus of feeding technologies. More recently, however, feed and feeding technologies are being adapted to also reduce the environmental impact of manure.

Housing

In the BSR, intensive livestock production is primarily kept indoors and therefore the housing system is where manure is deposited and collected during most of the year, with the exception of some countries where cattle must have access to summer grazing pastures. Housing systems are designed around different options for animal keeping, ventilation, insulation and temperature, manure collection and removal and potentially even manure storage (short- or long-term). All these factors will affect the potential for nutrient loss from manure in the housing system.

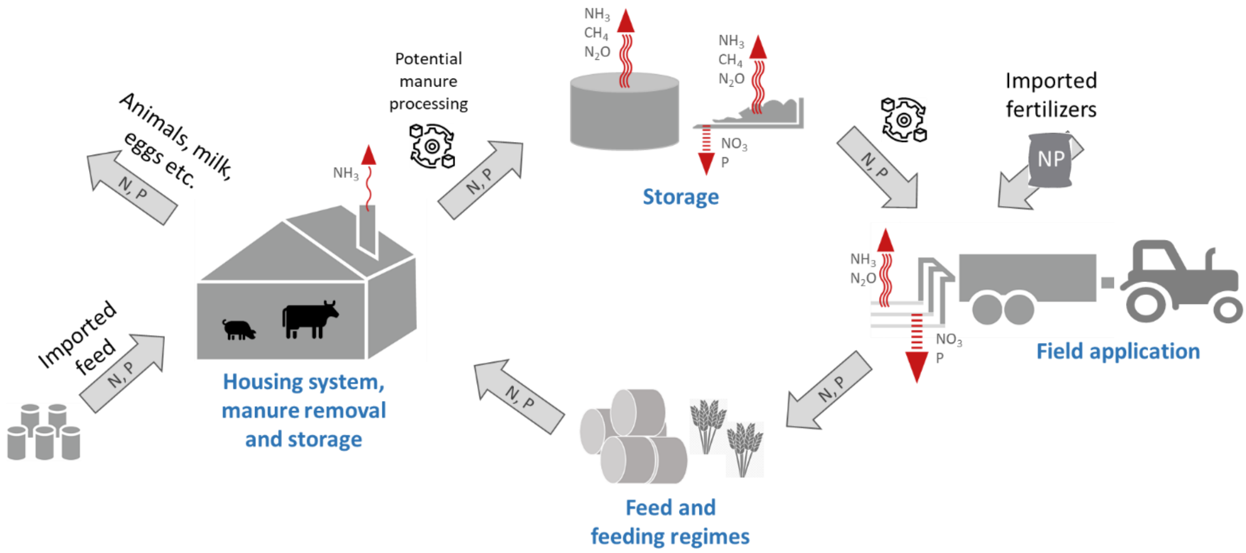

Figure 1. Description of basic livestock farm-level nutrient cycle and the major elements of the manure handling chain (blue). Red arrows point out risks for nutrient losses as either gaseous emissions or as leakage and runoff. Manure processing can be added to the chain at various places depending on the intended purpose.

Outdoor storage

Outdoor manure storage facilities are common on livestock farms in the BSR, even if there is some storage incorporated into the housing system. The placement, type, form and cover (or lack of) of the storage facility will all affect the potential for nutrient loss from manure during storage.

Spreading

Spreading manure on land as a fertilizer is the final step in the manure handling chain. Techniques used for spreading, time, placement, crop types, weather conditions during and after spreading, whether the manure is incorporated into the soil and how soon after spreading this takes place can all affect potential nutrient losses from spreading manure. Furthermore, to ensure that manure nutrients will be taken up by the crops after spreading, other management practices should be in place to minimize the risks of runoff and leaching losses.

Manure processing

In some cases, manure processing might enable the improvment some aspect of sustainability of manure use. Reasons for processing manure could include need to reduce volume, improve handling properties, adjust N:P ratios to crop needs, utilize manure energy potential, reduce odors, decrease ammonia emissions and subsequent nutrient loss and other reasons. More recently in the BSR, manure processing has been recognized as a potential regional strategy to improve recycling of manure nutrients from agricultural areas with nutrient surpluses to areas with nutrient deficits.

Generally, processing steps will be applied either before or after storage, depending on the purpose for processing and the chosen processing techniques. However, in some cases it could also be applied in the housing system as well.

3. Best practices for sustainable manure and nutrient use in the BSR

Here we present a synthesized summary of recommendations and results from the SuMaNu Interreg BSR platform projects and also from previous Interreg BSR projects that have dealt with different aspects of manure management. See the Appendix for a brief description of each of the projects included in the synthesis.

The recommendations are presented within the framework of a matrix to easily categorize each recommendation according to which aspect of sustainability they affect and where along the manure handling chain they are intended to be implemented (Table 1). The projects often made similar or overlapping recommendations, in which case they were merged here into one. Brief explanations of the recommendation for each part of the manure handling chain are given below.

Livestock feeding

Reduce P additives to feed by adding phytase for pigs and poultry
Phosphorus is an essential nutrient for animals to ensure production and health. The addition of mineral phosphate to feed is used since the digestibility of phytate (plant-bound phosphorus) is too low for adequate nutrition under intensive production levels, however, even mineral phosphorus has a low uptake efficiency and much of it ends up in the manure. The phytase enzyme aids the breakdown of phytate to phosphorus available for uptake by animals. The addition of phytase to feed decreases the need for mineral phosphorus supplements and reduces the excretion of phosphorus in manure. (Baltic Manure – Damgaard Paulsen et al., 2013)

Liquid feeding for monogastric animals for improved phosphorus and protein utilization
Liquid feeding systems used with pre-soaking allows the phytase enzymatic processes to begin even before the animals start to eat, which will increase phosphorus availability in the feed. Increasing phosphorus availability should decrease the need for mineral phosphorus supplements and lead to reduced excretion of phosphorus. However, this needs to be optimized and adapted to farm situations. Liquid feeding systems also seem to improve the digestibility of protein and amino acids in monogastric animals. (Baltic Manure – Damgaard Paulsen et al., 2013)

Replace soybean meal with specific amino acids in pig and poultry feed
Crystalline amino acids are commercially available and can replace crude protein in monogastric animals resulting in reduced need for imported protein feedstuffs like soybean. The use of crystalline amino acids also allows matching the animal's specific amino acid requirements. (Baltic Manure – Damgaard Paulsen et al., 2013)

Multiphase feeding
Differentiated feeding rations with optimized nutritive contents (energy, protein, fiber and minerals) according to the animal's specific nutritional requirements for their specific growth stage or lactation cycle, to reduce intake and excretion of P and N. Differentiated feeding in 2-3 phases for pregnant and lactating sows, and 4-5 phases in growing slaughter pigs depending on final body weight. (Baltic Manure – Damgaard Paulsen et al., 2013; Baltic Compass – Salomon & Sundberg, 2012)

Data collection on feeds and feeding practices
Data on feeds and feeding practices under the average or farm-level production conditions should be collected and made available for manure mass balance calculation and emission estimation. (Manure Standards - Manure Standards, 2020)

Animal housing

Implementation of In-house slurry acidification
In-house slurry acidification reduces ammonia emissions from slurry by adding acid to lower the pH, which also effectively reduces or eliminates methane emissions as well. In-house slurry acidification reduces emissions from the animal house as well as the slurry storage and during spreading. In-house acidification is listed as a BAT technique for reducing emissions in the BAT reference document for the Industrial Emissions Directive 2010/75/EU. (Baltic Manure – Sindhöj & Rodhe, 2013a; Baltic Slurry Acidification – Rodhe, Casimir & Sindhöj, 2018; Foged, 2019; Baltic Slurry Acidification, 2019)

Regular cleaning of corridors and slatted areas, and frequent removal of manure from housing
Corridors and corrals should be well drained, so the urine can easily drain away from the feces. Passageways and slatted areas with high animal traffic should be regularly and frequently scraped to remove feces and spilled bedding materials, for example to covered channels so it can be removed from the animal house. Frequent slurry removal from under slatted floors or from collection channels to the outdoor storage is an effective measure to reduce ammonia emissions from the animal house. Reducing ammonia loss will increase the manure value and nitrogen use efficiency and should be incorporated into general manure management on the farm. (Baltic Manure – Sindhöj et al., 2013)

Slurry cooling in manure channels
Cooling pipes installed in the floor of the manure channels of a housing system are effective at reducing ammonia and methane emissions. The recovered heat can be used for heating in pig houses, or for warming drinking water in dairy barns. (Baltic Manure – Sindhöj & Rodhe, 2013a)

Minimizing dilution of slurry with water from the animal house
Reducing dilution of slurry with water from cleaning activities and water leaks will increase the nutrient concentration of the slurry and will affect storage, transportation and handling costs. This is particularly of interest if slurry has a dry matter content lower than 7-8 %. Collection of data on waters directed to manures should also be measured on farms and collected as national averages to enable their consideration in manure mass balance calculation and emission estimation (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013; Manure Standards - Myrbeck et al., 2019a; Manure Standards, 2020)

Table 1. Synthesis of manure nutrient management techniques and practices to promote sustainable manure nutrient use that have been recommended during previous projects, along with which aspect of sustainability the practice can affect positively. The projects included SuMaNu platfrom projects Manure Standards, Baltic Slurry Acidification, GreenAgri and Bonus PROMISE as well as the former Interreg BSR projects Baltic Compass, Baltic Deal and Baltic Manure.

	Measure	**Decrease ammonia emissions**	**Reduce runoff and leaching**	**Decrease greenhouse gas emissions**	**Increasing nutrient utilization** (farm or field level)	**Increase manure nutrient recycling** (between farms or regions)	**Odor nuisance, pathogens, heavy metal and other risks**
Livestock feeding							
	Reduce P additives to feed by adding microbial phytase for pigs and poultry		✓		✓		
	Liquid feeding for pigs for improved phosphorus and protein utilization		✓		✓		
	Replace soybean meal with specific amino acids in pig and poultry feed	✓			✓		
	Multiphase feeding	✓	✓		✓		
	Data collection on feeds and feeding practices				✓		
Animal housing							
	Implementation of In-house slurry acidification	✓		✓	✓		
	Regular cleaning of corridors and slatted areas, and frequent removal of manure from housing	✓			✓		✓
	Slurry cooling in manure channels	✓		✓	✓		
	Minimizing dilution of slurry with water from the animal house			✓	✓		
Storage							
	Adequate storage capacity so manure can be applied when crops can utilize the nutrients		✓		✓		
	Acidification of slurry with in-house slurry acidification or a modified in-house system	✓		✓	✓		
	Fill slurry storage from bottom	✓			✓		✓
	Avoid slurry fountains when mixing the storage	✓			✓		✓
	The manure storage should be covered	✓		?	✓		✓
	Minimize surface area to volume ratio of storage	✓			✓		✓

	Measure	Decrease ammonia emissions	Reduce runoff and leaching	Decrease greenhouse gas emissions	**Increasing nutrient utilization** (farm or field level)	**Increase manure nutrient recycling** (between farms or regions)	Odor nuisance, pathogens, heavy metal and other risks
Storage cont.	Consider satellite storage tanks, closer to distant fields			?	✓	✓	
	Solid manure should be stored on concrete pad with side walls, preferably under a roof, and with collection of drainage water	✓	✓		✓		✓
	Collection of data on manure storage				✓		
Manure use							
Timing	Manure should be spread before sowing or in growing crops to maximize nutrient uptake, autumn spreading should only be in connection with establishment of winter crops	✓	✓		✓		
	Weather conditions favorable for spreading manure are humid, windless, cloudy, cool with a chance of light rain. In unfavorable conditions use acidification, injection or immediate incorporation	✓			✓		✓
	Do not spread manure when the soil is frozen, snow covered, flooded or if there is a chance for heavy rain		✓		✓		
Dosage	Nutrient status of manure should be determined by either national normative livestock values or according to rigorous standardized protocols	✓	✓		✓		
	Manure application rates should be based on nutrient content in manure and pre-planned nutrient needs for expected crop yield taking into consideration soil nutrient status.	✓	✓		✓		
	P content in manure for dosage calculations should be based total P content		✓				
Spreading	Equipment should be able to accurately regulate dosage and spread evenly across the working width	✓	✓		✓		
	Avoid spreading manure on high-risk areas		✓				

	Measure	**Decrease ammonia emissions**	**Reduce runoff and leaching**	**Decrease greenhouse gas emissions**	**Increasing nutrient utilization** (farm or field level)	**Increase manure nutrient recycling** (between farms or regions)	**Odor nuisance, pathogens, heavy metal and other risks**
Spreading cont.	Acidification of slurry (in-field, in-storage or in-field) spread with trailing hose applicators, no need for incorporation or injection	✓			✓		
	Injection techniques: choose most suitable equipment depending on conditions	✓	✓		✓		✓
	Incorporate slurry directly after spreading if not acidified, injected or spread in growing crops	✓	✓		✓		✓
	Ban broadcast spreading of slurry	✓	✓		✓		✓
	Solid manure should only be spread when possible to incorporate directly after spreading	✓	✓		✓		✓
	For solid manure use spreader with vertical beaters and horizontal spreading discs for wide working width and best spreading eveness				✓		
	Consider using a contractor with modern, environmentally friendly equipment for spreading				✓		
Other aspects	Farm gate nutrient balances				✓		
	Use seperate road transport tankers and field side buffer tanks for spreading on fields farther away to maximize output			✓	✓	✓	✓
	Consider establishing pipe connections to pump slurry to field buffer tanks as alternatives to tank vehicles for transport				✓		
Manure Processing							
	Farm-level processing to increase nutrient use	?	✓	?	✓		✓
	Regional level processing to increase nutrient recycling	?	✓	?	✓	✓	✓

Manure storage

Adequate storage capacity enabling manure application when crops can utilize the nutrients
Storage capacity for manure must be adequate so that all slurry can be spread just before sowing or when crops are actively growing to maximize nutrient uptake of plants from the manure. Autumn and winter application of manure should be avoided, with the exception of modest applications for the establishment of winter crops. Sufficient storage capacity should eliminate the need for spreading manure at unsuitable times with greater risk of losses. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013; Manure Standards - Manure Standards, 2019)

Acidification of slurry in storage with in-house slurry acidification or a modified in-house system.
In-house slurry acidification has also been shown to reduce ammonia emissions from the slurry storage. There is also a modified in-house system that acidifies all slurry leaving the animal house before it is sent to the storage container. Slurry acidification also reduces or eliminates methane emissions from slurry storage. The use of in-house systems or the modified version eliminate the need for covers to reduce emissions. (Baltic Manure – Sindhöj & Rodhe, 2013a; Baltic Slurry Acidification – Rodhe, Casimir & Sindhöj, 2018; Foged, 2019; Baltic Slurry Acidification, 2019)

Fill slurry storage from bottom
Filling the slurry storage from the bottom avoids disturbing or breaking the natural crust cover on the slurry and also avoids splashing which increases risk for ammonia emissions. (Baltic Manure – Sindhöj & Rodhe, 2013b; GreenAgri – Tamm et al., 2016)

Avoid slurry fountains when mixing the storage
Adequate mixing of the slurry storage before spreading is important for dosage calculations and even distribution of nutrients. While mixing the slurry storage it is important to avoid cascade fountains of slurry which increases ammonia emissions significantly. (GreenAgri – Tamm et al., 2016)

Slurry storages should be covered
Covers on manure storages significantly reduce ammonia emissions. Roofs or tents are most effective. A natural crust or one created from straw also reduces ammonia emissions but may lead to increased nitrous oxide emissions. A gas tight lid with utilization of the gas is needed to prevent methane emissions. Covering slurry and solid manure storage also prevents rainwater dilution of the manure and reduces the storage capacity or seepage water from solid manure. (Baltic Manure – Sindhöj et al., 2013; Baltic Compass – Salomon & Sundberg, 2012; Manure Standards – Manure Standards, 2019)

Minimize surface area to volume ratio of slurry storage
Ammonia is volatilized from the surface of the slurry. Minimizing the surface area to volume ratio of the storage will reduce ammonia emissions from storage. This favors concrete or metal storage tanks over lagoons, which are typically not as deep and cover a larger area instead. Installing the storage in the ground, or partially in the ground will help lower slurry temperature which also reduces emissions. (Baltic Manure – Sindhöj et al., 2013)

Consider satellite storage tanks, closer to distant fields, that can be filled using road transport trucks
This can eliminate the need for field side buffer tanks when spreading and also allows transporting the slurry ahead of time so not to interfere with spreading logistics, reducing the time needed to spread manure on the fields. If lorries are used to transport slurry to satellite storage, GHG emissions might be reduced due to larger capacity and increased fuel efficiency. (Baltic Manure – Sindhöj et al., 2013; GreenAgri - Tamm et al., 2016)

Solid manure should be stored on concrete pad with side walls, preferably under a roof, and with collection of drainage water
Storing solid manure in this way should eliminate loss of nutrients from leakage and covering it will reduce ammonia emissions. (Baltic Manure – Sindhöj et al., 2013; Manure Standards – Manure Standards, 2019)

Collection of data on manure storage
To enable manure mass balance calculation and emission estimation, data on national storage practices should be collected. (Manure Standards – Manure Standards, 2020)

Manure use

Timing

Manure should be spread before sowing or when crops are growing to maximize nutrient uptake, autumn spreading should only be in connection with establishment of winter crops
Spreading manure when crops are growing increases the chances for nutrient uptake from the manure and thereby reducing potential for losses through runoff and leaching. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013; Manure Standards – Manure Standards, 2019)

Weather conditions favorable for spreading manure are humid, windless, cloudy, cool with a chance of light rain. In unfavorable conditions use acidification, injection or immediate incorporation
Favorable conditions for spreading manure are conditions that will minimize the volatilization of ammonia from the slurry before it infiltrates into the ground. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013)

Do not spread manure when the soil is frozen, snow covered, flooded or if there is a chance for heavy rain
Spreading manure under these conditions will greatly increase runoff losses and decrease nutrient use efficiency. (Baltic Manure – Sindhöj et al., 2013; Manure Standards – Manure Standards, 2019, GreenAgri – Tamm et al., 2016)

Dosage

Nutrient status of manure should be determined by either national normative livestock values or according to rigorous standardized protocols
Manure nutrient content varies from farm to farm depending on livestock type, feeding regimes, production levels, housing systems, bedding and water additions and storage techniques. Without tools for good estimates of nutrient contents in manure, it will not be possible to dose and use the nutrients efficiently. Knowing what is in the manure is the first step. The optional methods to determine manure nutrient content are manure sampling and analysis and manure mass balance calculation. They both have their strengths and weaknesses and they are utilized differently in different countries. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013; Manure Standards - Myrbeck et al., 2019a, 2019b; Salo et al., 2020; Manure Standards, 2019, 2020; GreenAgri – GreenAgri, 2019)

Manure application rates should be based on nutrient content in manure and pre-planned nutrient needs for expected crop yield taking into consideration soil nutrient status.
Calculations of manure dosage rates must consider both N and P manure contents and both N and P fertilization requirements for the crops based on expected yields and soil nutrient status. Application rates should then be limited so that neither N or P are overapplied. (BONUS PROMISE – Bloem et al. 2017, GreenAgri – GreenAgri, 2019; Manure Standards - Grönroos et al., 2020; Manure Standards, 2020)

P content in manure for dosage calculations should be based on total P content
Phosphorus uptake from manure is essentially equal to mineral P fertilizers or can even be better. Basing manure dosage on total P content in manure will reduce overfertilization with P, increase P use efficiency and reduce P losses through run off and leaching (Baltic Manure – Schick et al., 2013, BONUS PROMISE – Ylivainio et al. 2017)

Spreading

Equipment should be able to accurately regulate dosage and spread evenly across the working width
Accurate regulation of manure dosage with even distribution across the working width is a prerequisite for achieving effective nutrient utilization. There are no regulated standards that equipment manufacturers have to fulfill so it is important to test and calibrate spreading equipment to maximize nutrient utilization. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013)

Avoid spreading manure on high-risk areas
Spreading manure on high-risk areas including areas directly adjacent to waterways, fields with steep slopes and waterlogged soils will greatly increase run off losses and decrease nutrient utilization efficiency. (Baltic Compass – Salomon & Sundberg, 2012)

Acidification of slurry (in-field, in-storage or in-field) spread with trailing hose applicators, no need for incorporation
All slurry acidification techniques (In-house, In-storage, In-field) have been shown to reduces ammonia emissions during spreading and is equivalent in effectiveness to injection techniques. Ideal for reducing emissions when spreading in growing crops and incorporation or injection is not an option, or when injection is not practical or economical. (Baltic Manure – Sindhöj & Rodhe, 2013a; Baltic Slurry Acidification – Rodhe, Casimir & Sindhöj, 2018; Foged, 2019; Baltic Slurry Acidification, 2019)

Injection techniques: choose most suitable equipment depending on conditions
On arable land before spring crops, closed-slot injectors with tines are suitable for first tillage if most pre-crop residues are decomposed and larger doses of slurry are needed to build a nutrient depot for growing season. Closed-slot injectors have very low ammonia emission. If the field is covered with lot of pre-crop residues and there is risk of jamming of tines, then using disc incorporators are preferable, also in spring. Open- or closed-slot injection may not be suitable for larger application rates as all the slurry may overflow the slots onto the surrounding ground and loose the beneficial effect. (GreenAgri – Tamm et al., 2016)

Incorporate manure directly after spreading if not acidified, injected or spread in growing crops
Most of the ammonia emissions occur within the first four hours after spreading and therefore it is critical to have logistics ready to incorporate the manure into the soil directly after spreading to avoid ammonia emissions and maximize nutrient use efficiency. If this is not possible use acidification techniques or injection techniques. (Baltic Manure – Sindhöj et al., 2013; Baltic Manure, 2013; GreenAgri – Tamm et al., 2016)

Ban broadcast spreading of slurry
Broadcast spreading of slurry results in high ammonia emissions, offers uneven distribution across the working width, and offers a high level of contamination when spreading in growing crops. This is not Best Available Technique. (GreenAgri – Tamm et al., 2016)

Solid manure should only be spread when possible to incorporate directly after spreading
Ammonia emissions are generally higher from solid manure than slurry, and broadcast spreading solid manure can lead to significant nitrogen loss through ammonia emissions. This can be

minimized by incorporating the manure directly after spreading, which will also decrease risk for run off losses in case heavy rain follows. (Baltic Manure – Sindhöj et al., 2013; GreenAgri – Tamm et al., 2016)

For solid manure use spreader with vertical beaters and horizontal spreading discs for wide working width and best spreading evenness
These two-step broadcast spreaders offer a wider working width with more even distribution of manure. (GreenAgri - Tamm et al., 2016)

Consider using a contractor with modern, environmentally friendly equipment for spreading
Aside from decreasing emissions and increasing nutrient utilization from manure when using modern equipment, there will be economic benefits of avoiding large investment costs and maintenance of equipment. (GreenAgri - Tamm et al., 2016)

Other Aspects

Farm gate nutrient balances
The farm balance is calculated as total nutrients imported to the farm minus nutrients exported from the farm. Input nutrients are in the form of fertilizers, feed, new animals and seed. Nutrients are exported from the farm in the form of animal products, sold animals, crops or manure if it is sold or given away. The farm balance gives an overview of the nutrient use efficiency of the farm and can help identify the risks for nutrient loss to the environment. (Manure Standards – Manure standards, 2019, 2020)

Use road transport tankers and field side buffer tanks for spreading on fields farther away to maximize output
In many cases, after a distance of a few kilometers it becomes economically viable to use road tankers to transport slurry to fields for spreading. This will cost less and improve spreading logistics which will help decrease the time needed to spread manure on fields. (Baltic Manure – Kässi et al., 2013; GreenAgri - Tamm et al., 2016)

Consider establishing pipe connections to pump slurry to field buffer tanks as alternatives to tank vehicles for transport
In certain cases, pumping slurry can greatly improve the logistics of manure handling and reduce tanker transport costs and greenhouse gas emissions. (Baltic Manure – Sindhöj et al., 2013; GreenAgri - Tamm et al., 2016)

Manure Processing

Processing to increase manure nutrient use at the farm-level
Different types or levels of manure processing can be implemented on the farm-scale to address issues of increasing nutrient utilization, adjusting N:P ratios for more rational farm-level nutrient use, reducing storage capacity needs, produce biogas for increased energy independency and others. (Baltic Manure – Sindhöj & Rodhe, 2013a; Baltic Slurry Acidification – Rodhe et al., 2018; SUMANU - Luostarinen et al., 2020)

Processing to increase manure nutrient recycling at the regional level
Manure processing options can be implemented to address issues of increasing nutrient utilization across the regional scale. These processing solutions will likely be more complex than processing for farm-level solutions. Processing can help recycling nutrients from areas of surplus to areas of deficit and reduce nutrient loss to the environment from areas with surplus. This can also lead to the replacement of mineral fertilizers with manure-based fertilizer products. Processing can also produce biogas for increased energy independence and will help create a circular economy for nutrients in society. (SUMANU - Luostarinen et al., 2020)

4. Economic sustainability of manure management

Value of manure

Nutrient content

The value of manure can be calculated based on its nutrient contents and the price of comparable mineral fertilizers. See Figure 2 for an example based on Finnish standard manure values.

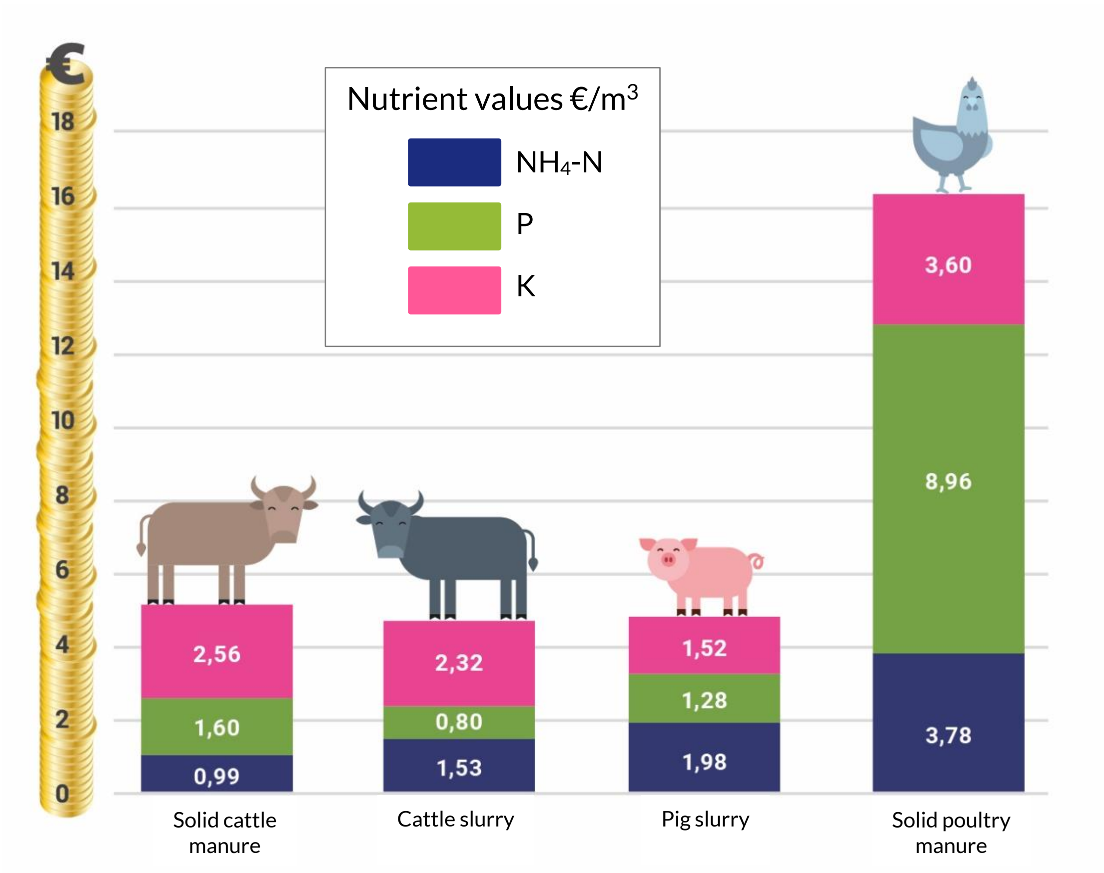

Figure 2. Value of manure based on its nutrient content and that of comparable mineral fertilizer prices. The portion of organic nitrogen is not included in the value calculations. Manure nutrient contents were taken from Finnish standard values and reference prices for mineral fertilizers from average prices in the Baltic Sea countries in the spring 2019. (Source: Manure Standards project 2019)

Excess nutrients

Calculating the monetary value of manure based on its total NPK nutrient content can be misleading and is only valid if application rates are made so that excess nutrients are not applied. Excess nutrients are determined by the difference between nutrients (NPK) in manure applied and nutrients required by the crop. The nutrient having the lowest requirement for optimal crop growth should determine the application rate of manure to maximize manure value. For instance, if application rates are based on providing the nitrogen needed for the crop, more P and possibly K will be applied than required for the optimum yield. Therefore, only the amount of P and K that is needed for reaching the optimum yield should be counted in the value of the manure, since the rest will not be used by the crop and may be lost to the environment. This means that manure can have a higher value for certain crops since they may be able to utilize a greater portion of all the nutrients. The closer the NPK ratio need of a crop is to the NPK ratio of the manure, the more valuable the manure will be. Generally, application rates are not based on the growth limiting nutrient because this would greatly increase the area needed for spreading manure and require supplemental fertilization with the other two nutrients.

Effects on soil fertility

Manure also has a value to improve soil fertility due to the input of organic matter, however, there are no approximations of the monetary value of this function. There is also a risk that using heavy slurry tankers on fields can contribute to soil compaction and decrease soil fertility.

Cost of manure use

Even though manure has value, there are costs associated with its storage, transport and application. We exclude costs for the manure removal system in the animal house, but storage and spreading systems are essential to adequately utilize the manure nutrients. The data on manure quantity and composition used for planning manure management structures and practices may also have an effect on the cost of manure use (Tamm & Vettik, 2019a).

Storage

Storage costs can be considerable for manure, and the lower the dry matter content of the slurry the greater storage capacity will be needed as well. Lagoons are cheaper than concrete or steel tank storages, but there are operative challenges with lagoons such as difficulties mixing which might over time reduce the usable storage capacity. Lagoons also have greater surface area to volume ratios than tank solutions and are more difficult to cover, both of which increases risk for ammonia emissions and loss of nitrogen. Covering a manure storage with a permanent cover is a large investment and often can double the cost of the storage. While these measures do save nitrogen, they are far more costly per kg of saved N than it is to purchase mineral N, and this greatly decreases the incentives of farmers to invest in good storage measures.

Transport

Cost calculations for transport are dependent on the farm, the distance to the field, and the condition of the roads and allowable speed limit. There is also the cost of loading the manure before transport, which is a time dependent cost. Transportation costs generally increases with distance from the animal house to the field but depend somewhat on which form of transport is used, i.e. if the tractor and tanker is used for transport or a separate transport. At a certain distance, it becomes economical to use separate specialized slurry transportation trucks which are cheaper, faster and they have greater capacity. Mobile buffer tanks placed on the side of the field help to minimize waiting times for transporters and spreaders in their workflow.

Spreading

Liquid manures have low concentrations of nutrients as compared to mineral fertilizers, which leads to much higher application rates and increased spreading costs compared to mineral fertilizers. Spreading costs depend on spreading techniques used and should also include costs for incorporation if that is done separately. Manure application rates and capacity of the spreader will also affect the time and operational costs of spreading and will affect the traffic intensity on the field.

Broad spreading with a splash plate is one of the cheapest methods of spreading slurry, however it should be phased out due to excessive ammonia emissions, odor problems and difficulty evenly distributing nutrients over the working width. Band spreading with trailing hose applicators should be considered the acceptable baseline spreading technology for slurry. Adding extra spreading technologies, such as acidification or injection, to reduce losses or increase nutrient uptake will generally increase costs. However, when including incorporation costs after spreading with the baseline trailing hose application, the cost can actually be greater than for acidification techniques, since incorporation is then not necessary (Tamm and Vettik, 2019b). Slurry acidification techniques and injection techniques have been shown to be equally effective at reducing ammonia emissions, however, the cost of injection could be greater due to the smaller working widths of the injection equipment and increased fuel consumption from greater draft requirements. There is also a risk in growing crops of damaging the plants or roots with certain injection techniques which can give added costs.

Soil compaction costs should also be included in spreading costs. Using large, heavy tankers for spreading slurry on moist soils early in the growing season increases the risk of soil compaction. Large tankers are heavier and increase compaction risks, but smaller tankers increase traffic intensity on the field.

Finding economic sustainability of manure management

Given the value and costs associated with manure use described above, profitability of using manure for fertilization compared to mineral fertilizers can be calculated for a specific farm based on which techniques are used, where the fields are located, and which crops are cultivated. For Finnish and Swedish case-study dairy farms with baseline spreading costs (not including storage costs) manure value based on NPK contents, using manure as a fertilizer for grasslands was profitable when transporting to a maximum of 10 km using specialized road transport trucks. Beyond 10 km the transport and spreading costs were greater than the nutrient value in the manure (Kässi et al., 2013). However, this balance was largely due to including K in the value since grasslands have a relatively high K requirement, when calculating the value only based on NP, the profitable transport distance was only around 3 km.

To increase the sustainability of manure nutrient use, better techniques and management practices need to be implemented. Most of these techniques and practices have higher costs associated with implementation and can include investment costs and extra operational or running costs. In the case that measures lead to decreased ammonia emissions, it can be argued that the value of the manure increases due to improved N utilization. Unfortunately, the increase in manure value due to increased N utilization is seldom enough to compensate for the extra costs of implementing the measure, mainly because mineral N is relatively inexpensive.

Measures to increase P sustainability are different in nature than for N. Sustainable use of manure P requires reducing application rates so that the P dose does not exceed the crop requirements when considering also soil phosphorus status. Smaller application rates will lead to a greater land base requirement to spread all the manure which will also likely entail increased transportation costs to fields farther away. Lowering manure application rates will also decrease yields unless the crops are also fertilized with supplemental mineral N. Another potential measure for sustainable manure P use is to balance the N:P ratio closer to the crop needs. This could be done by using processing techniques to separate out some of the P to produce a P rich fiber fraction and a liquid fraction with a more balanced N:P ratio. The P rich solid fraction could be used on fields further away from the farm that do not normally receive animal manure (Luostarinen et al., 2020), and the lower water content of the solid fraction should lower transportation costs. Another option for balancing the N:P ratio is increasing the content of plant available N in the manure. This could be done by converting some of the organic N to ammonium N, or by adding green N to the manure to balance the N:P ratio.

Considering efforts to reduce climate impact and greenhouse gas emissions from manure, there are essentially no economic advantages to encourage implementation of such measures.

5. Governance and regulation of manure management

Animal manure is a potential source of air and water pollution and contributes to greenhouse gas emissions. Poor manure management increases the risk for pollution and negative environmental and climate impacts. As environmental problems caused by manure continue to grow, there is growing pressure to make greater changes and move towards sustainable manure and nutrient use. There are three levels of intervention that authorities have to help steer this change.

Communication instruments

The first and possibly least invasive approach to instigate change is using communication instruments to encourage voluntary adoption of better measures and practices. Promoting change through knowledge and information transfer, education or even technical assistance is usually done through extension and advisory services.

> **Example**: The “Greppa näringen” program in Sweden, which translates to “Focus on nutrients” and was started in 2001 and is an example of how communication instruments can be successfully implemented to instigate change. Greppa näringen is a voluntary on-farm initiative to educate about the connection between nutrient management and farm economy. The program trains advisors and offers free individual on-farm visits to interested farmers to help reduce nutrient losses and improve sustainability. Greppa näringen is characterized by voluntary participation, a farm visits by an advisor with an initial calculation of farm gate nutrient balances, repeated visits to develop farm-specific measures to improve sustainability and then after 5-6 years a follow up visit on each farm to recalculate the farm gate nutrient balances. Farmers who sign up also have access to informational seminars and workshops dealing with various aspects of sustainable farming that are regularly organized. In 2015, the program had reached 8500 farms with over 1 million ha of arable land and had led to significant reductions in N and P surplus (Olofsson, 2015). The reductions in nutrient surplus were found to be from reduced use of mineral fertilizers, increased harvest and reduced import of feed on animal farms.

While this can be effective for some measures, other measures requiring investment and running costs need to be obviously profitable otherwise the farmer will not adopt them.

Economic instruments

The next approach is for authorities to use economic instruments to encourage adoption of good measures and practices. Economic instruments include both taxes and subsides and could even include tradable emissions rights. Taxes are generally a restricting approach while subsidies are encouraging. A common first approach to encourage change is using subsidies as incentives to promote the use of green technologies and good practices that decrease the environmental impact and work towards increased sustainability. These could be investment subsidies for green technologies above that of the standard regulated levels, or subsidies for implementing a good practice.

> **Example:** A common economic incentive used in agri-environmental schemes are investment subsidies for technologies that provide environmental protection beyond what the standard baseline regulation defines. The subsidies can be used for machinery, buildings or other structures but acceptance is usually dependent on how much of an effect the investment will have. This could be used, for example, to build extra storage capacity over the regulated requirements to allow spreading more manure during the active growing season to increase utilization. Support can generally not be used for the total cost of the investment but limited to a certain percentage of the investment costs with a maximum amount. There could also be other requirements such as not selling the investment for 5 years or other requirements.

Investment subsidies are a relatively easy way to support the adoption of environmental technologies, however, if the measures include both investment and operational costs, investment support might not be enough incentive to encourage adoption of the measure. For instance, investments in slurry injection or acidification equipment to reduce ammonia emission and increase nitrogen utilization will likely be done by contractors who sell the service to customers. With investment subsidies, contractors have lower costs but must have customers willing to pay the rest of the investment and the extra operational costs to spread with injection of acidification instead of just trailing hose. Operational costs may include the cost of acid, or increased fuel consumption, larger tractor and greater time needed for injection spreading due to smaller working widths and increased draft requirements. These extra costs will likely deter customers because the costs are usually not covered by the savings in nitrogen alone since mineral nitrogen is relatively inexpensive.

> **Example**: In Finland, the voluntary agri-environmental scheme of 2007 introduced a new measure incentivizing the use of slurry injection. A farmer could get support of 60 €/ha to cover the additional costs of injection, compared to trailing hose or broadcasting application. The payment required a minimum applied amount of 20 m^3/ha and that the farmer complied with the agri-environmental schemes limit on P application rates. This new payment created a market and strong demand for this new technology. As the investment costs were high, it was mainly contractors who started this new service. Before 2007, there was no machinery with injection units in use in Finland. After 2007, the demand for contracting services using trailing hose fell, and most of the slurry has been injected since. The growing demand on slurry contracting services also led to contractors buying separate trucks for slurry transport, which remarkably built up the capacity of slurry spreading in terms of m^3/hour. In 2015, the payment was reduced to 40 €/ha, but the measure of slurry injection is still one of the most popular in the Finnish agri-environmental program. In 2016, depending of the farm type, 40-50 % of the slurry in Finland was applied using injection.

One criticism of this agri-environmental scheme is that it favors one particular technology, injection, when there are other technologies that are equally effective at reducing ammonia emissions, such as slurry acidification techniques (Rodhe et al., 2018). Inclusion of all measures that achieve comparable results in such incentive schemes could increase their effectiveness and level of implementation.

Regulatory instruments

Regulatory instruments involve active restrictions on actions or technologies and practices used. These can include stricter permit requirements, fertilizer limits, bans on specific practices or techniques or implementation of higher minimum baseline standards. There are many examples on the EU levels which affect manure use including the Nitrate Directive, the Industrial Emissions Directive, and the National Emissions Ceiling Directive to name a few.

Regulations are generally based on the “polluter pays principle” which puts the extra costs of following the measures on the farmer. This could be argued as reasonable, at least to a minimum standard level of practices, as long as everyone has the same minimum standard. But this places the farmer at a competitive disadvantage when competing against agricultural goods produced in countries with lower restrictions. While the EU BSR countries are regulated by the same minimum standard for practices, some countries have stricter standards for manure handling and use which puts them at an economic disadvantage compared to countries only adhering to the minimum. For example, it is currently still allowed according to EU regulations to spread slurry with broadcast techniques, even though it has been known for decades to cause significant ammonia emissions which greatly reduced with modern bandspreading techniques. While many countries still rely heavily on broadcast spreading of slurry, Denmark and Sweden have banned the use of this technique in nitrate vulnerable zones, which for Denmark is the entire country. While regulations will establish a minimum baseline standard, implementing measures more stringent than the regulations will come as an extra cost to farmers and will likely never be realized unless the increased value added to their manure will outweigh the costs. This is difficult to achiev considering the relative inexpensive cost of mineral nitrogen fertilizers.

6. Conclusions

Livestock manure is a valuable resource if handled and used appropriately, however, poor manure management can cause public health problems and have a negative impact on the environment. During the past decade there have been several international projects in the Baltic Sea Region that have produced recommendations on various aspects of improving the sustainability of manure use to reduce its environmental impact. Sustainable manure management strategies should consider the whole manure handling chain so that the benefits of adopted measures at one handling stage are not lost later down the chain. There is a need to develop cost effective technologies and practices for sustainable manure use, since if the measures are not profitable, they will not be implemented unless forced to through regulations.

A combination of methods are needed to move towards sustainable manure practices in the Baltic Sea Region. We conclude that there is a need to increase the baseline standard regulations for manure handling and use, for instance broadcast spreading should not be allowed. This should be followed by communication campaigns to educate farmers about sustainable nutrient use and its relation to the farms’ economy. This should be complemented with the establishment of widespread economic incentives to help finance the implementation of sustainable technologies and practices.

7. References

Baltic Manure. 2013. Sustainable manure management in the Baltic Sea Region – Results, cases and project recommendations. Baltic Manure Report. Publication by Interreg BSR project Baltic Manure. Pp 24.

Baltic Slurry Acidification. 2019. Baltic Slurry Acidification final results and recommendations. Publication by Interreg BSR project Baltic Slurry Acidification. www.balticslurry.eu.

Bloem, E., Albihn, A., Elving, J., Hermann, L., Lehmann, L., Sarvi, M., Schaaf, T., Schick, J., Turtola, E., Ylivainio, K. 2017. Contamination of organic nutrient sources with potentially toxic elements, antibiotics and pathogen microorganisms in relation to P fertilizer potential and treatment options for the production of sustainable fertilizers: A review. Science of the Total Environment 607–608: 225–242.

Bolan, N., Adriano, D. & Mahimairaja, R. 2015. Distribution and bioavailability of trace elements in livestock and poultry manure by-products. Critical Reviews in Environmental Science & Technology 34: 291–338.

Damgaard Poulsen H., A. Kaasik, M. Karhapää, J.C. Henriksen, H. Kliver, T. Kortelainen, E. Sindhöj, K. Blaabjerg. 2013. Determine feeding strategies for reducing P and N content in manure. Baltic Manure Knowledge Report. Publication by Interreg BSR project Baltic Manure.

EEA. 2020. Ammonia emissions from agriculture. European Environmental Agency (EEA) under the Convention on Long-range Transboundary Air Pollution.

Foged, H. (editor). 2019. Policy recommendations for supporting SAT implementation. Report from WP6 of Baltic Slurry Acidification project. Publication by Interreg BSR project Baltic Slurry Acidification. www.balticslurry.eu.

Gerber, P.J., H. Steinfeld, B. Hendersson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci, G. Tempio. 2013. Tackling climate change through livestock - A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

GreenAgri. 2019. Videi draudzīga mēslošanas līdzekļu apsaimniekošana, 2019. Project Report.

Grönroos, J., K. Kuka, A.K. Eriksson, N. Kozlova, F. Lehn, S. Lehtoranta, L. Leitans, U. Listh, K. Rankinen, V. Ribikauskas, T. Salo, P. Skowron, I. Subbotin, A. Toomsoo, D. Wach. 2019. Environmental impact of using new manure tools. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Luostarinen S., E. Tampio, J. Laakso, M. Sarvi, K. Ylivainio, K. Riiko, K. Kuka, E. Bloem, E. Sindhöj. 2020. Manure processing as a pathway to enhance nutrient recycling. Report of Interreg BSR SuMaNu platform. Natural resources and bioeconomy studies 62/2020. Natural Resources Institute Finland, Helsinki.76 p.

Olofsson S. 2015. Focus on Nutrients, a voluntary on-farm initiative that benefits both the environment and the economy. Agricultural Catchments Programme, Johnstown Castle Environment Research Centre, Wexford, 28-30 September 2015. ISBN 978-1-84170-619-1.

Kässi P., H. Lehtonen, H. Rintamäki, H. Oostra, E. Sindhöj. 2013. Economics of manure logistics, separation and land application. Baltic Manure Knowledge Report. Publication by Interreg BSR project Baltic Manure.

Manure Standards. 2019. How to make the most of manure. Handbook on good manure management practices. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Manure Standards. 2020. Final recommendations of Manure Standards project. Publication by Interreg BSR project Manure Standards.www.luke.fi/manurestandards/.

Myrbeck Å., A. Kaasik, S. Luostarinen (Editors). 2019a. Manure data collection – experiences from pilot farms. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Myrbeck Å., L. Rodhe, M. Hellstedt, A. Kulmala, J. Laakso, F. Lehn, M. Nørregaard Hansen, S. Luostarinen. 2019b. Manure sampling instructions. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Poulsen, H.D. 1998. Zinc and copper as feed additives, growth factors or unwanted environmental factors. J. Anim. Feed Sci. 7, 135–142.

Rodhe L., J. Casimir, E. Sindhöj. 2018. Possibilities and bottlenecks for implementing slurry acidification techniques in the Baltic Sea Region. Report from WP2 of Baltic Slurry Acidification project. Publication by Interreg BSR project Baltic Slurry Acidification. www.balticslurry.eu.

Salo T., Å. Myrbeck, L. Leitans, V. Ribikauskas, I. Subbotin, S. Luostarinen. 2020. Instructions for manure analysis. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Salomon E., M. Sundberg (editors). 2012. Implementation and status of priority measures to reduce nitrogen and phosphorus leakage – Summary of country reports. Report 405, Agriculture & Industry. JTI – Swedish Institute of Agricultural and Environmental Engineering. Uppsala, Sweden. ISSN-1401-4963.

Schick J., S. Haneklaus, E. Schnug. 2013. Guideline catalogue for sustainable use of manure and manure-based fertilizer products for farmers. Knowledge report from WP4 of the Baltic Manure project. Publication by Interreg BSR project Baltic Manure.

Sindhöj E., A. Kaasik, K. Kuligowski, I. Sipilä, K. Tamm, A. Tonderski, L. Rodhe. 2013. Manure properties on case-study farms in the Baltic Sea Region. Knowledge report from WP3 of the Baltic Manure project. Publication by Interreg BSR project Baltic Manure.

Sindhöj E., L. Rodhe. 2013a. Examples of implementing manure processing technology at farm-level. Report 412, Agriculture & Industry. JTI – Swedish Institite of Agricultural and Environmental Engineering. Uppsala, Sweden. ISSN 1401-4963.

Sindhöj E., L. Rodhe. 2013b. Manure handling techniques on case-study farms in the Baltic Sea Region. Report 417, Agriculture & Industry. JTI – Swedish Institite of Agricultural and Environmental Engineering. Uppsala, Sweden. ISSN 1401-4963.

Tamm, K., Vettik,R., Viil,P., Vosa,T., Kažotnieks, J., 2016, Comparative Survey of Manure Spreading Technologies. GreenAgri Project Report.

Tamm K., R. Vettik. 2019a. Economic analysis of using slurry acidification technologies in the BSR region. Report from Baltic Slurry Acidification project. www.balticslurry.eu.

Tamm K., R. Vettik. 2019b. Economic impacts of using manure tools. Publication by Interreg BSR project Manure Standards. www.luke.fi/manurestandards/.

Ylivainio, K., Lehti, A., Sarvi, M., Turtola, E. 2017. Report on P availability according to Hedley fractionation and DGT-method. BONUS PROMISE deliverable 3.4. 20 p.

8. Appendix, Project descriptions

Brief project descriptions

SuMaNu

SuMaNu is an Interreg BSR platform project that took place from September 2018 to June 2021.

Eutrophication of the Baltic Sea is still a major problem caused by the excess nutrient loading mainly from agriculture. Thus, more efficient manure and nutrient management in agriculture is required to minimize nutrient losses and close the nutrient loops. The situation calls for transnational measures both at the farm and regional level throughout the catchment area. Several previous projects have been tackling this challenge during the recent years from different perspectives, but more holistic recommendations are still needed.

To boost development towards more sustainable agriculture SuMaNu (Sustainable Manure and Nutrient Management for reduction of nutrient loss in the Baltic Sea Region), as an Interreg Baltic Sea Region funded platform project, synthesizes sustainable manure and nutrient management practices both at the farm and regional level (work package 2) promoted by four international projects; Interreg Baltic Sea Region funded Baltic Slurry Acidification and Manure Standards, Interreg Central Baltic funded GreenAgri, and BONUS Programme funded BONUS PROMISE. In addition, the results from previous Interreg Baltic Sea Region funded projects such as Baltic Manure, Baltic Deal, Baltic Compass and Baltic Compact are utilized. This synthesis is a basis for jointly formulated policy recommendations for environmentally and economically sustainable manure management (work package 3). All the recommendations are prepared in cooperation with different target groups to enhance their implementation.

Via the broad partnership (Natural Resources Institute Finland (Luke) as a coordinator, Research Institute of Sweden (RISE), HELCOM, BSAG, Estonian Crop Research Institute (ECRI), Union Farmers Parliament (ZSA, Latvia), Agricultural Advisory Center in Brwinów (CDR, Poland), Organe Institute ApS (Denmark) and Julius Kühn Institute (JKI, Germany)) the recommendations are communicated to various target groups, such as policy makers, advisors and via farmers' unions to farmers (work pack-age 4). The policy recommendations are also utilized in the process of HELCOM Nutrient Recycling Strategy and in the revision of the Baltic Sea Action Plan.

More information at www.balticsumanu.eu

Manure Standards

Advanced manure standards for sustainable nutrient management and reduced emissions (Manure Standards) was a flagship project for EU strategy for the Baltic Sea Region, mainly funded by Interreg Baltic Sea Region Programme and implemented in 2017-2020. Manure Standards was coordinated by Natural Resources Institute Finland (Luke) and included 19 partners from 9 countries around the Baltic Sea: Finland, Sweden, Denmark, Germany, Poland, Lithuania, Latvia, Russia and Estonia.

The project focused on developing more harmonized methods for manure data collection and use to improve the use of the valuable resource and to minimize losses into the environment.

The methods developed were 1) manure sampling and chemical analysis and 2) manure mass balance calculation. The methods were tested on approximately 100 pilot farms around the Baltic Sea Region and experiences in their use reported. Detailed instructions for manure sampling, recommendations for manure analysis and calculation tools for manure mass balances were published. The impact of manure data on the environment and farm economy was also assessed, methods for nutrient balance calculation compared and current status of regulation and voluntary actions of manure fertilizer use in the participating countries collected.

In the final recommendations the following issues were raised:

- Main principles:
    - Manure management should maximize its benefits as a valuable fertilizer while minimizing losses to the environment. Thus, manure fertilization should be based on up-to-date data on manure quantity and composition generated with clearly documented methods.
    - Data on manure quantity and composition in all measures should be regularly updated. The same national data should be used as the basis for all manure regulation, emission inventories, national nutrient budgets etc. to avoid conflicts between different measures.
    - The official national manure data (quantity and composition) should be made easily available for all users and for
        - Farm-scale uses, including manure quantity and nutrient content to ensure sufficient manure storage capacity and precise manure fertilization planning and implementation, and
        - National/regional uses, including average statistics of manure quantities and nutrient contents in different animal production types and in shares of different manure types to enable effective guidance, emission control and regulation aiming at efficient manure use.
- Manure sampling and analysis can be used as a means to measure manure composition, including nutrient content provided the sampling is properly done (representative of the conditions and manure type) using at minimum the sampling instructions prepared by the project "Manure Standards"; the samples are preserved and pretreated in a manner minimizing losses, and the analyses are performed using standardized analysis methods in accredited laboratories experienced with manure as a matrix.
- Laboratories analyzing manure samples are encouraged to improve their expertise and accuracy in manure analysis via proficiency testing or interlaboratory comparison. To improve usability of the analyzed manure data as a databank, laboratories are encouraged collect and save more precise background data per manure sample.
- Due to the importance of recycling organic matter into field soil, the organic matter and/or carbon content in manure should be included into the analyzed parameters.
- Manure composition, including nutrient content, can be derived from a manure mass balance calculation, provided there is a suitable calculation tool available, the tool matches the national animal feeding and rearing and manure management practices, there are sufficient and high quality input data available for the calculation, and the tool is tested and documented for each country before its official use.
- Manure mass balance is the recommended method for determining manure quantity taking into account animal production (feed, growth, product yield, reproduction), management choices in housing (housing technology, addition of water and bedding), and choice of manure storage (covering, precipitation, evaporation).

- Manure mass balance calculation is the recommended method to quantify manure and its nutrients for a country or a region.
- To enhance regional nutrient recycling and to improve nutrient self-sufficiency, manure nutrients should be utilized as precisely as possible also on regional scale. Mineral fertilizers should be used as additional nutrient sources, if needed.
- Fertilization planning using manure should always be based on up-to-date data on manure nutrient content regardless of the nationally supported method for data generation. Also the fertilization requirements of different crops, soil quality, precrop and climate conditions have to be taken into account. All fertilization should always take into account national limits for nitrogen and phosphorus use.
- Farm-specific nutrient balances should always be calculated and their results implemented to ensure balanced nutrient input-output on farms. They would also reveal the potential need to export part of the manure nutrients to other farms or to manure processing outside the farm.
- The expertise of advisors should be strengthened to improve farmer support on practical and efficient manure-related measures.

GreenAgri

Green Agri – "Environmentally-friendly Management of Organic Fertilizers in Agriculture"

Specific objective: Reduced nutrients, hazardous substances and toxins inflow into the Baltic Sea

The project GreenAgri was implemented in 2016 – 2019. The project was a joint effort of farmers from Estonia and Latvia contributing to the improvement of eutrophication status of the Baltic Sea. During the project 22 farmers from Estonian and Latvian implement innovative technologies and methods in real life using their own financial resources. Experts and researchers gathered and analyzed nutrient runoff data and provided the farmers with information about the efficiency of different solutions demonstrating real results in reducing nutrient losses from farms. Sustainability was ensured through dissemination of new knowledge to more than 300 farmers. Advisors who received knowledge and experience during the project implementation, can support farmers at both sides of the border.

Recommendations:
Manure storages:

- Covering existing manure storages (solid roofs for lagoons, metallic and concreate storages) is not recommended, since there are no technical and economically reasonable solutions available in the market. Especially because of slurry mixing and pumping.
- While lagoon type storages require smaller investments, technology is rather difficult for mixing, cleaning, and management. Additionally, in high precipitation periods, high amount of water is stored in lagoon.
- Further studies are recommended on the manure storages capacities, since due to climatic changes, vegetation periods are becoming longer, and there are possibilities to spread manure on the fields earlier. Shorter storing period capacity is suggested.

Education and information of farmers

- Make regular soil agrochemical analysis in order to determine the level of nutrients in soil,
- Create an accurate fertilization plan for the fields
- Spread the fertilizer in accordance with two previously mentioned points.

- More individual communication between control institution representatives and farmers is suggested, with the first aim to educate and consult, but not to start with sanctioning.
- A creation of correct and precise fertilization plan is major leap forward a sustainable farming

Manure spreading:

- During the stubble tillage after harvest it is recommended to add some nitrogen. Incorporation spreading with disc device is suitable method to join the stubble or green manure tillage and fertilizing with slurry into one work operation and to get even mixture from soil, manure and plant residues. The slurry is bound with soil and plant residues particles and the emission of ammonia and odor is low. The slurry is not buried to deep layers and emerging crops sown after some weeks can start to use nutrients from upper layer of soil layer.
- Alternative way is to use trail hose spreader. However, it causes higher ammonia emissions and need for separate tillage immediately after application.
- Closed-slot injector with tines is suitable for first tillage after winter if most pre-crop residues are molded and bigger amounts of slurry per hectare should be applied to build nutrient depot for growing season. Closed-slot injector has very low ammonia emission and in weather conditions favorable for ammonia emission is this equipment most cost effective.
- If the field is covered with lot of pre-crop residues and there is risk of jamming of tines then it is suggested to use disc incorporator also on in spring time. Alternative way is to use trail hose spreader. However, higher ammonia emissions and need for separate tillage ASAP after application should be taken into account if slurry is not acidified.
- Trail hose spreader and open-slot injector are suitable to fertilize grasslands or growing crops with slurry. Trail hose spreading is cheaper in conditions unfavorable for ammonia emissions.
- For transportation from storage to the field it is cheaper to use separate tank which is not loaded with spreading device and can move faster than spreader.
- In the case of suitable distances and landscape (no disturbing obstacles, roads or settlements) it may be considered to establish pipe connection as alternative for tank vehicles.
- To minimize waiting times of spreader and transporter, it is suggested to use buffer tank on the field. The umbilical system can be used to connect buffer tank and spreader.
- The payoff period of spreading equipment is the shorter the bigger is the slurry amount in the farm. In dairy farm is the payoff period over 50 year for farm with 100 dairy cows for trail hose spreader and open-slot injector both. In farms with 900 cows the payoff period was under 4 years.
- If farmer plans investments to manure spreading equipment, then it is suggestable recommended to calculate manure-handling costs in the case of own equipment and compare it with prices with available spreading service providers. For smaller farms, the price offered by service provider is often cheaper than usage of own equipment.
- From technological point of view is suggestable to avoid semi-liquid manure (DM 12-20 %) because this is not well pumpable nor heapable and is hard to handle with either liquid or solid manure spreader both.
- If the semi-solid manure is not separated, then most suitable is to use universal spreaders with watertight box and rear wall.

- It is advised to spread solid manure with a spreader with vertical beaters and spreading discs. It gives a wider and more even manure distribution than spreaders the horizontal beaters and without discs.
- Humid, windless, cloudy and cool weather is favorable for manure spreading. However, the soil is not allowed to be frozen, covered with snow nor over-flooded.
- Solid and semi-liquid manure incorporation for grasslands before sowing in springtime leaves a positive effect both on reduction of potential pollution and increase of yield, so this technology could be recommended for small sized farms which are not able to invest in advanced farming equipment.
- It is recommended to do all efforts to arrange spreading of organic fertilizer in spring – time when the vegetation is on its peak.

BONUS PROMISE

BONUS PROMISE focused on P-rich materials such as manure and/or sewage sludge and their contents of harmful contaminants (trace elements, antibiotics, pathogens) as well as for phosphorus (P) bioavailability as affected by variable processing. The materials were collected from 29 biogas plants in Finland, Sweden and Germany before and after digestion (e.g. digestates, separated end products or compost), including pig, cattle and poultry manures, plant material, industrial byproducts and sewage sludge in varying ratios. Additionally, pig and cattle manure ash, sewage sludge treated with ASH DEC –method (gasification followed by chemical treatment) and one commercial struvite product were studied. Trace element (As, Cd, Cr, Cu, Ni, Pb, Zn, Hg) concentrations were under the limits set by the sewage sludge directive (86/278/EEC) while the stricter national limits in Finland, Sweden and Germany were exceeded only occasionally. However, sewage sludge, pig slurry and poultry manure had most often measurable quantities of antibiotics. The concentrations of tetracyclines and fluoroquinolones were highest in undigested poultry manure, pig slurry and sewage sludge as well as in end-products of poultry manure and sewage sludge, revealing that digestion is not able to eliminate antibiotic contamination. Also, pathogens were frequently found both in undigested materials and in end-products (Salmonella spp., Cryptosporidium spp., Giardia). For achieving significant pathogen reduction with digestion, thermophilic temperature is required, and recontamination needs to be prevented. Phosphorus bioavailability in undigested manures, their digestates and struvite was comparable to that of mineral fertilizer, whereas in sewage sludge digestates it was on average only 35%, and was depressed by the increasing molar ratio of iron + aluminum to that of P. Gasification reduced P bioavailability, but further chemical ASH DEC –treatment (for sewage sludge) improved the bioavailability beyond mineral fertilizer.

Baltic Slurry Acidification

Baltic Slurry Acidification was an Interreg BSR project that took place from March 2016 to February 2019.

Ammonia emissions from livestock manure causes airborne eutrophication and other negative impacts on the environment. In addition, ammonia emissions represent an economic loss for farmers and leads to increased use of mineral nitrogen fertilizers. Slurry acidification technologies (SATs) developed in Denmark are easily implemented on farms and have been shown to significantly reduce ammonia emissions from slurry. The Baltic Slurry Acidification Project (BSA) has studied and analyzed various aspects of slurry acidification that could hinder adoption of these techniques, including worker health and safety, potential corrosive effects on concrete and equipment, effects on soils, farm economy as well as legislative barriers and possibility to import technologies from Denmark. In general, no major barriers were found that would directly hinder implantation of current slurry acidification technologies in Baltic Sea Region (BSR) countries. There was considerable interest among farmers in the potential benefits from SATs, however, there were concerns about costs and profitability. In conclusion, SATs were shown to be effective green tech solutions that reduce nitrogen loss from agriculture, do not negatively affect yields and can be readily implemented, however, political incentives or compensation mechanisms are necessary to initiate investments and promote implementation of SATs.

Recommendations:

- Farmers should consider SATs as cost-effective BATs for reducing ammonia emissions from animal production, especially large scale IED (Industrial Emissions Directive) farms.
    - In-house SATs are effective at reducing ammonia emissions from the entire manure handling chain (animal house, storage and during spreading)
    - In-storage SATs, as they are commonly used today, are effective at reducing ammonia emissions during speading. There is a modified in-house SAT which is applied after the housing system so that only the storage and spreading are affected.
    - In-field SATs are effective at reducing ammonia emissions during spreading.
- Health and worker safety experts should be consulted before implementation of SATs on the farm.
- Authorities and policy makers should implement compensation mechanisms to promote implementation of SATs and other Green-Agri technologies.
- All BSR countries should establish national expert groups to examine the potential for SATs to be implemented as an abatement measure to reduce national ammonia emissions.

Baltic Manure

Baltic Manure was an Interreg BSR project which took place from January 2011 to December 2013.

The Baltic Manure project created a forum for innovative technologies for sustainable manure management to aid communication between farmers and other end users, businesses and enterprisers, advisors, researchers, authorities and policy makers. The long-term strategic objective of the Baltic Manure project was to change the general perception of manure from a waste product to a resource, while also identifying its inherent business opportunities.

Basic general recommendations were:

- Close the nutrient cycles
- Get the energy out
- Increase knowledge on manure quality
- Stimulate innovation
- Incentives for cooperation
- Communicate technologies for farmers and advisors.

More detailed recommendations were specified according to various stages of the manure handling chain and other relevant aspects to consider including:

1. Feed and feeding system

a. Reduce the import of crude protein by replacing soybean meal with industrially produced amino acids for pigs and poultry
b. Reduce the import of mined phosphates by replacing feed phosphates with microbial phytase for pigs and poultry
c. Use protein and energy optimized for dairy cattle
d. Use Multiphase feeding as a tool to supply the animals with nutrients required for optimal health and production
e. Use liquid feeding as a powerful tool to improve the utilization of phosphorus and protein in animals.

2. Animal housing system
    a. Control water additions to slurry as an integral part of manure management
    b. Separate and re-use cleaning water when possible
    c. Collect manure frequently from housing to outdoor storage, thus reduce emissions from the housing system.
3. Manure processing technologies
    a. Calculations of investments and consequences should be made on a farm level for choosing manure handling technologies to find profitable options.
    b. Analysis of the consequences on the manure handling chain and nutrient management strategies on a farm-level
    c. Consider the environmental benefits
4. Storage
    a. Ensure sufficient covered storage capacity
5. Spreading
    a. Place more focus on the timing, dosage and spreading evenness of manure application in the field
    b. Minimize losses after spreading by harrowing directly after spreading, use of injection or acidification
    c. Use precision agriculture for field application including manure analysis, dosage, high spreading evenness according to spatial data
    d. Use upper limits for P dosage in the fields.

Baltic Deal

Baltic Deal project was from July 2010 until September 2013 and gathered farmers and farmers' advisory organizations around the Baltic Sea in a unique effort to raise the competence concerning agri-environmental practices and measures. The aim was to support farmers to reduce nutrient losses while maintaining production and competitiveness.

Baltic Deal provides advisory organizations with improved, cost efficient methods and tools of how to support farmers to reduce nutrient losses from farms. Baltic Deal aimed to increase the knowledge exchange of sustainable agri-environmental practices in the Baltic Sea region. The project establishes a network for farmers and advisory services to exchange knowledge about good practices and learn from each other. Baltic Deal also organized study trips for farmers and advisors both within the country and to other countries in the region.

Pilot activities for demonstrating improved water management was tested in everyday farming and adjusted to farming conditions in each country. In pilot areas, such as at the B7 islands, the seven largest islands in the Baltic Sea, farmers tested how to apply good agri-environmental practices. Tested measures were for example using plant cover outside growing season, improved fertilization methods, manure management and treatment of run-off waters. The project established and maintained a large network of demonstration farms around the Baltic

Sea. The farms demonstrated suitable agri-environmental investments, practices and measures from a farm business perspective.

The problem of farm nutrient run-off eventually entering the Baltic Sea was recognized by the farmer's federations in all the countries surrounding the Baltic Sea. Baltic Deal was therefore a joint effort to improve the Baltic Sea environmental status by using cost efficient and competitive measures to reduce the nutrient losses from agriculture.

Guidelines on agri-environmental practices for farmers and advisors where focused on the project website which held detailed information on 50 different agri-environmental measures and their suitability for different farms. Through implementing these measures, farmers could reduce nutrient losses and save money by improving practices and investing in best available technology. Some of the measures required public funding to be sustainable, but some did not require any additional funding.

A demonstration farm network was established and operational in all 7 project countries (FI, EE, LV, LT, PL, DK, SE) uniting 117 farms. The description of all network farms was available on the project website.

A strategy for development of agri-environmental advisory services in BSR outlined the future cooperation possibilities of the agricultural advisory organizations in BSR. The key message of the strategy was to continue to strengthen the transnational co-operation among advisory actors. Another key message was the need to strengthen demonstration farm networks nationally and internationally and provide advisory support. Transnational internet platform for exchanging experiences provided information on different topics related to farm advisory, such as recommendations for group advice, advisory services and methods, communication, best cases from the Baltic Deal project and other projects as well as training materials from all countries involved in the project. The information was open to any farmer or advisor who was interested in improving the environmental performance of agriculture.

Baltic Compass

Baltic COMPASS (2009-2012; Interreg Baltic Sea Region Programme 2007-2013) was a response to the need for a transnational approach to reduce eutrophication of the Baltic Sea. The project set out to remedy the gaps in the stakeholders' capacity and resources to combat eutrophication and communicate on the different policy levels and build trust between the environmental and agricultural sectors.

Implemented by a consortium of 23 partners throughout the Baltic Sea Region, Baltic COMPASS project raised awareness in adaptive governance measures and advanced trustful dialogue between the environmental and agricultural interests. The project outputs highlight win-win solutions in farm measures as well as policy approaches. The specific comprehensive decision support outputs on i.a. spatial planning of agri-environment measures, local scenarios, effect of advanced technologies and policy adaptation concepts are used by national ministries, HELCOM, EC and the farmers and advisory communities. As a strategic project having also prepared investments, Baltic COMPASS was extended by 2 years in a form of an extension stage project Baltic Compact.

With respect to knowledge on manure management, the most relevant outputs of the extended Baltic COMPASS project were:

- investments in advanced manure processing in Denmark and Latvia. In Denmark, investment in an extruder for straw and other solid substrate was made to demonstrate improvement of efficiency of anaerobic digestation. Also, in Denmark, an investment in a mobile manure separator was made for shared use among several farmers. In Latvia, the project invested in design and upgrading of a biogas plant to a CHP plant using cattle manure (report: Improvement and enlargement of Vecauce Biogas Plant, Latvia; Agro Business Park A/S, 2012)

- a compilation of win-win agri-environmental technologies, https://www.agrotechnologyatlas.eu/
- several reports and policy briefs on nutrient and manure management measures, including *Implementation and status of priority measures to reduce nitrogen and phosphorus leakage, Summary of Country Reports* (JTI-Swedish Institute of Agricultural and Environmental Engineering, 2012) and *Sector Study - prioritized innovative agro-environmental technologies for sustainable food production in the Baltic Sea Region* (Agro Business Park A/S, 2011)

In its final conclusions, Baltic COMPASS raised the importance to look for and support local business models which contribute to environmental objectives and nutrient circulation. The conclusions also maintained nutrient-balanced farming as a standard backbone. Of individual measures, the project recognized biogas as an example of a potential win-win measure, but sustainability with respect to nutrients and energy must be secured and for this legislation and economic incentives need to be developed.

SuMaNu in brief

Eutrophication of the Baltic Sea is still a major problem caused by the excess nutrient loading mainly from agriculture. Thus, more efficient manure and nutrient management in agriculture is required to minimize nutrient losses and close the nutrient loops. The situation calls for transnational measures both at the farm and regional level throughout the catchment area. Several previous projects have been tackling this challenge during the recent years from different perspectives, but more holistic recommendations are still needed.

To boost development towards more sustainable agriculture SuMaNu (Sustainable Manure and Nutrient Management for reduction of nutrient loss in the Baltic Sea Region), as an Interreg Baltic Sea Region funded platform project, synthesizes sustainable manure and nutrient management practices both at the farm and regional level (work package 2) promoted by four international projects; Interreg Baltic Sea Region funded Baltic Slurry Acidification and Manure Standards, Interreg Central Baltic funded GreenAgri, and BONUS Programme funded BONUS PROMISE. In addition, the results from previous Interreg Baltic Sea Region funded projects such as Baltic Manure, Baltic Deal, Baltic Compass and Baltic Compact are utilized. This synthesis is a basis for jointly formulated policy recommendations for environmentally and economically sustainable manure management (work package 3). All the recommendations are prepared in cooperation with different target groups to enhance their implementation.

Via the broad partnership (Natural Resources Institute Finland (Luke) as a coordinator, Research Institute of Sweden (RISE), HELCOM, BSAG, Estonian Crop Research Institute (ECRI), Union Farmers Parliament (ZSA, Latvia), Agricultural Advisory Center in Brwinów (CDR, Poland), Organe Institute ApS (Denmark) and Julius Kühn Institute (JKI, Germany)) the recommendations are communicated to various target groups, such as policy makers, advisors and via farmers' unions to farmers (work package 4). The policy recommendations are also utilized in the process of HELCOM Nutrient Recycling Strategy and in the revision of the Baltic Sea Action Plan. More information at

https://balticsumanu.eu/

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,800 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

I internationell samverkan med akademi, näringsliv och offentlig sektor bidrar vi till ett konkurrenskraftigt näringsliv och ett hållbart samhälle. RISE 2 800 medarbetare driver och stöder alla typer av innovationsprocesser. Vi erbjuder ett 100-tal test- och demonstrationsmiljöer för framtidssäkra produkter, tekniker och tjänster. RISE Research Institutes of Sweden ägs av svenska staten.

RISE Research Institutes of Sweden AB
Box 857, 501 15 BORÅS, SWEDEN
Telephone: +46 10-516 50 00
E-mail: info@ri.se, Internet: www.ri.se

Agriculture and Food
RISE Report 2020:77
ISBN: 978-91-89167-62-9