WaterPro - Northern Runoffs into Profits

T1 Good Practice Tools and Guidance

Output T.1.2.

An Inventory of Good Management Practices for Nutrients Reduction and Recovery from Agricultural and Mineral Extraction Runoff

Good Management Practices for Nutrients Reduction and Recovery from Agricultural Runoff

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Background

The "Good Agricultural Practices (GAP or GPs) or "Best environmental management practices (BEMPs)" (Europe) or Best Management Practices, BMPs (North America) are broadly defined as '*methods and/or practices designed to reduce or prevent soil and water pollution without affecting farm productivity*'. They were developed in the 1950s as the conservation measure to combat soil erosion and were implemented as soil remediation practices for two decades prior to the first awareness and recognition that non-point source (NPS) phosphorus (P) pollution from soil run-off and erosion, fertilizer and livestock runoff results in eutrophication of water bodies in 1970s (Logan, 1993). Throughout this report the term GAP will be used to cover all other terminology related to agricultural management practices, e.g. BEMP, BMP etc.
Despite over 4 decades of efforts and considerable financial investments in implementation of conservation control interventions and management strategies pollution mitigation, excess loading of nutrients generated by agricultural activities remains a major water quality issue in Europe and across the globe (e.g. Logan, 1990; Jarvie et al, 2013; Schoenberger et al, 2015; Sharpley et al, 2015; Pannel, 2017; European Comission, 2018; Drizo, 2019). Nutrient pollution also represents a growing concern for oligotrophic water bodies in the arctic environment (Prowse et al, 2006).

Given the recognition and extent of water pollution resulting from agricultural activities, over the past 15 years there have been considerable investments in the development of the Guidelines and User Manuals of GAPs for the entirety of Europe and globally. Today almost every country of the world has a Guide or Code of Practice. Drizo (2019) recently summarized some of these guides. Those pertinent to Northern Periphery and Arctic (NPA) areas and WaterPro project are presented in Table 1, bellow:

Table 1: List of Guidelines and Reports describing GAPs for Agricultural P and Nitrogen (N) pollution mitigation. Modified from Drizo, 2019:

Year	Title	Pages	Author
2011	Mitigation options for reducing nutrient emissions from agriculture. A study amongst European member states of Cost action 869.	147	Schoumans et al (2011) http://www.cost869.alterra.nl/
2011	An inventory of mitigation methods and guide to their effects on diffuse water pollution, greenhouse gas emissions and ammonia emissions from agriculture.	162	Newell-Price et al (2011)
2012	Best management Practices Policy Tool Box Presentation	18	UNEP (2012)
2014	Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice. Learning from frontrunners Promoting best practice.	26	Schoenberger et al (2014)
2015	EU Database of Best Practices		Living Water Exchange (2019)
2018	Best environmental management practice for the agriculture sector - crop and animal production	628	European Commission (2018)

However, most of the above guides are focused on the GAPs descriptions and applications, with a very limited information on the treatment efficiency and functionality, costs of implementation, ease of operation and maintenance, potential for nutrients recovery and ability for climate change mitigation, which are the main selection criteria for GAPs that will be used in our project's Inventory and a Tool Box.

Randall et al (2015) conducted the most comprehensive research to date on the effectiveness of the most commonly used on-farm mitigation measures (e.g. vegetated buffer strips, cover/catch crops, slurry storage, woodland creation, controlled animal trafficking and subsoiling) in improving water quality in temperate farming systems in Europe, Canada, New Zealand and northern states of the United States of America. The aim of their study was to categorize all available evidence on the effectiveness of these practices and generate systematic map of agricultural practices effectiveness in pollutants (nutrients, sediment, faecal indicator organisms (FIO) and other pathogens) mitigation and provide a large database of research to be used by decision makers and delivery agencies to facilitate catchment planning as required by the water framework directive (WFD). This is very similar to the objectives of the WaterProT1 Good Practice Tools and Guidance Work Package. However, in our project, apart from treatment efficiency and functionality, we also proposed GAPs categorization according to costs of implementation, ease of operation and maintenance, ability for climate change mitigation and potential for nutrients recovery (Table 2) i.e. their overall practicality reflecting their ease of implementation and uptake.

The literature search performed by Randall et al (2015) included 718 articles collected from online publication databases, search engines, specialist websites and bibliographies of topic and specific reviews. They found that

Vegetated Buffer Strips (including woodland buffers) were the most commonly reported agricultural practice (n = 364), followed by cover/catch crop (n = 245) and slurry storage (n = 93). The majority of articles originated from the northern states of the USA (n = 256) and these mainly investigated buffer strips. The remainder of the articles originated from Europe, and most were from the UK (n = 80) where cover/catch crops were reported marginally more frequently than buffer strips. The most frequently measured water quality parameter in 718 reviewed articles was N (n = 473), followed by P (n = 178) and sediment (n = 165). Most reported measurements were in buffer strips (209 studies on N, 136 on P and 128 on sediment), followed by cover/catch crop (203 studies on N, but only 24 on P and 28 on sediment and slurry storage (n = 58).

The major research findings relevant to our project were:

1) Few studies measured the effectiveness of GAPs (interventions) at catchment scale;
2) Further, long term studies with controls, pre and post water quality measurements and multiple sampling points from both field and rivers would improve the evidence base.
3) Further research investigating seasonal variations in the effectiveness of GAPs, particularly buffer strips, woodland creation and cover/catch crops would also be useful.

Furthermore, two main specific Knowledge gaps specific to the use of buffer strips were identified:

4) There was limited research investigating the effectiveness of buffer strips for reducing Leaching of organic forms of N or P,
5) An evidence gap exists for the impact of cover/catch crops in reducing organic forms of N and P.

The gaps and limitations in the research on GAPs are not surprising given *that these practices are typically recommended, not required, so practical implementation is principally voluntary in nature and offered via various governmental monetary subsidies* (Sidemo-Holm et al, 2018; Drizo, 2019).

The Costs of Good Practice Implementation

Sidemo-Holm et al (2018) highlighted that action-based payments that compensate farmers for adopting land-management measures to preserve and protect the environment have been criticized for being ineffective. They suggested that the root of the problem is in the fact that farmers are not paid for achieving a desired environmental benefit, but compensated for their costs of management. According to the OECD study (OECD, 2012) which investigated the range of GAPs deployed at the local, catchment, regional, national and international scales across an array of different governmental agencies, the implementation of these GAPs cost taxpayers billions of dollars annually. For example, the agro-environmental monetary payments to farmers and other landholders over two year period (2007-2009) was the highest in the EU (€ 6000 million) followed by the USA (€ 4,400 million). Of these, in the EU, about 7% was allocated for the Producer Support Estimate (PSE), an indicator of the annual monetary value of gross transfers from consumers and taxpayers to support agricultural producers, measured at farm gate level, arising from policy measures, regardless of their nature, objectives or impacts on farm production or income (OECD, 2012; Drizo, 2019). Governmental expenditures typically include 1) the financial agro-environmental payments provided directly to agricultural producers as a compensation for a loss of income for adopting sustainable agricultural conservation management practices and 2) expenditures on various technical assistance for GAPs/BMP implementation (OECD, 2012). In the EU27 these payments are fully financed by the EU, and account for 70% of the Common Agricultural Policy budget (European Commission, 2015).

Northern Periphery and Arctic (NPA) areas Codes of Good Practice and Legislation for the prevention of Environmental Pollution from Agricultural Activities

When dealing with the nutrient pollution from agricultural sources, water directives and/or national policies across Europe and North America prescribe particular compliance options for the "best possible measures" (GAPs or GPs, BEMPs or BMPs) leaving it to national regulators and permitting agencies to determine what these measures and practices are.

In order to create the GAPs Inventory for the NPA Region several discussions were held during project meetings in Sweden (Nov 2016) and Ireland (May 2017), a set of questionnaires were prepared by the consultant (Dr. Drizo) and distributed to WaterPro partners via email during summer and fall of 2017. The first round of questions focused on collecting information on:

1) whether there is a Code of Good Practice for the prevention of Environmental Pollution from Agricultural Activites for the partner country/region? If so,
2) whether there is any legislation (regulatory requirements) for nutrients (phosphorus, nitrogen or both) removal from agricultural sources (effluents and runoff)?
3) what are the current practices recommended in the Code for the management of agricultural nutrient runoff?

Responses from the Partners are presented in Appendix 1. In addition, oral presentations on current legislation and Good practice guidelines for agriculture in Iceland (Loftsson, 2017; Fjeld, 2017) and Finland (Rantala, 2017) were presented during WaterPro meeting held in Iceland, November 20-24th 2017.

These results are presented in Tables 1-3, bellow:

Table 1: NPA Country/Region Code of Practice for the prevention of Environmental Pollution from Agricultural Activities.

NPA Country/Region	**Code of Practice**
Finland	While Finland has a long history of environmental protection and in particular for Forest management, e.g. Best Practice Guidelines for Sustainable Forest Management (Tapio, 2019; Yrjölä, 2002) the most of their documents are in Finish language and they do not seem to have Guidelines document specific to Good Agricultural Practices (Kauppinen and Puustinen, 2017). However, as an EU member country, recommended Best environmental management practice for the agriculture sector - crop and animal production are listed in the European Commission Guide (2018).
Iceland	Starfsreglur um góða búskaparhætti. The Environment Agency of Iceland – Umhverfisstofnun (2002). Good practice guidelines (GPG) for agriculture and their implementation are compiled and published by the Environmental Agency of Iceland (Umhverfisstofnun) in close cooperation with Farmers Association and Advisory Centre Guidelines supporting farmers in preventing/minimizing pollution from Agriculture (Loftsson, 2017).
Faroe Islands	Government regulation from 2012 regarding fertilizing with slurry in order to avoid runoff. (https://logir.fo/Kunngerd/72-fra-29-05-2012-fra-tading)
Scotland	Code of Good Practice. Government of Scotland (2005). The purpose of this Code is to provide practical guidance for farmers and those involved in agricultural activities, including farm advisers, on minimizing the risks of environmental pollution from farming operations. Additional information can be found in the European Commission (2018) guide on the Best environmental management practice for the agriculture sector - crop and animal production.
Northern Ireland (NI)	Code of Good Practice (CGP) for the Prevention of Pollution of Water Air and Soil Guidelines, for Northern Ireland (NI) are provided at the Department of Agricultural Environment and Rural Affairs website (DAERA NI, 2008). The CGP contains statutory management requirements (SMRs) and good agricultural and environmental conditions (GAECs) and under cross-compliance farmers must adhere to these guideline if they are to claim Single Farm Payments or other direct farm subsidies. The SMRs covered under cross-

	compliance include Nitrates Action Programme regulations (2015), Phosphorus (use in Agriculture) Regulations (2015) and Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations (Northern Ireland) 2003 (DAERA NI, 2019). *Similar to other NPA countries the current CGP does not contain a clear inventory of good agricultural practices (GAPs) for nutrients reduction and recycling and or recovery (N3R).* Instead, the CGP guideline is categorized according to the air soil and water environmental resources degraded by agricultural practices. The European Commission (2018) guide on the Best environmental management practice for the agriculture sector - crop and animal production also applies in NI.
Republic of Ireland	Irish Statue Book (2014). S.I. No. 31 of 2014. European Union (Good Agricultural Practice for Protection of Waters) Regulations 2014. As an EU member country, recommended Best environmental management practice for the agriculture sector - crop and animal production are also listed in the European Commission Guide (2018).

Table 2: European Legislation related to nutrient pollution from agricultural activities. Source: (modified from Amery and Schoumans, 2014 and Drizo, 2019).

Directive	
Nitrates Directive	91/676/EC
Integrated Pollution Prevention and Control Directive (IPPC)	96/61/EC
Water Framework Directive (WFD)	2000/60/EC
Groundwater Directive (developed from Water Framework Directive)	2006/118/EC
Marine Strategy Framework Directive	2008/56/EC
Waste Framework Directive	2008/98/EC

The WFD has been widely accepted as the most substantial and ambitious piece of European environmental legislation. It consolidated and updated earlier EU water legislation and extends the concepts of river basin management planning to the entirety of Europe. The major purpose of the WFD was to establish a framework for the protection of European waters in order for Member States to reach “good status” objectives for all surface and ground water bodies throughout the EU and to prevent any further deterioration (Drizo, 2019). These efforts were based on a six-year cycle, where the WFD environmental objectives were expected to be met by 2015. Member States that did not achieve the objectives had extensions to second (from 2015 to 2021) and third (2021 to 2027) management cycles respectively (Voulvoulis et al, 2017).

Table 3: NPA Country/Region Water Legislation for the prevention of Environmental Pollution from Agricultural Activites.

NPA Country/Region	**Legislation/Rule**
Finland	Nyroos (2014) outlined major water policy instruments in Finland. These include: • Finland’s Programme for the Protection of the Baltic Sea in 2002 • 2005 Action Plan for the Protection of the Baltic Sea and Inland Watercourses. • River Basin Management Plans 2010-2015 (2009) • The implementation programme of the River Basins Management Plans (RBMP) (2010) Government Decree on Limiting Certain Emissions from Agriculture and Horticulture (Finlex, 2014).

Iceland	Based on EU Nitrates Directive (regulation 91/676/EC, Table 2) on water protection against agricultural pollution (Loftsson, 2017). EU regulation transposed to Icelandic legislation by regulation 804/1999.
Faroe Islands	• The oldest code of law found in the Faroe Islands regarding livestock (sheep) farming practices is a Royal Decree from 1298 named the Sheep Letter (Faroeislands, 2019). • Circular regulating sheep number on each farm in order to control grazing pressure.1873 • Act about management of sheep farming. Hagalógin 1937. • Regulation regarding fertilizing with slurry in order to avoid runoff. 2012 (https://logir.fo/Kunngerd/72-fra-29-05-2012-fra-tading) • The constitutional status of the Faroe Islands as well as foreign relations (https://www.government.fo/en/home/)
Scotland	*Nitrate Vulnerable Zones (NVZs)* 1) The Private Water Supplies (Scotland) Regulations 1992 maximum admissible nitrate concentration in water of 50 mg/l and are implemented by the local authorities (6A.1) 2) 6A.2 The Protection of Water Against Agricultural Nitrate Pollution (Scotland) Regulations 1996 transpose into Scots law the requirements of EC Nitrates Directive (91/676/EEC). 3) 6A.3 Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2003. 4) Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003.
Northern Ireland	1) the Nitrates and Phosphorus Regulations 2007-2010 (Daera-NI, 2019) 2) Nitrates Action Programme (NAP) 2011 -2014 and Phosphorus Regulations (Daera-NI, 2019) Compliance with the Nitrates Action Programme is one of the Cross Compliance Statutory Management Requirements. Therefore, farmers claiming Basic Payment Scheme and other direct payments are required to comply with the NAP Regulations. Measures relating to the Phosphorus Regulations are not Cross Compliance Verifiable Standards. However, adherence to both sets of Regulations is required by law.
Republic of Ireland	Department of Agriculture and Food Ireland (2008). Explanatory Handbook for Agricultural Practice Regulations. https://www.agriculture.gov.ie/media/migration/farmingschemesandpayments/goodfarmingpracticesregulations/crosscompliance/publications/revisedhandbook2008.pdf

Evaluating the effectiveness of agricultural management practices at reducing nutrient losses to surface waters

Many agricultural agencies across Europe and North America have worked with landowners and agricultural producers to implement various agricultural GAPs/BMPs/BEMPs to reduce nutrient and sediment losses to streams and rivers. However, it has been difficult to document the effectiveness of these practices at field and watershed scales. Moreover, those studies that succeeded in accessing practices performances revealed that there has been very little reduction in agricultural P pollution and/or improvement in agricultural water quality (Kleinman et al, 2011; Jarvie et al, 2013; Withers et al, 2015; Sharpley, 2015, cited in Drizo, 2019). While demonstrating the success of regional mitigation strategies has been difficult, Barry and Foy (2016) show significant improvements in water quality in 40 headwater streams in Northern Ireland over a 25 year period. However, in many of catchment nutrient concentration were still elevated and there was not the corresponding improvement in ecological water quality required under the WFD. Drizo (2019) recently reviewed challenges in assessing treatment efficiency of agricultural management practices in P reduction. She highlighted the extreme complexity of solving the pollution problems which originate from diffuse sources. For example, diffuse P pollution from agricultural activities may be a combination of livestock and cropping systems agricultural surface and subsurface runoff, their field level interactions (both temporal and spatial) and climate (storm frequency and hydrology, temperature). Therefore, controlling this type of contamination requires integration of scientific, technological, socio-economical and educational factors. Moreover, the evaluation of AMPs treatment efficiency is further hindered by the issues of scale and the fact that they are implemented on individual farm scales while water quality improvement is assessed at the watershed scale (Drizo, 2019).

Mulla et al (2015) investigated factors that affect the assessments of the effectiveness of AMPs practices at reducing nutrient losses to surface waters in the USA. They concluded that an assessment at the watershed scale had been impeded due to:

1) Temporal variability in weather, runoff and drainage which lead to highly variable nutrient and sediment exports from one day or month to another and one year to another. Therefore, it is difficult to know how much of a change in nutrient and sediment export has resulted from a change in management, without long-term data;
2) Luck of scientifically rigorous studies of BMP effectiveness at the watersheds scale;
3) Long lag times in response to changes in management. Because of large soil pools of N and P, response to implementation of management practices can take many years, perhaps as many as 5 to 10 years. In addition, stream and river responses may be obscured by previous accumulation and transport of in-stream sediments and nutrients that mask reduced export from fields.
4) Sparse and non-targeted implementation of most management practices at watershed scales. Most conservation programs at the watershed scale only involve a small percentage of the land area and often do not target the most critical areas.
5) Modeling limitations including uncertainty in many parameters (e.g., soil hydraulic properties, denitrification, mineralization rates, biological N fixation), incomplete representations of field and watershed processes and limited data for validation can make projections uncertain. Because of limited long-term data sets, modeling is often used to project responses to management (e.g. Randhir et al, 2000; Srivastava et al, 2002, Gaddis et al, 2014, cited in Drizo, 2019).

Good Agricultural Practices Recommended for Use in the Northern Periphery and Arctic (NPA) areas

The current GAP Guidelines and Codes of Practice do not contain a clear description of good agricultural practices (GAPs) for nutrients reduction and recycling and/or recovery (N3R). Instead, the Guidelines are usually categorized according to the air soil and water environmental resources degraded by agricultural practices (Table 1). Moreover, different Guidelines group GAPs into different categories. For example Schoumans et al (2011) provided information for 32 practices which were grouped as Nutrient application management, Crop Management, Soil management, Agricultural water management, Land Use Change, Land Infrastructure and Measures in Surface Waters. They also provide link to SERA 17 factsheets. The more comprehensive and recent report by the European Commission (2018) grouped them according to their intended purpose as: 1) Soil Quality Management; 2) Nutrient Management; 3) Soil preparation and Crop Planning; 4) Grass and Grazing Management; 5) Animal Husbandry; 6) Manure Management; 7) Irrigation and 8) Crop Production Products.

As four of the NPA partners belong to the European Union, for the purpose of this Inventory, we will follow the categorisation proposed by the European Commission (2018). Our focus will only be on practices whose major purpose is to achieve nutrients reduction. In addition, we will review their ability for nutrients recycling and/or recovery, the potential to mitigate climate change, Cost of Implementation and Operation and Maintenance (Table 4). For example, while the Assessment of Soil Quality is an important GAP for overall Soil Quality Management, its major purpose is to assess and ensure soil health for crop production. Therefore although aerated and well-drained soil would contribute to better runoff infiltration and as such have potential for nutrients reduction, this practice is not included in the GAPs summary for Nutrients Reduction, and Recycling and/or Recovery (N3R) presented in Table 4. However, it is important to remember that a Soil Protection Plan is fundamental to farm sustainability to maximise resource use efficiencies by maintaining soil quality and functionality. According to the European Commission (2018) a plan should include measures that address components highlighted in the European Soil Protection Strategy as the main threats to soil such are erosion, decline in organic matter, contamination (point source and diffuse), compaction, decline in soil biodiversity, salinization, floods/landslides and soil sealing.

Table 4: Good Agricultural Management Practices for Nutrients Reduction, and Recycling and/or Recovery (N3R).

1. Soil Quality Management (N3R)	
1.1.	**Soil Quality Assessment**
NPA Location	**Description and Purpose:** Soil quality consists of physical, biological and chemical measures. For example, for

Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	physical measures the European Commission Guidelines (2018) recommend 1) regular field soil testing to maintain appropriate organic matter and pH values; 2) regular visual inspections of fields for signs of compaction, erosion, surface ponding and 3) knowledge of farm soil types – referring to publically available soil maps. In the UK for example, all the outdoor pig producers are encouraged to develop a comprehensive Soil Management Plan (SMP) for the land on which they are keeping pigs. The main objective of the SMP is to describe all the possible and feasible measures for soil management in order to avoid the surface runoff and soil erosion, to record the success and the results of those measures and eventually to report potential mitigation measures. The SMPs consist of three main steps: i). production of a map showing the risk class for each field (or part of the field), which is occupied by pigs, ii) for each field develop measures and steps to minimise the run off and erosion and iii) retain the plan and review it in an annual basis (BPLEX, 2019). European Commission Guide (2018) provides a list of appropriate Indicators for <u>Soil structure</u>: Rooting depth (mm); Penetrometer or other bulk density (kg/m3) reading; Visual evaluation of soil structure; Macro-porosity; Aggregate stability; Above-ground plant biomass (kg/m2); Soil water holding capacity (% of dry weight) and Infiltration capacity (mm/hour).
	Benefits: According to the experiences from Finland, field benefits from improved soil quality are significant, and long-term increase in crop production revenue even up to 50 % is possible. Avoidance of soil compaction can increase cross margins over 110 €/ha. Alone subsoiling method can increase cross margins around 10 – 20 €/ha European Commission Guide (2018).
	Nutrients Reduction (Effectiveness): This mitigation option is not included in the Cost 869 list of Mitigation options for nutrient reduction in surface water and ground waters (Schoumans et al, 2011; Table 1) nor in the European Union Database of Best management Practices (Living Water, 2015; Table 1). While this practice is thoroughly described in the European Commission Guide (2018) the efficiency of this practice in nutrients reduction is not mentioned. Although this practice has been initially developed for the management of soils, and not for nutrients reduction, it is well established that soil structure, type and texture influence nutrient circulation, leaching and run-offs from the catchment basin. For example compaction caused by heavy machines and grazing reduce water infiltration capacity, root growth and nutrient uptake by plants and thus cause more surface run-offs into water bodies. However the contribution of this practice to the actual nutrients reduction has not been quantified. <u>Yield benefits</u> Yield benefits from improved soil quality (and in parallel implementing fertility improvement measures) can be significant, potentially increasing crop/animal production revenue by up to 50% in the long term depending on the extent of degradation and subsequent soil improvement although 10- 20% may be more likely in most cases. However, it may take a number of years for the full benefits of better soil management to be realised following initial soil degradation (European Commission, 2018).
	Recycling/Recovery: More research is needed in order to evaluate the exact contribution of this practice in nutrients recycling.
	Climate Change Mitigation Potential: According to the climate change connection, an organization providing a website regarding solutions for greenhouse gases mitigation, testing of soil for residual nutrient levels is the first step toward reducing nitrous oxide emissions from crop land (Climate Change Connection, 2019). According to the experience from Finland sustainable soil quality management plays an important role in compensating harmful effects foreseen to be caused by climate change, like rainy and dry seasons variations as well as increased flooding. Good soil structure could considerably diminish surface runoff and soil degradation caused by erosion. The role of soil quality in climate change mitigation can be summarised as following (Brevik, 2012): (1) Along with changes in temperature, climate change will bring changes in global rainfall amounts and distribution patterns. Since temperature and water are two factors that have a large influence on the processes that take place in soils, climate change will therefore cause changes in the world's soils. (2) There are several ways that climate change will affect soil. Soils are also part of the global carbon and nitrogen cycles. The carbon-based gases carbon dioxide (CO2) and methane (CH4), and the nitrogen-based gas nitrous oxide (N2O), are important greenhouse gases. So, as carbon dioxide, methane, and nitrous oxide levels change in the atmosphere, there will be corresponding changes in the soil. (3) Higher temperatures also mean increased rates of organic matter decomposition by soil microorganisms. If the microorganisms decompose organic matter more rapidly than it's replaced, then soil organic matter levels will decline. Working out relationships like this are key to our understanding of the exact effects of climate change on soil.
	Operation and Maintenance (O & M): <u>Management indicators (</u>Test fields every 3–5 years for P, K, Mg, pH, Om and bulk density; test every year for SNS); Walk fields weekly to inspect signs of compaction, erosion, surface ponding; Produce a soils map for the farm Maintain environmentally appropriate levels of soil P, K, Mg, (index or kg/ha), pH, SNS (kg/ha), trace elements; Soil Organic Matter balance (+/-); the relation of SOC of a specific field towards a grassland can be used as the maximum level of SOC of a specific site. In Scotland, the guidelines (Government of Scotland, 2005) suggest that for Soil Protection and Sustainability, 1)

	compliance with the Sludge (Use in Agriculture) Regulations 1989 is necessary if sewage sludge is to be applied (to prevent contamination with Potentially Toxic Elements); 2) On arable land, farmers should (i) use suitable break crops in an arable rotation (Practice 3.2., bellow) ; or (ii) optimise the use of organic materials by basing rates of application on soil and crop needs. Where break crops are not used, a record should be kept for 5 years of organic materials and the quantities applied to arable land; 3) All cropped land over the following winter must, where soil conditions after harvest allow, have either: crop cover, grass cover, stubble cover, ploughed surface or a roughly cultivated surface (1.2.). Fine seedbeds must only be created very close to sowing; 4) (i) Maintain functional field drainage systems, including clearing ditches, unless environmental gain is to be achieved by not maintaining field drainage systems (1.2. to 1.4.).
	Cost: <u>Soil testing costs</u> In the UK, soil testing works out at approximately 12 €/field (assuming one soil sample) which includes analysis for P, K, Mg and pH accompanied by fertiliser and lime recommendations based on RB209 Fertiliser Manual (DEFRA, 2010) for a specified crop following a specified previous crop, specified soil type and specified level of productivity. A penetrometer can measure compaction and costs from 82 € which could be shared amongst neighbouring farms. Cultivating compacted soils takes longer and uses more fuel. Soil maps are usually free via the internet, libraries and academic institutes. In Finland Basic soil test (soil type, pH, conductivity, Ca, K, P, Mg, S, cation exchange) 15 €/sample, fertility assessment (microbiological activity, C/N-ratio, organic content) 60 €/sample. (Finland Infocard)
1.2.	**Maintaining Correct Soil pH Level**
NPA Location Finland, Sweden, Northern Ireland, Republic of Ireland, Scotland	**Description:** Nutrient availability is dependent on soil pH, therefore sub-optimum soil pH can greatly reduce productivity and nutrient use efficiency. For example, Winham and Beaverstock (1984) showed that the estimated loss in grazing yield at a mean field pH of 5.6 is 15% when compared with the optimal pH of 6.0 is 15% because of reduced capacity of grass to take up applied N at sub-optimum soil pH. Therefore, addition of lime (or other materials with elevated pH) would improve yield at a given nutrient application rate, or allow the same yield at a lower nutrient application rate (and also incur emissions from producing and spreading lime). Data on silage grass yield deficits at different soil pH ranges showed that at pH levels < 4.5, max yield was 87% while at pH of 6.0 - 6.5, the yield reached 100% (EBLEX, 2013). One of the primary reasons for our soils becoming more acidic (lower pH values) over time is through the use of nitrogen (N) fertilizers containing ammonium-N. As the ammonium-N in fertilizers undergoes nitrification (conversion of ammonium to nitrate in soils by bacteria), hydrogen (H+) is released, which can increase acidity. As the percentage of ammonium increases in a given fertilizer the acidifying potential will also be increased, thus reducing pH (Brookside laboratories, 2019). <u>Lime requirement</u> Liming has been considered in the context of replacing Ca_2^+ leached as the balancing cation with bicarbonate (HCO_3^-), chloride (Cl^-), NO_3^-, SO_4^{2-} and Ca^{2+} removed in farm products. Thus, for example considering only nitrate leaching: $Ca^{2+} + 2\ NO_3^- = Ca(NO_3)_2$ Some 3.6 kg CaCO3 is required to balance the Ca2+ lost with NO_3^-, when 1 kg ammonium-N is nitrified; at field rates, this is approximately 180 kg CaCO3 for every 50 kg ammonium-N. Lime requirement calculators have been available for many years. In the UK, Rothamsted constructed a lime requirement model, RothLime (http://www.rothamsted.ac.uk/rothlime) based on data from the Long-term Liming experiments at Rothamsted and Woburn and the Park Grass Experiment (Goulding, 2016).
	Nutrients Reduction (Effectiveness): This practice was developed with the aim to improve soil health and crop productivity, and as such does not have a direct role in nutrients reduction from runoff. However, rainfall, nitrogen fertilizers, intensive tilling of the soil and temporarily uncultivated fields increase acidity of the soil. Most of the nutrients are available in neutral pH range e.g. phosphorus. In neutral pH cation exchange capacity of the soil is increased and reserved nutrients are released more easily. Under pH 6 e.g. aluminum is in dissolved form and harms plant roots. However more research is needed to assess the potential of healthy soil pH in nutrients reduction.
	Recycling/Recovery: No.
	Climate Change Mitigation Potential: When the soil structure and nutrient utilization is improved it has potential to decrease the risk for unforeseeable changes due to climate change e.g. less soil erosion in torrential rains. However more research is needed to assess the potential and contribution of healthy soil pH to climate change mitigation.
	Operation and Maintenance (O & M): Lime is applied on the field surface before soil tilling. The most commonly used liming materials are ground limestone, dolomitic ground limestone, chalk, ground chalk, burnt lime and hydrated lime; almost 70% of the material currently used in the UK is ground limestone… Other acid-neutralizing materials A number of 'waste products' are available that neutralize acidity: sugar factory lime, basic slag, wood ash, coal

	combustion products such as fly ash and bottom ash, calcium humates and fulvates from oxidized brown coal and by-products of the paper and pulp industry (e.g. Bolan et al., 2003; Gagnon et al., 2014).
	Cost: The spreading and application equipment is needed. In Finland, cost of labour and lime ≈ 30 €/tn
1.3.	**Conservation Tillage**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Conservation tillage (CT) is defined as any form of tillage that minimizes the number of tillage passes, where soil aggregate disruption is reduced, and a minimum of 30% of the soil surface covered with residues, with the aim to reduce soil erosion (CTIC, 2004). *It is an umbrella or generic term used to describe tillage systems that have the potential to conserve soil and water by reducing their loss relative to some form of conventional tillage.* Precise definitions of conservation tillage are only possible within the context of known crop species, soil types and conditions, and climates. A well-accepted *operational definition of CT is a tillage or tillage and planting combination that retains a 30% or greater cover of crop residue on the soil surface.* Generally, there are four main types of CT: mulch tillage, ridge tillage, zone tillage, and no-tillage. A main variant of the latter is direct drilling (sometimes termed zero-tillage), while other variants of CT are reduced tillage and minimum tillage (CTIC, 2004; Carter, 2005). **Purposes:** i) Reduce erosion and transport of adsorbed particulate phosphorus (P); ii) Reduce runoff and transport of soluble P; iii) Conserve soil moisture for crop use and increased yield; iv) Reduce particulate emission to the atmosphere (Busari et al, 2015).
	Nutrients Reduction (Effectiveness): Conservation tillage has been widely promoted to reduce sediment and nutrient transport from agricultural fields. It is generally accepted that CT can provide several benefits for agricultural systems such as soil conservation, economic advantages associated with reductions in crop establishment time and energy use, reduction in soil sheet erosion and nonpoint pollution, and enhanced storage or retention of soil organic matter and improvement of soil quality at the soil surface Carter, 2005). *However, the effect of conservation tillage on sediment and nutrient export in snowmelt-dominated climates is not well known* (Tiessen et al, 2010). They conducted a long-term study in a long-term paired watershed study to compare sediment and nutrient losses from a conventional and a conservation tillage paired watershed in the Northern Great Plains region of western Canada. They found that N concentrations and exports were reduced by 41 and 68%, respectively, relative to conventional tillage. However, after conversion to conservation tillage, concentrations and exports of P increased by 42 and 12%, respectively, with soluble P accounting for the majority of the exported P, especially during snowmelt. These and other results from cold northern climate suggested that these management practices are less effective in cold, dry regions where nutrient export is primarily snowmelt driven and in the dissolved form (Tiessen et al, 2010; Puustinen et al, 2007; Ulen, 1997). The European Commission (2018) Guide for BEMs recommends that: • Crop residues (e.g. maize stalks, straw and stubble) should be retained over winter to reduce soil erosion rather than over-winter bare soil and provide high molecular weight C (lignin) with high C:N ratio when incorporated in Spring. Moreover, that ryegrass cover crop can be seeded between maize rows which can be grazed or returned to the soil in spring. • Grass-clover ley are invaluable as in crop rotation as an organic source of N by virtue of symbiotic bacteria that fix atmospheric N. Ploughing in grass-clover leys adds to soil organic matter, though care has to be taken to avoid N-mineralisation leading to leaching. • Cover crops reduce both wind and water erosion, by increasing soluble organic carbon (SOC) through above and below ground plant parts over winter and at the same time retains N and P in the root zone for use by the following crop. • Catch crops immobilise available nitrogen remaining in the soil after the harvest of the main crop by taking it up and storing it in the catch crop root and shoot.
	Recycling/Recovery: Conservation tillage decreases soil disturbance and decomposition, leaving surface residue cover that can increase water retention, soil C and N, and potentially accumulates P in the surface, thus it has some potential for nutrients recycling and recovery (Carter, 2005; Johnson et al, 2017). However, much more research is needed in order to evaluate cover crops and tillage potential to recycle nutrients.
	Climate Change Mitigation Potential: Current research is limited and non-conclusive. A study of the Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality conducted in Scotland showed that CO_2 emissions in the few weeks after sowing were not strongly influenced by tillage and diurnal variations were related to soil temperature. However, periods of low or zero CO_2 fluxes and very high N_2O fluxes under no-tillage were associated with reduced gas diffusivity and air-filled porosity, both caused by heavy rainfall. The researchers indicated that CH_4 oxidation rates may best be preserved by no-tillage. Moreover that due to the loam/clay-loams and the climate, ploughing to 300 mm depth, and the control of compaction may be necessary to minimise soil N_2O and CO_2 losses (Ball et al, 1999). More recently,
	Operation and Maintenance (O & M): Up to seven years of continuous management may be required before full benefits of these practices can be realized. Existing soil compaction (1.3.2.), as well as perennial weed control, must

	be addressed early in the tillage modification. Perennial weeds can be controlled with crop rotations and mode of herbicide action (Schoumans et al, 2011; SERA 17, 2019).
	Cost: Boyle (2006) provided comprehensive overview of the Economics of On-site Conservation Tillage and provided evidence in the improvements in economic resources such as: • Input and operating cost reduction, as CT uses less machinery in fewer hours. • Better machinery management • Decreased machinery repair and maintenance costs • Lower weed management operating costs (with herbicide-tolerant crops) • Lower overall nutrient management costs Boyle (2006) also reported that the economic efficiency of CT was measured using corn production data from the USDA, Economic Research Service's 2001 Agricultural Resource Management Survey. These data showed that CT has higher economic efficiency, regardless of location or farm size, than conventional tillage. Moreover that it saves between \$0.14 and \$0.73 for every dollar of output produced (it is between 15.5% and 41% less costly), regardless of farm size.
1.3.1.	**No-till farming: direct drilling**
	Description and Purpose: No-till farming is a way of growing crops or pasture from year to year without disturbing the soil through tillage. It is an agricultural technique which can increase the amount of water that infiltrates into the soil, the soil's retention of organic matter and its cycling of nutrients. *It has been found that no-tillage is generally difficult to use in cool, wet soils, or in soils with a relatively high tillage requirement* (Carter, 2005). However, it has been widely promoted both in Europe and North America. According to the Conservation Technology Information Center (CTIC), in the USA alone there had been 60.4% increase in no-till use between 1994 and 2004. The most comprehensive review on no-till practice application and performance with particular emphasis on research on commercial uptake and environmental concerns in northern, western and south-western Europe was conducted by Soane et al (2012).
	Nutrients Reduction (Effectiveness): The infiltration rate of no-till soils is usually found to be appreciably higher than in ploughed soils. Studies from Scandinavia showed that high losses of particulate-bound P (PP) in runoff occur in from cultivated clay soils during warm, wet winters but losses of P can also occur as dissolved reactive P (DRP) which can account for 9-93% of the total P lost in runoff (Ulén et al., 2010). No-till can greatly reduce losses of PP but a stratified surface layer rich in P can develop in no-till soils from which an appreciably higher loss of DRP can occur than on ploughed soils. Puustinen et al.(2005) found that the loss of PP on no-till soil was 30% of that from ploughed soil (1.13 compared to 3.71 kg ha-1) but DRP increased by 348% under no-till (2.02 instead of 0.58 kg ha). Such very considerable increased losses of DRP in runoff after no-till compared to ploughing have also been attributed to the release of DRP from dead weeds following glyphosate application (Ulén et al., 2010) and to P leaching from fertilizers retained near the surface (Puustinen et al., 2005). There is a lack of consensus in the literature on the effect of no-till on nitrate leaching (Oorts et al., 2007c; Hansen et al., 2010). This variability appears to depend on soil type, the use of catch crops before spring-sown crops and the various pathways for water movement in structured soils. Nevertheless, Tebrügge (2001) reported that a lack of soil loosening in autumn leads to less mineralization of nitrogen and reduced leaching of nitrate into ground water in some notill soils with well-developed vertically orientated macroporosity through which excess rain water is conducted as bypass flow. This may be of major environmental importance in areas designated by the EU as Nitrogen Sensitive Areas.
	Recycling/Recovery: No-till may help improve soil properties such as compaction and infiltration and consequently help nutrient recycling. However, much more research is needed in order to evaluate the potential of this practice in recycling nutrients.
	Climate Change Mitigation Potential: Johnson et al (2017) highlighted that although CT (no- or reduced tillage) can decrease GHG emissions and sequester soil C, these benefits can be region-specific and require careful accounting. Furthermore, they reported that a meta-analysis by van Kessel et al. (2013) found no overall reduction in yield-scaled N_2O emissions in no-tillage compared to tilled systems (239 comparisons); however that some N_2O reduction was observed in no-till systems in dry climates. Soane et al (2012) highlighted that highly contrasting soil and climate types within and between these regions exert a strong influence on the success of no-till. The higher moisture content and reduced aeration under no-till, especially after rainfall on heavier poorly drained soils in northern Europe, leads to greater denitrification and emission of N2O than under ploughing. Regina and Alakukku (2010) reported that emissions of N_2O from 6 contrasting soils in Finland was strongly correlated with the total C and N contents of the 0-20 cm. They postulated that increased N_2O formation in no-till soils may also be associated with higher numbers of earthworms since the gas is formed in their intestine. Soane et al (2012) highlighted that true mitigation of global warming potential (GWP) by no-till is only possible if any increased carbon sequestration effect exceeds the GWP attributable to the net upward fluxes of the three major biogenic greenhouse gases (i.e. CO_2, N_2O and CH_4).

	Operation and Maintenance (O & M): For direct seeding the specialized machine is needed. It suites for almost all soil types (except for heavy clay soils) with good drainage of the field. Usage of the herbicides is needed. Adoption of no-till introduces important changes to the incidence of weeds, crop diseases and pests, as well as the problem of volunteer cereals. Successful and economic control of these problems is a vital component in ensuring the commercial acceptability of no-till. Weed populations under no-till show marked differences from those after ploughing with new or previously unimportant weeds often becoming dominant after a period of no-till in which weed seeds are retained near the surface and their dormancy and germination characteristics will be quite different than if buried during ploughing (Soane et al, 2012). In addition, herbicide resistance has been identified in several species of grass weeds in the UK which could threaten the effectiveness of no-till systems dependent on herbicides. Resistance to atrazine, simazine and glyphosate has been extensively reported for numerous weed species on no-till farms in the USA. These problems, if widespread, may reduce the opportunities for adoption of no-till. There are thus opportunities for improvements in the use of existing herbicides and the adoption of new ones.
	Cost: Reducing fuel, labor, and equipment costs are the most quantifiable benefits of not doing any tillage. Boyle (2006) reported that no-till results in decreased labor costs and that researchers showed that no-till, under Pennsylvania corn production, cut labor by 20% (0.82 hours per hectare) for minimum tillage and 54% (2.12 hours per hectare) for no-till. Lindwall et al. (2000) found that no-till wheat tied up nitrogen in residue and soil organic matter. They concluded that no-till decreased yields unless accompanied by better nutrient management. They cited research showing that zero-till, accompanied by appropriate nutrient management, increased net returns by 5% for canola, 30% for wheat, and 25% for peas, but only raised fertilizer costs for the canola crop (14%). They found that although fertilizer was the most significant economic input, machinery and weed control costs explained most of the difference in net returns. Soane et al (2012) highlighted that the costs of adopting a no-till system relative to those for ploughing will vary with time. Their comprehensive literature review showed that over the past 30 years the cost of gyphosate relative to the cost of diesel has decreased considerably. In addition, they concluded that economic factors related to the production of winter- and spring-sown cereals are currently tending towards a more favourable basis for the adoption of no-till but a number of technical problems continue to restrict uptake in practice.
1.4.	**Agricultural Drainage Management (Soil and Ditch/Water)**
NPA Location Finland, Sweden, Northern Ireland, Republic of Ireland, Scotland	**Description & Purpose:** In areas with high water tables, drainage ditches effectively lower the water table to allow farm machinery to operate at critical times such as planting. They act as direct conduits between agricultural fields and surface waters and as such have potential to mitigate nutrient movement and transport (SERA 17, 2019). Drainage water management also influences the amount of soil movement, which occurs during rain/snowmelt. The sustainable measures that have to be taken should ensure that all the soil nutrients loss and soil biology because of the soil movement are minimised. According to the Cost869 Project (http://www.cost869.alterra.nl/) in Europe, practices recommended for nutrient loss (e.g. pollution reduction) from agricultural water management involve measures to control drainage and irrigation (Schoumans et al, 2011). Practices are categorized on those focused on pollutant reduction of i) overflow to surface water (e.g. construction of ponding systems and grassed waterways, installation of sedimentation boxes); ii) subsurface flow to surface water (removal of trenches and ditches to allow field drainage systems to deteriorate and installation of artificial drains to improve sub-surface drainage systems) and iii) loss by artificial drainage to surface water (e.g. implementation of controlled drainage for reducing the amount of water leaving a field; Letting tile drainage water to irrigate meadows / interrupt artificial drainage). For nutrient pollution control from irrigation, nutrient loss with surface irrigation and water recovery on irrigated fields for water and nutrient cycling are listed as good practices. For each of the listed practices a two page fact sheets are provided on the website. Similar to SERA17 Fact sheets, they include short description, rationale, applicability, effectiveness, time-frame and costs. In addition Cost869 fact sheets also include potential environmental side-effects, but do not address costs of operation and maintenance (Drizo, 2019). The latest report on the Best environmental management practice (BEMP) for the agriculture sector (European Commission, 2018) lists the following measures as BEMP to mitigate tile drainage pollution impacts: Contour ploughing, Break slopes, Cultivation of tramlines, Avoidance of compaction, Low ground pressure impact tyres on vehicles and Erosion risk planning. However, while all of these recommended measures may improve soil infiltration and therefore aid in reducing surface flows, their contribution to minimizing P loading has not been quantified (European Commission, 2018).
	Recycling/Recovery: Current research is limited and non-conclusive.
	Climate Change Mitigation Potential: None.
	Operation & Maintenance: Sediment removal and periodic mowing of vegetation are necessary costs of maintaining effective drain function (Schoumans et al, 2011; SERA 17, 2019). Visual inspections for defining ponding (intervals to be defined by local parameters) (European Commission, 2018).

	Disadvantages: Much of the surface and subsurface flow is conveyed by ditches directly to surface waters. This can Have negative influence on both hydrology and P loading at the field and watershed scales (More, 2016). Maintenance costs for ditches and outlet pipes (SERA 17, 2019).
1.4.1.	**Controlled Drainage**
NPA Location Finland, Sweden, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Water control structures at the final point of drainage outlet can be used to regulate water depth in the ditch, field-water table depth and water outflow. Water level can be lowered to allow access for farm machinery at critical times. The water level can be raised when desirable resulting in several beneficial effects such as 1) providing water storage in the field, for use by crops during dry periods; 2) reducing the amount of drainage water by 20-30% thereby decreasing nutrient export load; 3) increase denitrification and reduce nitrate-nitrogen losses by 10-20% and 4) increase sediment and particulate P retention. Negative effects include possible increase in dissolved P losses from sediments under anaerobic conditions and maintenance costs for outlet pipes (SERA 17, 2019). In the USA, AgriDrain corporation is the leading provider of smart drainage systems (https://www.agridrain.com/smart-drainage-system/).
	Nutrients Reduction (Effectiveness): According to SERA 17 fact sheet on average, controlled drainage can reduce the loss of total nitrogen and total P by 45 and 35%, respectively. (http://www.cost869.alterra.nl/SERA17_BMP/BMP_drainage_ditch.pdf).
	Recycling/Recovery: Current research is limited and non-conclusive.
	Climate Change Mitigation Potential: None.
	Operation & Maintenance: Sediment removal and periodic mowing of vegetation are necessary costs of maintaining effective drain function.
	Cost: The cost depends on the type of control drainage used and is site specific.
1.5.	**Agricultural Tile Drainage**
NPA Location Finland, Sweden, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Similar to other drainage practices, tile drainage works by providing an open pathway for soil water to drain away, lowering the water table and allowing the upper soil layers to dry out. For farmers, tile drainage has multiple benefits: better growing conditions, improved soil structure, more timely planting and harvest, and improved yields. Tile drainage pipes are typically installed at depths of 0.6 – 1.2 m and spaced 10–100 m apart, depending on soils, crop type, and cost. Historically, tile drainage was often installed strategically, targeting low spots and other frequently saturated areas. Today, in the US drainage tends to be installed in a regular grid pattern, with pipes located 5 to 30 m apart under an entire crop field. Most drainage networks discharge directly to an open ditch or stream. Although tile drainflow can respond to large precipitation or snowmelt events at almost any time of year, the largest drainage volumes tend to occur from fall through spring, with tile drainflow becoming very small or entirely absent during the summer growing season (Moore, 2016). **Benefits:** Tile drainage 1) increases total annual water output from a field, often by a factor of ~2; 2) Reduces surface runoff (including peak flows); 3) subsurface drains lower the water table, eliminating saturated areas and providing more capacity for infiltration during rainfall events; 4) Delivers the majority (50 to >90%) of field water loss as tile drainflow; 4) Extends the duration of water flow from a field.
	Nutrients Reduction (Effectiveness): Current research is non-conclusive. Generally, it is believed that Tile drainage often reduces sediment and nutrient export in surface runoff because of the reduction in overland flow from tile drained fields. However, as tile drains convey much of the subsurface flow directly to surface waters, they can also serve as the conduits for pollution (nutrients, pathogens, pesticides) transport. For example, once dismissed as negligible, in the USA P levels in subsurface tile drainflow have been recognized as potentially significant, and tile drainflow has been clearly shown to influence both hydrology and phosphorus loading at the field and watershed scales (Moore, 2016).
	Recycling/Recovery: Not directly from tile drainage. However, Drizo developed a simple passive filtration system which can be placed to collect runoff from the tile drainage or other surface and subsurface flows on farms (1.5.1.), described below (Drizo, 2012; WSSI, 2019). She has also shown that spent P from the filtration media can be used as a slow release fertilizer (Bird and Drizo, 2010).
	Climate Change Mitigation Potential: None.
1.5.1.	**Phosphorus Removal System #782**
	Description and Purpose: Recognizing the need for a new solution to reduce (and recover) P from agricultural tile drains Drizo and co-researchers developed, implemented and tested a simple passive P filtration and harvesting system to intercept, reduce and retain subsurface (tile) flow, ground water or surface runoff flow, and reduce the concentration of phosphorus on farm outflows. The system was developed as an outcome of a decade (1999 – 2009) of research by Drizo and co-workers on the use of steel slag aggregates (SSA) for P removal from wastewaters (e.g. Drizo et al, 2002; Weber et al, 2007; Drizo et al,

	2008; Bird and Drizo, 2009; Bird and Drizo, 2010; Drizo, 2012; Drizo, 2019). They were among the first researchers who conducted series of field-scale investigations on the potential of SSA for P removal from a variety of wastewater effluents (dairy, barnyard runoff, surface and subsurface agricultural drainage, urban stormwater runoff, industrial sites runoff and sewage). This extensive research resulted in the development of operational parameters for six different classes of technologies for phosphorus, suspended solids and pathogens reduction and P harvesting, recycling and re-use from any point or nonpoint pollution source, known as PhosphoReduc™ (Drizo, 2012; WSSI, 2018). It took 9 years of pilot and demonstration testing across the USA and internationally, and several years of negotiating with the regulatory agencies (e.g. Vermont USDA Natural Resources Conservation Services (VT NRCS) and Vermont Agency of Agriculture, Food and Markets (VAAFM) before they finally recognized Drizo's P removal system in 2013 as the very first interim conservation practice standard for P removal from surface and subsurface flows in the USA, known as the Phosphorus Removal System #782 (USDA NRCS Vermont (2013). In the last few years, P removal System Code 782 (invented and developed by Drizo for the USDA NRCS of VT) received the interim conservation practice standard status in several additional states: Wisconsin (USDA NRCS WI, 2015), New York (USDA NRCS NY, 2016), Maryland (USDA NRCS NY, 2016) and Pennsylvania (USDA NRCS NY, 2017). However due to the lack of P removal regulations from agricultural lands in the USA, to date only one system had been installed (Sheboygan county, WI, 2017). Two more filters are planned to be installed in Minnesota, US this fall. *The practice applies to reducing the amount of P from subsurface drain (tile) flows and other subsurface and surface phosphorus- containing runoff outflows. Sources of agricultural outflows may include agricultural tile drains, ditches and animal heavy use areas such as milk-house wastewater, feed bunks, and silage leachate runoff.*
	Nutrients Reduction (Effectiveness): In the past 11 years Drizo implemented and evaluated her P removal systems in over 40 different pilot, demonstration and full scale projects across four continents. These projects showed on average 90% phosphorus, 95% pathogens and 90% suspended solids reduction (WSSI, 2018). The Phosphorus Removal System #782 Standard recommends that the media should have a P retention capacity of at least 0.50 percent by weight of materials, or 4.5 kg P/ton of media. It also underlines that the particle diameter of the media ought to provide sufficient permeability for the anticipated flow (e.g. USDA NRCS Vermont, 2013).
	Recycling/Recovery: Bird and Drizo (2009) showed that P sorbing material used in filters to reduce P from waste streams has potential to act as a slow release P fertilizer. However more research is needed to quantify the amount of P than can be recovered from different farm pollution sources.
	Climate Change Mitigation: P removal system media is porous and available in different sizes. Drizo is currently developing novel designs so that the system can also be used for water retention (and floods mitigation). Also vegetated with local grasses and shrubs, P removal system can contribute to both N_2O and CO_2 emissions mitigation.
	Operation and Maintenance (O & M): The system is a user friendly treatment unit with minimal annual operational and maintenance requirements for the Owner. Its unique design does not require any mechanical or moving parts, and eliminates the need for electrical components, and is a totally passive system. By properly monitoring the system performance, periodic maintenance can be performed at the operator's convenience. The owner should visually inspect filters for signs of scum formation or preferential flows, after major precipitation/snowmelt events.
	Cost: The cost of filters depends on the volumes of wastewater that need to be treated, influent and effluent P concentrations and availability of the SSA filtration media. Majority of the cost is for media transportation (generally 40 euros/ton). The initial capital costs for larger filters (flows 60-150 m3/d) can be high. However, the filter has a life span of 30+ years and minimum maintenance fee. In general for base flows of up to 20 m3/d systems design cost is 7,000 USD (6,200 euros), plus the cost of media and transportation and system construction. For greater flows (60-150 m^3/d) filter media and transportation costs can reach 35,000 euro, and with the excavation, implementation costs can reach 70,000 euro. However such filter would be able to treat (remove and also provide possibility for recycling) 55,000 m^3 of agricultural runoff per year containing 1-40 g P (after manure spreading).
2. Nutrient Management	
2.1.	**Field Nutrient Budgeting**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** A Nutrient Management Plan (NMP) is a key BEMP strategy in running a farm to optimise crop yield and quality, minimize fertilizer input costs and protect soil and water (European Commission, 2018). The principles of nutrient management are simple and include: • applying fertilizer only to make up the difference between what is there and what is required to achieve the target yield, which also ensures cost-effectiveness for the producer; and • ensuring that the added nutrient is available to the crop. The nutrient balance at the farm gate provides information about the nutrient input from purchased goods (animals, seeds) including the N fixation of legumes. All sold products (crops, animals, milk etc.) are summarized as output (Stein-Bachinger et al, 2013). The preparation of nutrient balances is a beneficial tool for long-term planning of fertilizer

	use. Nutrient balances inform farmers on the efficiency of nutrient utilization and help to identify the cropping phases in which nutrients are lost. The calculation of nutrient balances help to strengthen water protection measures for each farm and parcel (European Commission, 2018; Living Water Exchange, 2015). In all of the NPA areas involved in WaterPro project, Departments of Agriculture and other responsible agencies have developed rules and require from farmers to have Nutrient Management Plans (NMPs). In Scotland, for example, A Fertiliser and Manure Plan is mandatory in Nitrate Vulnerable Zones (NVZs). Adequate records must be kept for land within NVZs relating to livestock numbers, use of inorganic fertiliser and use of organic manures (Government of Scotland, 2005). In Northern Ireland, DAERA provides Guidance on the information required in a Nutrient management Plan (https://www.daera-ni.gov.uk/articles/nutrient-management-plan) however, they are not compulsory except for derogated farms; In the Republic of Ireland, guidelines for the NMPs were initially provided by the Department of Agriculture, Food and the Marine (DAFM). Since 2014 it became responsibility of Teagasc, the state agency providing research, advisory and education in agriculture, horticulture, food and rural development in Ireland (https://www.teagasc.ie/). A new, online system developed to facilitate NMPs was introduced in early 2016 (Murphy, 2016). In Finland farms are encouraged to implement 4 R's principle (right rate, source, application method and application timing) in order to provide proper amount of nutrients to the crop where and when it is needed. Also, estimates of plant available nutrients are recommended to be made every 5 years. Farmers are encouraged to install maps and devices on their equipment in order to adjust the manure spreading volume (Rantala, 2017). In Iceland, it is recommended to estimate fertilizer needs considering soil type, vegetation (crop) type and growing conditions on the field (Environment Agency of Iceland, 2002).
	Nutrients Reduction (Effectiveness): Studies from UK showed that for arable land there is a reduction of about 5 kg N/ha leached per year. For grassland, reductions are 1-5 kg/ha per year (dairy) and 2 kg N/ha per year (beef). With respect to P, expert analysis estimates that the method reduces the fertiliser component of the baseline loss by 20% (Cuttle et al, 2007; Living Water, 2015). McCrackin et al (2018) recently investigated pportunities to reduce nutrient inputs to the Baltic Sea by improving manure use efficiency in agriculture especially for the Baltic Proper, Gulf of Finland, and Gulf of Riga sub-basins. They develop different scenarios which suggest that reducing N and P inputs by redistributing manure nutrients, together with improving agronomic practices, could meet 54–82% of the N reductions targets (28–43 kt N reduction) and 38–64% P reduction targets (4–6.6 kt P reduction), depending on scenario.
	Recycling/Recovery: Accurate fertilizer application, which is based on the crop type, its yield and the characteristics of the parcel to the economic optimum, will ensure that the necessary quantities of the essential crop nutrients are only available when required for uptake by the crop. However, although its major aim is to ensure better fertilizer applications this practice does not provide nutrient recycling and recovery (unless additional practices are incorporated into the plan such is for example passive filters which can harvest P, which then can be reused as a soil amendment instead of traditional chemical fertilizers, e.g. Bird and Drizo, 2009; Schoumans et al, 2010; Drizo, 2019, or addition of Phosphorus Immobilizing Amendments to Soil (http://www.cost869.alterra.nl/).
	Climate Change Mitigation: The UK CCC report on GHG abatement options for agriculture emphasised the high potential for optimised fertiliser and manure management to reduce GHG emissions and generate economic savings within the agricultural sector (CCC, 2008).
	Operation and Maintenance (O & M): The principles of operation are in 4 R's principle (right rate, source, application method and application timing) in order to provide proper amount of nutrients to the crop where and when it is needed.
	Cost: Fertiliser and lime prices have increased considerably over the past decade. EC (2018) reports that one tonne of CAN fertiliser has increased from approximately EUR 150 to EUR 350 over the past ten years. In Spring 2013, one tonne of 20:10:10 N:P:K compound fertiliser was EUR 353/t, similar to CAN. In the UK, the cost for a farmer to establish a N balance is in the range of 200-500 € per farm per year, depending on the installed/existing farming system and on the assistance of accountancy and/or advisory provided services. However, these estimations do not include education, promotion and start-up costs (Bittman et al., 2014). UNECE (2014) reported that the costs of establishing a nitrogen budget at national level are in the range of €1,000 to €10,000 per year. The cost of increasing N use efficiency through improving management range between €-1.0 to €2.0 per kg N saved.
2.2.	**Crop rotation for efficient nutrient cycles**
NPA Location Finland, Northern Ireland, Republic of Ireland,	**Description and Purpose:** Crop rotation is the succession of humus-increasing and humus-demanding crops on a field throughout a cycle of several years, whilst taking account of regulatory and edaphic constraints. The primary goal is to optimise N cycling by incorporating legumes into crop rotation. Deep rooting legumes, N-fixing, humus - and soil fertility - building crops, are grown in combination with a balanced proportion of N- and humus- demanding crops such as cereals and root crops. Following a 3 years European project (2010-2013) Stein-Bachinger et al (2013) provided a comprehensive guide on ecological recycling in agriculture for Baltic Sea Region which is applicable to all NPA areas. Although it had been practiced for decades throughout Europe, the awareness of the importance of crop rotations in

Scotland	increased during the 70s, along with the increased interest in organic farming. Today the effective crop rotations are acknowledged as a foundation of successful organic cropping systems. Many EU member States include crop rotation as one of their farmers cross compliance obligations under the current CAP (IFOAM EU, 2012). Main aims of designing crop rotations are to produce economically profitable cash crops and high quality feed. This is achieved by designing economic and agronomic sound rotations taking phytosanitary constraints and crop nutrition into account. In addition, well designed crop rotations provide many other benefits such are weeds, pests and diseases control, stabilization of yields and ensuring the quality of products, both food and feed. In addition they support nature conservation goals (Stein-Bachinger et al, 2013; European Commission, 2018). Standards for crop rotation have specifically been implemented as part of 'good agricultural and environmental condition' (GAEC) to fulfil cross-compliance requirements in a number of member states since 2003. (IFOAM EU, 2012).
	Nutrients Reduction (Effectiveness): Over time crop rotation can improve crop root structure, and consequently the chemical, biological, and physical structure of the soil. This will improve the organic matter and nutrients retention and increase the water-holding capacity of the soil. As crops are removed, nutrients are withdrawn or exported from the system. As legumes, manures, composts, or other amendments are added to the soil, the nutrient bank balance increases. By examining rotations through time, a farmer can make general estimates of the increase or decrease in potentially available nutrients and change his or her management accordingly (IFOAM EU, 2012).
	Recycling/Recovery: Leaving the land bare for a season allows the land to regenerate the soil nutrients lost through absorption by plants harvested in the previous season**.** Therefore**,** crop rotation allows the land to regenerate and rejuvenate its nutrients without having to apply more nutrients through the use of fertilizers.
	Climate Change Mitigation: According to IFOAM (2012) crop rotation results in better nutrient management and can decrease nitrogen fertiliser use by up to 100kg N per ha per year, substantially lowering related greenhouse gas (GHG) emissions. Nitrous oxide has a global warming potential 310 times greater than CO_2. Reduced synthetic fertiliser use also leads to reduced GHG emissions from the manufacturing process and transportation.
	Operation and Maintenance (O & M): The conversion process to crop rotation starts with the establishment of perennial legumes, mainly legume-grass mixtures, which are used as fodder or mulch. In many cases, farmers have more than one rotation sequence on their farm due to field variation and business decisions.
	Cost: Smarter use of nutrients – creates a more balanced nutrient cycle at the field level and helps farmers to use fewer inputs to maintain nutrient availability. This results in lower costs and increased profit margins (IFOAM EU, 2012).
2.3.	**Precision nutrient application**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Precision Nutrient Management means applying N, P and lime in a site specific manner (with specialized application equipment or multiple application events) based on the site specific recommendations for each GPS-referenced sampling point to minimize entry of nutrients to surface and groundwater and improve water quality. Mineral fertilizers and manures should be applied in accordance with the basic principles of '4R Nutrient Stewardship' (Sutton et al., 2013; European Commission, 2018): • <u>Right fertiliser</u> (crop needs, that complements organic matter with nutrients) • <u>Right time</u> (crop uptake, soil protection): The right time to apply fertilizer is usually during, or just before, periods of fast growth, when the crop requires significant amounts of nutrient. *Applications to waterlogged or frozen land should be avoided.* Similarly, manures are best spread in spring than summer or autumn to achieve a better NUE (nutrient use efficiency). • <u>Right rate</u> (spreader calibration, crop needs, slurry analysis, field variability): According to DEFRA (2010), i.e. accurate and even application of fertilisers, is very important in order to maximise the benefits from their use to improve crop yield and quality and profitability. Even where correct decisions have been made on the amount of fertiliser to apply, inaccurate application, uneven spreading or spreading into hedgerows or ditches can cause a range of potentially serious problems, including: uneven crops, lodging and disease, reduced yields and poor or uneven crop quality at harvest, more risk of the transfer of nutrients to watercourses at field margins causing nutrient pollution. • <u>Right method</u> (N losses, grazing palatability): Choosing the right method for applying manures means using the technique that maximises N conservation by limiting ammonia-N losses. Slurry application by injection or trailing shoe optimises N delivery to pasture whilst injection or immediate incorporation techniques are best on arable land. Spreading fertilisers and organic manures as uniformly and accurately as is practically possible to the cropped area is a requirement in Nitrate Vulnerable Zones (NVZs). Avoiding spreading into the edges of hedgerows and ditches is a requirement of Cross Compliance. Fertiliser spreaders and sprayers should be regularly maintained and serviced, replacing worn out parts as necessary. Spreaders should be calibrated for rate of application every spring and whenever the fertiliser type is changed (European Commission, 2018). However, Higgins et al (2017) recently underlined that despite technological advances which have been made in Precision Agriculture (PA) in the past decade, its adoption of PA in intensive grassland areas in North West Europe is

	still low. Precision farming is also defined as the “management of farming practices that uses computers, satellite positioning systems, and remote sensing devices to provide information on which enhanced decisions can be made” whilst a broader definition would be to optimize field level management with regard to crop science, environmental protection and economics.
	Nutrients Reduction (Effectiveness): The introduction of GPS alone (in autosteer) onto farm machinery can increase efficiencies by 5–10% through a reduction in overlaps and gaps in fertiliser spreading (Craighead and Yule, 2014). In Finland, farm gate balances on farms around the Baltic Sea showed that nutrient surpluses can be reduced effectively with precise application and farming techniques. Balance of (+/- 20 kg N/ha around zero) indicates a good status. Precision nutrient application results in reduced fertiliser application and Ammonia abatement, however its efficiency in reducing P loses needs to be further investigated.
	Recycling/Recovery: Reduced fertiliser application and improved crop yield, in particular regarding N management could indicate that nutrient recycling is also improved. However, there is a luck of research on the potential contribution of this practice to nutrient recycling and or recovery.
	Climate Change Mitigation: Good timing of nutrient application conserves N by reducing nitrate-N leaching losses and runoff and also by reducing N_2O emissions. Hultgreen and Leduc (2003) reported that when urea was applied in a band below and to the side of the seed row, NH_3 and N_2O emissions were reduced in comparison to broadcast surface application in two years of a three-year study at two sites in Saskatchewan, Canada.
	Operation and Maintenance (O & M): A crop’s nutrient uptake can be calculated by multiplying its expected yield by its nutrient content per tonne. According to experience from Finland, all farms can implement some aspects of precision application practices. The European Commission (2018) Guidelines recommend for farmers to know: 1. what nutrients they are applying (to check nutrient content of manures etc.) 2. the quantity they are applying – application rate (to check flow rate from spreader) 3. when it is optimum timing for spreading – to match crop requirement, when soil moisture allows access and when weather is appropriate (no heavy rain forecast nor onto frozen soil) usually in spring (Feb-Apr in N. Europe). 4. how to spread to gain maximum nutrient delivery and minimum nutrient loss to the environment via gaseous emissions or surface runoff (Ammonia is a key pollutant associated with spreading organic manures and the agricultural sector is responsible for 90% of ammonia emissions (Oenema et al., 2012)). 5. where not to spread manures. Further precision in the application of nutrients can be achieved by using Global Positioning Systems (GPS) technology. The application of GPS has two main applications: • To inform variable nutrient applications within a field or in different parts of a field, where variation in crop canopy development can be identified, inspected and then managed using variable rate application, and • To allow accurate locational placement of fertilisers, agro-chemicals and keep to tramlines.
	Cost: Slurry ammonium-N measuring equipment costs c. £250 (EUR 295) + consumables. Simple GPS units can be purchased for around £300-400 (EUR 350-475)-and these can be transferred between vehicles. Where there is a built-in unit then these can be either a standard item where the cost is built in to the vehicle cost or as an optional extra with a price range of up to EUR 11,750 depending upon the complexity of the unit. Farmers’ Weekly (2013) reported a situation where GPS installation costs of almost EUR 12 000 were paid back in about three years (European Commission, 2018). In the UK, equipping a farm for precision farming costs from £2/ha to £18/ha (EUR 2.35-21.20/ha) depending upon the complexity of the system and farm size. Data collection and interpretation to enable real time agronomy incurs costs from £7/ha (EUR 8.25/ha) depending upon the total area surveyed by aircraft or tractor-mounted radiometry. The project highlighted additional benefits. Correcting waterlogging was worth £185/ha; rectifying uneven nitrogen application returned up to £65/ha (76.5/ha) in a year (HGCA, 2010).
3. Soil Preparation and Crop Planning	
3.1.	**Mitigate tillage impacts**
NPA Location Finland, Northern Ireland, Republic of Ireland,	**Description and Purpose:** The European Commission Guidelines (2018) document recommends that *tillage operations should be matched to soil conditions, and the need to sustain or improve soil condition over time*. <u>The following measures are recommended:</u> • *Contour ploughing:* Farmers should cultivate and drill land along the slope (contour) to reduce the risk of developing surface runoff. On fields with simple slope patterns, cultivating and drilling across the slope reduces the risk of surface runoff being initiated and increase re-deposition rates where surface runoff does occur. Hedges give a long-term slope break, and if additional drainage is not required, they are more effective if planted

Scotland	on a wide bank running along the contour to help retain sediment and prevent fine particles from reaching watercourses. Where long slopes are unavoidable or cannot be broken by planting hedges, consideration should be given to contour strips. These work on the principle that close ground cover such as creeping grass will both slow surface flow from above, and increase infiltration rates. As a guide, strips 5-15 metres in width positioned every 50-150 metres down the slope, should be effective on most erosion susceptible areas. • *Break slopes* - the technique of sowing a grass strip across slope to intercept run off and nutrients. • *Cultivate* tramlines: Tramlines caused from machinery during autumn sowing can act as conduits for runoff. It is best practice to cultivate tramlines after tillage operations. • *Avoid compaction* • *Low ground pressure impact tyres on vehicles* Controlling where wheels go reduces soil damage when harvesting in wet weather, because the permanent tramlines support traffic better. Controlled traffic farming (CTF) is a system which confines all machinery loads to the least possible area, as permanent traffic lanes. Conventional approach where machines track randomly over the land can compact around 75% of the area within one season and at least the whole area by the second season. Soils can take years to recover. A CTF system can reduce tracking to just 15% and this is always in the same place. • *Erosion risk planning* : Creation of roughened seedbeds that provide increased surface area to rain drops reduce surface capping and run off, compared with fine seed beds. Leaving the autumn seedbed rough encourages surface water infiltration and reduces the risk of surface runoff, thereby reducing particulate P and associated sediment loss risks and erosion.
	Nutrients Reduction (Effectiveness): Cultivation techniques that reduce the depth and extent of soil disturbance protect soils by avoiding formation of natural channels and preferential flows thus have potential for nutrients reduction. Burial of organic matter and nutrients to soil depths beyond the major rooting zone; Fragmentation of soil aggregates resulting in mineralisation of organic matter. The research on the impact of minimal tillage on nutrients reduction is non-conclusive. Some studies indicate that contour ploughing may reduce particulate P and associated sediment losses. Stevens et al (2009) investigated the effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss in the UK over 2 years period. Half of the field was cultivated with minimum tillage (shallow tillage with a tine cultivator) and half was conventionally ploughed. Results showed no significant reduction in runoff, sediment losses or total P losses from minimum tillage when compared to the conventional plough treatment, but there were increased losses of total dissolved P with minimum tillage. *The mixed direction cultivation treatment increased surface runoff and losses of sediment and phosphorus*. Increasing surface roughness with contour cultivation reduced surface runoff compared to up and down slope cultivation in both the plough and minimum tillage treatment areas, but this trend was not significant. *Sediment and phosphorus losses in the contour cultivation treatment followed a very similar pattern to runoff.* Combining contour cultivation with a vegetative barrier in the form of a beetle bank to reduce slope length resulted in a non-significant reduction in surface runoff, sediment and total phosphorus when compared to up and down slope cultivation, but there was a clear trend towards reduced losses. *However, the addition of a beetle bank did not provide a significant reduction in runoff, sediment losses or total phosphorus losses when compared to contour cultivation, suggesting only a marginal additional benefit*. The economic implications for farmers of the different treatment options are investigated in order to assess their suitability for implementation at a field scale.
	Recycling/Recovery: No reliable information is available.
	Climate Change Mitigation: No reliable information is available.
	Operation and Maintenance (O & M): Minimum tillage is best carried out on any stable soil that maintains its structure throughout the growing season. Clays, silty clay loams and clay loams are particularly suitable. Avoid adopting minimum tillage on sands, compacted soil, fields with serious weed problems and with crops that require specific tilth conditions such as potatoes. Minimum tillage runs the risk of weed infestation. This can be managed by skilful crop rotation and practices such as stale seedbeds. The use of min-till techniques is constrained to arable soils. If field shape is changed so that the long side is across the slope, cultivations will tend to follow this and help reduce erosion risk. On longer slopes, it may be appropriate to install a new ditch across the slope to intercept water part-way down. This will help stop the accumulation of large volumes of surface water run-off. The ditch should have a grass strip a few metres wide on its upper side to filter sediments from run-off and reduce discharge to watercourses.
	Cost: According to Newell-Price et al. (2011) cost of implementing reduced or no-till operations are based on contractor being used and the plough retained for occasional use in difficult seasons. The net effect from selling most cultivation equipment and using a contractor was a saving of £40/ha. Schulte et al. (2012) reported that application of min-till across Irish cereal production would lead to a total saving of €43.58 million annually, principally from savings in fuel usage of €29.20 /ha saving.

3.2.	**Establish cover/catch crops**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Cover crops contribute to soil quality improvement principally through their decomposition by soil microbes. The products of decomposition, while generally adding to the soil organic matter (SOM) reservoir, benefit the soil in two specific ways, i.e., through soil physical conditioning and through fertility building. The degree of enrichment depends on the quantity and quality of cover-crop biomass. Cellulose-rich plants or plant parts degrade far more rapidly than if they were ligneous – as is the nature of mature grasses (Edwards and Burney, 2005). Catch/cover crops are grown in the period between two main crops in order to retain nutrients in the root zone (catch crops) or to protect the soil against erosion and minimise the risk of surface runoff by improving the infiltration (cover crops). They can be under sown with the previous main crop or sown immediately after harvest of the previous main crop. Catch/cover crops are mainly used prior to spring sown crops. Their main purposes are to: • Minimise erosion from winter rain • Reduce N leaching losses • Protect soil surface during first tillage/seeding • Prevent Soil crusting • Under-sowing e.g. grass into maize • Increase Soil Organic matter (SOM) • Capture and subsequent release of N Cover crops add Organic Matter (OM) and reduce damage to soil structure by protecting surface (reduce erosion, prevent soil crusting) over winter and in spring operations – sometimes referred to as green manures. Cover crops can also act as a 'catch crop' to mop up spring flush of nitrate-N (e.g. barley, rye) and as a 'nurse crop' for reseeded pasture. The incorporation of cover/catch crops also provides available N, reducing fertiliser N needs.
	Nutrients Reduction (Effectiveness): According to the Environmental Agency (2008) cover crops planted on land destined for spring crops can reduce nitrate leaching by 50% and thus help reduce fertiliser application rate. In a study conducted in Ireland, Hooker et al. (2008) found soil solution nitrate concentrations were between 38% and 70% lower when a cover crop was used, and total N load lost over the winter was between 18% and 83% lower. Similarly, Premov et al. (2012) reported a significant decrease in groundwater nitrate concentration under mustard cover compared to no cover. Berntsen et al. (2006) showed that nitrate leaching can be reduced by approximately 25 kg N/ha as an average for spring cereals on sandy and loamy soil, being greater on sandy soils than on loamy soils. Since this N is largely available for the cereal crop, the use of fertiliser can – and should– be reduced correspondingly, since part of the build-up of N in the soil may otherwise be lost though leaching. In Finland, it is estimated that winter plant cover can reduce erosion and nutrient leaching by 10-15%. However, in many parts of Europe there are severe issues of post maize harvest erosion and runoff caused by compaction, and nitrate leaching, which are exacerbated by the late dates of harvest into the autumn. Therefore one may suggest harvesting early in order to broaden the window for crop covering.
	Recycling/Recovery: No reliable information is available.
	Climate Change Mitigation: Cavigelli and Parkin (2012) reported results from four studies conducted in eastern and central U.S. show few impacts of grass cover crops on soil N_2O emissions. Jarecki et al. (2009) found that a rye + oat cover crop planted in the fall in Iowa had no impact on annual soil N_2O emissions during the growth of the cover crop and a succeeding corn crop regardless of whether manure had been applied in the fall or in the spring. However, injecting the manure in this 1-year experiment damaged the growing cover crop, thereby likely reducing its effectiveness at assimilating soil nitrate and water. Legume cover crops can contribute to soil N_2O emissions by increasing soil C and nitrate levels after incorporation.
	Operation and Maintenance (O & M): Implementing cover/catch crops requires a high level of knowledge from the farmer or advisor. In particular, successful crop production under Northern growing conditions requires specific adaptation mechanisms to cope with climatic exceptionalities and handicaps. Soil type, fit with rotation, weeds, plant pathogens, weather patterns, yield, market price and livestock requirements all need to be considered (Peltonen-Sainio et al, 2015). Where cover crops were established as part of the Nitrate Sensitive Area scheme, it was shown to be preferable (for agronomic reasons) to destroy the crop in January or February (at the latest) (NewellPrice et al., 2011). In particular, cover crops provide at least 25% ground cover by early winter to offer effective protection against erosion.
	Cost: Information insufficient. One study by Schulte et al. (2012) reported cost of implementation € 71.20 /ha (including seed and fuel).
	4. Animal Husbandry
4.1.	**Nutrient Budgeting on livestock farms**
NPA Location	**Description and Purpose:** According to the European Commission BEMPs guidelines (2018) Nutrient budgeting is

Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	the best practice measure for deciding the nutrient requirement of a farm. It involves balancing of nutrient imports and exports for a farm. A budget requires calculating the macronutrient (N, P, K) and energy intake demand of a livestock unit, recording how much of the nutrient is exported as kg of meat or kg of milk then, considering the land bank area, and shortfall in nutrient that has to be imported as feed concentrate. Nutrient surplus and use efficiency indicators Gross nitrogen or phosphorus balance is calculated as the potential surplus of N or P on agricultural land (kg/ha/year). Nitrogen use efficiency (NUE) is the amount of N imported to the farm system (fertilisers, feed and bedding materials) that is exported from the farm in products (e.g. cereal grain, straw, animal live weight, milk).
	Nutrients Reduction (Effectiveness): According to the Environmental Agency (2008), limiting total N fertilisation and requiring manure N to be calculated at utilisation efficiency relative to artificial N (60%), reduction of 70% and 75% is possible in dairy and pig farms, respectively. Whole-farm nutrient budgets have been used effectively in the USA. Limited results showed voluntary BMP on concentrated animal feeding operations (e.g. feedlots) was more effective (30 – 60% reduction in P accumulation) than mandatory nutrient management plans and buffer strips (5–7% reduction in P accumulation) in reducing nutrient surpluses (Goulding et al., 2008). Farms in Denmark and the Netherlands have been able to achieve decreases in N surplus and increases in NUEN by ca. 30% in a 5-y period and 50% over 10 years.
	Recycling/Recovery: The information is very limited. In general there is not much interest in nutrients recovery from agricultural activities (Drizo, 2019).
	Climate Change Mitigation: Raising animals for food contributes to the production of greenhouse gases implicated in the global warming that is causing climate change. Livestock contribute both directly and indirectly to climate change. Enteric fermentation and manure associated emissions are direct, while production and transport of feed (including the fossil fuels used in manufacturing chemical fertilizers) and land use changes (such as conversion of forest to pasture and crop land) contribute indirectly. It has been shown that about 44% of the emissions generated by livestock are CH_4, which is released during enteric fermentation (eructation in ruminants) and emitted from manure decomposition; 27% are in the form of CO_2 emitted during the production and transport of animal products and feed, and 29% are N_2O attributable to manure and fertilizer (Gerber et al, 2013). According to the FAO Report (2006) the most promising approach for reducing CH_4 emissions from livestock is by improving the productivity and efficiency of livestock production, through better nutrition and genetics. Greater efficiency means that a larger portion of the energy in the animals' feed is directed toward the creation of useful products (milk, meat, and draught power), so that methane emissions per unit product are reduced. More recently, Shields and Orme-Evans (2015) made a comprehensive review of the livestock climate change mitigation practices and their effects on the animal welfare.
	Operation and Maintenance (O & M): The European Commission BEMPs guidelines (2018) provides information on two different online Tools for carrying out a nutrient budget in the UK. For example, PLANET (http://www.planet4farmers.co.uk/) provides field-level record keeping, industry standard recommendations allowing for organic manure nutrients, nutrient application plans, and help with carrying out calculations and producing reports. It can also be used to produce balances and NUE allowing farm standards or benchmarks to be produced. Commercial farms are then scored at 25%, 20%, 15% or 10% above or below the benchmark value for a specific farm system. Benchmarks can be expressed either as kg nutrient/ha or per livestock unit. MANNER (http://www.adas.co.uk/MANNER/tabid/270/default.aspx) is a decision support system that can be used to accurately predict the fertiliser N value of organic manures on a field specific can be used to accurately predict the fertiliser nitrogen value of organic manures on a field specific basis. It also provides estimates of NH3 and NO3 losses, and calculates the amount of applied organic N that remains available to plants, according to application method and timing and organic composition. Best practice measures in soil, grazing management and manure management are to tighten the N loop to maximise retention in the system and minimise losses to air and water.
	Cost: The European Commission (2018) Guide reported that • the cost of undertaking a farm nutrient balance are €200-500 per farm p.a. • Net cost of improving N management is ca. €-1 to +1 per kg N saved. • Default fertiliser costs used in MANNER-NPK to calculate fertiliser replacement value of manures are (converted into EUR at 0.85 EUR/GBP): o EUR 1.06 per kg N o EUR 0.94 per kg P o EUR 0.71 per kg K
4.2.	**Dietary reduction of N and P excretion (ruminants and monogastric)**
NPA Location Finland,	**Description and Purpose:** Adjust the composition of livestock diets to reduce the total intake of N and P per unit of production. Recent research has shown that animal feed can be formulated to reduce nitrogen (N) and phosphorus (P) excretion without reducing animal performance (Utah State University Cooperative Extension, 2010;

Northern Ireland, Republic of Ireland, Scotland	Shields and Orme-Evans, 2015) . The ideal protein concept is a feeding method in which crude protein levels are reduced and amino acids are supplemented in order to reduce N excretion. For reduction of P excretion, adding phytase to the diet has been shown to increase P availability to hogs and chickens. According to the European Commission Guidelines for BEMPs (2018), there is a close relationship between the excretion of N and P by dairy cattle and the amounts consumed with feed. The guide highlights that nutritional measures are good options to reduce N and P excretion by animals. However, the EC (2008) underlined that in the western and eastern-southern type of dairy production in Europe, cow diets already have moderate N contents so that it is not realistic to reduce the N supply further without impairing the milk yield. Furthermore they highlighted that it is unrealistic to reduce the dietary N in beef systems given that beef fattening units tend to have optimised N supply, whilst for grazing animals (suckler herds and steers) small amounts of complementary protein rich feed is provided. The two main imports of P are through feed and mineral fertiliser. However, one must take into account the negative effects of diet changes on cattle, pigs and other livestock. These have been described in detail by Shields and Orme-Evans (2015).
	Nutrients Reduction (Effectiveness): Data are fairly limited. One study from the Netherlands in 2010 showed that agreement between farmers and the feed sector was reached to reduce P in feed by 10% which led to a reduction from 179 Mkg P_2O_5 to 161 Mkg P_2O_5.This was driven by informed farmers seeing the need to reduce P in feed as the only course of action once they stopped applying P fertiliser. European Commission (2018) cited research stating that for typical Danish (Northern Europe) pig production, the N excretion per pig could be reduced from 5.3 kg N per pig produced to 3.9 kg N, by using two feed mixtures for sows (differing in N content) and reducing the N concentration in slaughter-pig feed by 5 % and instead adding synthetic amino acids. They further underlined that this measure alone would reduce ammonia emission by 22 %, i.e. from the current 1.26 kg ammonia to 0.98 kg. For all pig farming systems, implementation of optimised feeding is expected to reduce the overall N excretion in manure by 32 %. The EC (2008) stated that in the UK dairy systems, an optimised feeding (going from 17 % crude protein in dry matter to 14 %) in the relevant systems could reduce the overall N excretion from the cattle by approximately 48 kg per cow and year. Maguire et al (2005) reviewed dietary strategies for reduced P excretion and improved water quality. They stated that reduction of P overfeeding, use of feed additives to enhance dietary P utilization, and development of high available phosphorus (HAP) grains are successful measures to decrease fecal P excretion without impairing animal performance.
	Recycling/Recovery: The information is limited. In general there is not much interest in nutrients recovery from agricultural activities (Drizo, 2019).
	Climate Change Mitigation: Given that feed production accounts for about 47% of livestock emissions it is a key target for mitigation. Nousiainen et al. (2004) showed that ammonia emissions from all farm sources may decrease by 5-15% (average 10%) from a reduction in mean protein content by 10 g per kg in the diet. Low-protein feeds is one of the most cost-effective and strategic ways to reduce NH_3 emissions. Oenema et al. (2012) stated that low-protein animal feeding also decreases N_2O emissions and increases the efficiency of N use in animal production but is only really applicable to housed animals. Swensson (2003) (cited in European Commission, 2018) observed that a 25 % lowered N supply to dairy cows did not impact milk yield, and reduced ammonia emission in the stable by over 65%.
	Operation and Maintenance (O & M): The EC Guide (2018) provides operational data for Dietary reduction of N and P excretion. The guide underlines that energy (as metabolisable energy, ME) and protein (crude protein, CP) are the critical nutrients for practical rationing on farm as these are the most costly nutrients to supply. CP is a simple measurement of N content of feed (assumed 16% N for budgeting purposes). Recommended CP and ME requirements for livestock are available in farm reference documents and websites e.g. Tried & Tested (2019).
	Cost: Schulte et al. (2012) (cited in EC, 2018) estimated that reduced fertiliser N usage rates per kg produce use (i.e. improved NUE) can result in an abatement potential 0.080 Mt CO_2eq for Ireland, with an associated cost saving of M€ 28.9.
	Feed management (Reduce runoff from waste forage)
4.3.	**Silage runoff management**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Of the agricultural discharges, silage leachate and runoff represents one of the potentially most contaminated and harmful wastes generated on a farm, often being toxic to surrounding freshwater sources. Due to its high biochemical oxygen demand (BOD), nutrient rich composition (up to 600 mg/L of phosphorus) and low pH, silage leachate is approximately 200 times stronger than raw domestic sewage and 40 times stronger than dairy shed waste (USDA NRCS, 1995; Drizo et al, 2009). Micthell et al (2002) discussed methods for controlling silage leachate. Farmers can opt to capture silage leachate by constructing lined ponds or collection basins. Once captured, leachate could then be pumped or directed into an existing manure or milkhouse wastewater storage. However, this could contribute a significant amount of volume to the storage, particularly when rainwater runoff from a bunker is collected. Moreover, since leachate produces dangerous hydrogen sulfide when mixed with liquid

	manure, it should only be considered in well-ventilated, outdoor storages. The USDA NRCS developed Vegetated Treatment Area (VTA) Practice Code 635 as the best practice for silage runoff management (USDA NRCS, 2008). According to the USAD NRCS a VTA system typically consists of grading the land to capture all of the leachate, while preventing any clean water from entering the area. The leachate is concentrated to one (or more) point(s) to force the highly concentrated low flows into a waste storage facility, or pumped into a tank. The system uses a series of screens for solids separation and sediment settling pools and piping to direct flows to the proper part of the system. High flows which contain a lesser concentration of pollutants, are directed to a spreading device that creates a shallow sheet flow to spread across a well vegetated area dedicated to the system. Allowing higher flows to bypass the leachate collection and storage system makes storage of the higher concentrated pollutants more affordable to the producer since its size, cost to build, and cost to maintain will be much less than trying to manage all of the effluent coming from the bunk silo. In Finland (Infocard 4.3.) the collection of the silage effluent into closed container prevents nutrient runoff to the surface and ground water and the effluent can be used as fertilizer on the field. Silage stacking should be at least 10 m away from watercourse.
	Nutrients Reduction (Effectiveness): A two year project performed on a farm in Vermont, USA showed that implementation of an innovative "treatment train" system consisting of a PhosphoReduc filter, a single vegetative treatment area and a trench filled with PhosphoReduc adsorbing material and vegetated with local grasses, would be cheaper and have significantly higher performance in pollutants reduction. For example, addition of a single trench filled with P retaining material increased dissolved P reduction was from 58% (VGA) to 84%. Total P reduction was 84% (Drizo, 2011).
	Recycling/Recovery: None from the vegetative treatment area. However if P retention media are being incorporated there could be potential for both P recycling and recovery. Bird and Drizo (2009) showed that P sorbing material used in filters to reduce P from waste streams has potential to act as a slow release P fertilizer. However more research is needed to quantify the amount of P than can be recovered.
	Climate Change Mitigation: Needs to be investigated.
	Operation and Maintenance (O & M): According to the USDA NRCS information (2019), silage runoff management starts in the bunk. Harvesting crops at more than 30 percent solids will greatly reduce the amount of leachate. Good management such as maintaining a clean bunk floor, and removing spoiled silage piles from flow paths, will reduce the amount of contaminated flows as well. The low flow collection and separation area needs to be maintained to capture enough of the low flows volume so the vegetation downstream in the system is healthy with no kill zones. The solid separation screens and settling pools also need to be maintained. Developing a standard operating procedure for the feed manager on the farm is needed to keep up with the maintenance. The spreader and the vegetated area require maintenance also. They should be checked regularly to be sure the high flows are moving through the VTA as sheet flow, and are not concentrated to one area. Additional spreaders (gravel trenches) may be needed at intervals along the length of the VTA.
	Cost: According to the experience in Finland, the costs include groundwork, pipeline laying and cesspit tank installation. The value of the effluent is evaluated to be 2,23 €/m3 and the handling of it costs 1,15 €/1000 l. Drizo et al (2009) conducted a two year project which investigated the use of P sorbing media (steel slag aggregates) to improve treatment performance of VTA. They performed comprehensive cost-benefit analysis of different methods and found that addition of simple trenches filled with P sorbing materials could considerably improve the performance of VTA 635 at the fraction of costs spent on VTA. In 2011, the cost of Currently the cost of vegetative treatment area implementation was $13,170 for a bunk silo 1 acre in size and the implementation of a low flow gravity runoff diversion $2,050 per acre area that needs treatment, resulting in a total of $15,220,15 per acre (about $37,610 per hectare). The life span of a practice is estimated to 15 years and the cost of materials $11,040.
4.4.	**Passive filters for Phosphorus retention on farms – Innovative Practice**
Could be implemented throughout NPA	**Description and Purpose:** PhosphoReduc filter system is a"closed loop" gravity fed passive filtration system for P harvesting/removal, re-use and recovery, and as such also the enabler of the circular economy. The technology was developed as an outcome of a decade (1999 – 2009) of research by Drizo and co-workers on the use of steel slag aggregates (SSA) for P removal from wastewaters (Drizo et al, 2002; Weber et al, 2007; Drizo et al, 2008; Bird and Drizo, 2009; Bird and Drizo, 2010; Drizo, 2012). They were among the first researchers who conducted series of field-scale investigations on the potential of SSA for P removal from a variety of wastewater effluents (dairy, barnyard runoff, surface and subsurface agricultural drainage, urban stormwater runoff, industrial sites runoff and sewage). Between 2004 and 2008 they established over 15 different long-term pilot and medium scale experiments and investigated a number of operating parameters known to affect filters field performances. This extensive research resulted in the development of operational parameters for six different classes of technologies for phosphorus, suspended solids and pathogens reduction and phosphorus harvesting, recycling and re-use from any point or nonpoint pollution source from agricultural activities as well as residential, municipal and stormwater runoff effluents (Drizo, 2012; Drizo and Picard, 2014; WSSI, 2019).

	Nutrients Reduction (Effectiveness): PhosphoReduc filtration systems consisting of one or more filter units filled with iron and/or calcium based PhosphoReduc filtration media (PRM). They are customizable and scalable to provide over 90% phosphorus reduction of any point or nonpoint pollution source.
	Recycling/Recovery: Bird and Drizo (2009) showed that P sorbing material used in filters to reduce P from waste streams has potential to act as a slow release P fertilizer. However more research is needed to quantify the amount of P than can be recovered.
	Climate Change Mitigation: PhosphoReduc systems also reduce organic matter, suspended soldis, metals and nitrate from wastewaters. New designs for climate change mitigation are currently being developed.
	Operation and Maintenance (O & M): The PhosphoReduc system is a user friendly treatment unit which requires minimal operational and maintenance requirements. Its unique design requires no mechanical or moving parts, eliminates the need for electrical components, and is a passive filtration system. By properly monitoring the system performance, periodic maintenance can be performed at the operator's convenience. WSSI (2019) offers operation and maintenance manual, along with a training session if required. Portion of the media needs to be excavated and media replaced every 7-10 years (depending on the P cocnentrations in the influent).
	Cost: The cost of filters depends on the volumes of wastewater that need to be treated, influent and effluent P concentrations and availability of the SSA filtration media. In general for 60-150 m3/d the implementation cost of filter is up to 25,000 euros. Majority of the cost is for media transportation (generally 40 euros/ton). However the filter has a life span of 25+ years and minimum maintenance fee (about 300 euro/year).
5. Manure Management	
5.1.	**Physical Manure Treatment (Solids Separation)**
NPA Location Finland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Solid/liquid manure separation, or de-watering, involves the partial removal of solids from liquid manure (slurry). The process converts the initial slurry manure into two streams: solids and liquids. Solid/liquid manure separation is generally conducted using a gravity system or mechanical separation system (USDA NRCS, 2011; Koger et al, 2014).The gravity separation system involves the use of settling basins where solids settle to the bottom and the liquid portion remains at the top and is pumped out to a separate tank for storage or application. The mechanical separation system uses some form of mechanical process to separate liquids from solids. A variety of systems are available on the market such as vibrating screens, roller systems, rotary centrifuges, and screw presses. Solid-liquid separation methods have been traditionally used to reduce lagoon solids buildup by separating solids from liquid raw manure prior to flowing into the anaerobic lagoon or other holding pond, or to recover solids from lagoon sludge (Szogi et al, 2015). Solids separation makes the storage of liquid and solids easier and safer by reducing the potential of contaminating surface and groundwater. In addition, it facilitates the use of further methods to recover nutrients that would otherwise be unsuited for use with raw manure (Szogy and Vanotti, 2014). *The advantages* of Solid/Liquid Separation Equipment include: • It is less likely to plug transfer pipes and requires less power to pump; • Solid component of manure separation is more cost effective to transport due to lower moisture content; • Liquid component is easier to apply/irrigate due to reduced viscosity; • Liquid component requires less agitation time relative to untreated slurry • The odours associated with separated liquids and solids is reduced compared to unprocessed slurry; and • N : P ratios of the solid and liquid components are different (solid component has higher P while liquid component has higher N). Thus, the separation allows for more accurate application of nutrients based on the needs of each field. *Disadvantages of Solid/Liquid Manure Separation* • High initial cost associated with implementation; • Ongoing maintenance costs; • System creates two waste streams and farms may not be set up to manage two streams of manure; • Solid/liquid manure separation adds an additional step to the manure management system, which requires attention; and • The system may require modification to existing facilities such as the construction of new buildings to house the equipment or new electrical systems.
	Nutrients Reduction (Effectiveness): Usually, solid-liquid separation efficiencies of mechanical manure separators are less than 60 % solids removal. However, new advances over the last 15 years in equipment and flocculant applications for chemically enhancing solid-liquid separation treatment have improved removal efficiency of solids and nutrients (Hjorth et al, 2010). For example, swine manure treated using a high-rate solid-liquid separation system combined with flocculant (polyacrylamide) injection separated 89 % of total suspended solids, 72 % of organic N, and 66 % total P (Szogi et al, 2015). This separation process also efficiently removed heavy metals such as Cu (88 %) and Zn (87 %).

	Recycling/Recovery: The number of technologies/products applied on farms at the full scale are very limited. Drizo (2019) reported process developed and patented by Vanotti et al. (2010) to recover phosphate from liquid swine manure. In their treatment system polymers are added to the raw liquid swine manure treated in an enhanced solid-liquid separation process; the liquid swine manure is then treated with the nitrification to oxidize ammonium to nitrate (Desmidt et al., 2015).
	Climate Change Mitigation: According to the LPELC (2019), there is some limited research which suggests that separating swine manure into solids and liquids can slightly reduce greenhouse gas (GHG) emissions emitted from the manure itself. However it is not likely to be significant enough for separation to be a viable strategy by itself. Wang et al (2017) meta-analysis and an integrated assessment of gaseous emissions and mitigation potentials for NH_3, methane (CH_4) and nitrous oxide (N_2O) (direct and indirect) losses from four typical swine manure management systems in China. Their analysis showed that changing swine manure management from liquid systems to solid-liquid separation systems, coupled with mitigation measures, could simultaneously reduce GHG emissions by 65% and NH_3 emissions by 78%.
	Operation and Maintenance (O & M): Maintenance costs are high.
	Cost: As explained under disadvantages, the initial costs required for implementation are high as well as the ongoing maintenance costs.
5.2.	**Appropriate slurry processing and storage systems**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description and Purpose:** Before the use of the slurry e.g. in the field, proper process techniques must be applied. For farmers, the loss of NH_4^+ via the NH_3 emissions will reduce the fertiliser value and amount of the animal manure. Therefore the implementation of measures to reduce NH_3 emissions may contribute to reduce the oversupply of N to crops. One of these measures is the 1) acidification of slurry which can decrease the amount of NH_3 emissions from the animal house, the store and after having applied the slurry to the land. Others include 2) solidification/stabilisation techniques which can be implemented but properly modified and adapted on site-specific applications (taking always into consideration the end-use of the treated material and the chemical characteristics of the slurry); 3) slurry cooling – a process which has similar characteristics with the geothermal heat generation. It also lowers ammonia levels in the stable thus contributing to creating better environmental and health conditions (Joergensen, 2009; European Commission, 2018). The Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs (EC, 2017) provides the comprehensive list of all best available techniques for the slurries processing. <u>Slurry Storage Systems</u> Storage systems have an important influence on three key environmental burdens arising from farm operations: global warming potential via CH_4 and N_2O emissions, and eutrophication and acidification via NH_3 emissions. According to the EC (2018), the best practice is to install tall (> 3 m) slurry tanks with a comparatively small exposed slurry surface area (new stores), and to cover slurry with some form of fixed or temporary cover (retro-fit existing stores). The maximum duration of slurry storage depends on the capacity of slurry stores in relation to slurry generation (animal numbers). It can have a significant influence on the efficiency and environmental impact of slurry application. According to the EC (2018), insufficient slurry storage capacity leads to winter application of slurry onto wet soils, when a high proportion of N may be lost via runoff and leaching, and when plant uptake is low. Thus, adequate storage capacity is a second key component of best practice. The Ontario Ministry of Agriculture, Food and Rural Affairs provides excellent Fact sheets and design guide for different types of of Slurry Storage Systems used in Canada (Hilborn, 2010).
	Nutrients Reduction (Effectiveness): EC (2018) cited research by Cuttle et al. (2007) who stated that increase in a slurry storage capacity from an average of three to 6 months, under a cool, temperate, wet climate (UK) resulted in: • 25% reduction in slurry P losses to water • For arable land, a 10-20 kg N/ha (20-40%) reduction in annual N leaching via optimised application timing, or a 15-30 kg N/ha (30-60%) reduction if fertiliser application rates are reduced accordingly; • For grassland, a 2-5 kg N/ha reduction in n leaching for dairy farms, and 1 kg N/ha reduction for beef farms.
	Recycling/Recovery: The number of technologies/products applied on farms at the full scale are limited. More research is needed.
	Climate Change Mitigation: According to the EC (2018), under worst case open lagoon systems, slurry storage can contribute up to 38% of farm system GHG emissions, 30% of farm system eutrophying emissions, and 52% of farm system acidifying gas emissions for a large dairy farm. The type of slurry storage system, in particular the surface area exposed to the atmosphere in relation to the slurry volume, strongly influence CH_4 and NH_3 emissions to the atmosphere. Life cycle assessment of a large dairy farm system where animals are indoors for 10 months of the year showed that shifting from lagoon storage to tank storage with a crust cover can reduce farm-level GHG emissions by 29%, eutrophying emissions by 25% and acidifying gas emissions by 42%.
	Operation and Maintenance (O & M): EC (2018) summarized best measures for slurry management and storage identified by Newell-Price et al. (2011). These include: 1) Increase the capacity of farm slurry (manure) stores to

improve timing of slurry applications; 2) Adopt batch storage of slurry (slurry should be stored in batches for at least 90 days before land spreading; fresh slurry should not be added to the existing storage during this storage period); 3) Install covers on slurry stores; 4) Allow cattle slurry stores to develop a natural crust (e.g. retain a surface crust on stores, composed of fibre and bedding material present in cattle slurry, for as long as possible).

Cost: EC (2018) summarized data reported in EC (2013) showing necessary investments and annual costs for four different usable storage capacities (e.g. 500, 1000, 3000 and 5000 m^3). For example, the investments for a 500 m^3 storage unit were 100 €/m^2 for a tent roof, 39.5 €/m^2 for floating bricks and 10.2 €/m^2 for light bulk materials, while for a 5000 m^3 storage unit they were 46, 39.5 and 7.6 €/m^2, respectively. Klimont and Winiwarter (2011) calculated storage investment costs for different storage scales (Figure 1).

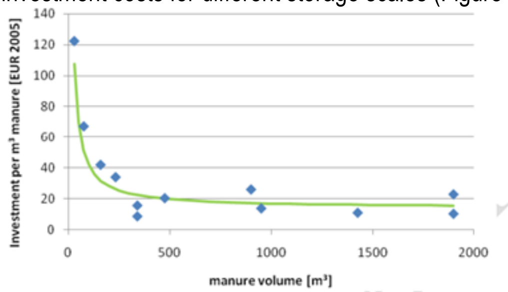

Figure 1: Storage investment costs for different scales.

5.3. Appropriate solid manure storage

NPA Location
Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland

Description and Purpose: Manure is usually managed as dry solid manure or liquid slurries, stored in especially designed Storage Facilities or Structures. Liquid manure and wastewaters are sent to detention ponds or lagoons for settling out the solids fraction and reducing the volume through evaporation (5.1.). Lagoons also serve as a temporary storage facility for land application. However, the quantities of manure generated on the confined animal operations often exceed local crop needs and areas available for application, posing considerable challenges in P management (e.g. Sharpley et al, 1994; Sims et al, 2005; Doody et al, 2012; Doody et al, 2013; Teenstra et al, 2014). This is particularly the case in the USA, Canada and other temperate regions of the world where manure spreading winder ban had been introduced for a period of 6 months (December 15th to April 1st). In addition, in many areas manure has been stored in open pits that can still cause significant P pollution at each precipitation event (Teenstra et al, 2014). According to EC (2018) anaerobic digestion or separation of animal excreta prior to storage is best practice for farms with liquid slurry systems. Best practice is to compost or batch store the solid fractions arising from all manure management systems, especially farm yard manure and poultry litter. As a general recommendation, the manure storage facility must be located in well-drained area and the surface water should not enter it. An appropriate effective buffer strip must be constructed between the manure storage facility and the watercourse (EC, 2018). Siting manure heaps away from drains reduces the risk that preferential flow of effluent through the soil might transport N, P and fecal indicator organisms (FIOs) to field drains. Similarly, an adequate separation distance between the heap and a watercourse reduces the risk that any effluent from the heap might run over the soil surface directly into the watercourse (Haygarth, 2011).

Nutrients Reduction (Effectiveness): Small.
Nitrogen**:** A small reduction in nitrate leaching is estimated on the fields in the USA to which the option was applied. This assumes that 20% of manure heaps are at risk (i.e. over a drain, etc), and only 2% of total N is leached. Averaged over the farm area, this corresponds to a very small reduction in nitrate leaching losses per unit area.
Phosphorus: Cuttle et al. (2007) estimated that option implementation would result in a small reduction in the manure component of the baseline P loss.

Recycling/Recovery: None.

Climate Change Mitigation: Manure storage units contain little oxygen, promoting production of the greenhouse gas (GHG) methane. Methane is estimated to be 86 times more powerful than CO_2 (over 20 years) in contributing to climate change. Recent research has shown that covering and flaring methane from most storage units would reduce GHG emissions by 62% at a cost of \$13 Mg CO_2e^{-1}, which is within the range currently paid in carbon markets (ACSESS, 2016).

Operation and Maintenance (O & M):
General recommendations/rules are presented in Table 1:
Table 1: Best practice measures for solid manure management according to Newell-Price et al. (2011)

Adopt batch storage of manure	Store 'fresh' solid manure in separate batches for at least 90 days before land spreading
Compost solid manure	turn the solid manure at least twice in the first seven days of composting to facilitate aeration and the development of high temperatures

Site solid manure field heaps away from watercourses/field drains	where solid manure is stored in a field heap it should not be sited within 10m of a watercourse or (effective) field drain
Store solid manure heaps on an impermeable base and collect leachate	Manure heaps are sited on an impermeable base, with leachate collection facilities.
Cover and protect solid manure stores from rain	Solid manure field heaps are covered (e.g. with heavy duty polythene sheeting) in a similar manner to a silage clamp.

	Cost: Handling manure has many costs connected with it, including equipment purchase and maintenance, the opportunity cost of the time it takes to apply manure to fields, and the liability if something goes wrong and there is a spill. Additional costs may be incurred where the land base is limited and additional land must be rented, or in situations where manure agreements must be established. The Eurostats provide thorough information on the manure storage statistics (https://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Agriculture_-_manure_storage_statistics). Manure value and economics is also explained by LPELC (2019b).
5.4.	**Injection slurry application and manure incorporation**
NPA Location Finland, Iceland, Northern Ireland, Republic of Ireland, Scotland	**Description & Purpose:** *Manure injection* is a specialized category of manure placement in which organic nutrient sources (including manures, biosolids, and composted materials) are mechanically applied into the root zone with surface soil closure at the time of application. Injection is expected to provide the greatest level of nutrient loss reduction to both atmospheric and surface runoff pathways (including both dissolved and sediment bound nutrients), as well as odor reduction, due to limited quantities of material left on the soil surface, limited soil disruption, and immediate soil closure. In the USA it is recommended that soil surface disturbance for injection plus planting and any other field operations should be less than 40% so that the practice is compatible with the Low Residue, Strip Till/No-Till practice (Chesapeake Bay Program CBP, 2016). *Manure incorporation* is defined as the mixing of dry, semi-dry, or liquid organic nutrient sources (including manures, biosolids, and compost) into the soil profile within a specified time period from application by a range of field operations (in the USA, the rules are ≤24hr for full ammonia loss reduction credit and 3 days for P reduction credit(s)).
	Nutrients Reduction (Effectiveness): Nutrient loss reductions are primarily due to lower ammonia-N volatilization and in some cases lower dissolved P and N losses in surface runoff. Nutrient loss reductions may vary with timing between application and soil mixing, degree of soil mixing, and percent soil surface disturbance. The EC (2018) reported NH_3 abatement efficiencies of up to 90% with closed-slot deep injection, and 70% for open slot shallow injection.
	Recycling/Recovery: None.
	Climate Change Mitigation: According to the EC (2018), pig slurry application on land increases the lifecycle acidification burden of barley production by over 320%. Slurry emissions are also responsible for a large share of soil GHG (N_2O) emissions and eutrophying (NH_3, NO_3 and P) emissions. There is no clear evidence to date on N_2O emission effects arising from injection application of slurries compared with broadcast application. Injection application and manure incorporation require more energy (diesel) than broadcast application. However, according to the EC report (2018) total diesel consumption for all operations contributes just 10% to farm system GHG emissions, compared with 28% for fertiliser manufacture and 58% for soil emissions.
	Operation and Maintenance (O & M): There are two ways to apply the slurry injection technique: i) open slot and ii) closed slot. The first one is applied for use in grassland, while the second one is applied either shallow (5-10 cm depth) or deep (15-20 cm). The EC report (2018) highlights that the use of the deep injection is rather limited due to the fact that mechanical damage may decrease the herbage yields on grassland. In addition, there is a considerable risk of N losses as N_2O and NO_3 in some circumstances. Other potential limitations include the soil depth, soil and clay content, moisture of soil. The EC (2018) recommendations for this particular practice are: • Shallow injection application of slurries • Incorporation of manures within one hour of spreading. In addition, it should be combined with field nutrient budgeting (2.1) and precision nutrient applications (2.3).
	Cost: The initial investment of injection equipment (tank and injector) is very high. In the USA the cost can exceed $100,000 US (Cornell University, 2019). The Cornell University Extension recommends the following factors to be considered when investing in equipment: (1) the size of and/or the number of animals in the operation, (2) the number of hours the equipment will be used in the field, and (3) the need for nurse trucks and draglines, including equipment, accessories, fuel, labor and operator costs (Cornell University, 2019). According to the EC (2013) injection applicators have slower work rate and higher tractor costs per unit of slurry spread. In addition, machinery, repair costs are higher for band spreaders, due to higher soil/machine contact and more moving parts (EC, 2013).
	Chemical Amendments
5.5.	**Treating Poultry Litter with Aluminum Sulfate (Alum)**
NPA Location	**Description & Purpose:** Aluminum sulfate can be added to poultry litter in a poultry house to reduce ammonia

Could be used throughout.	volatilization. It has been accepted as the best management practice in the USA (Moore, 2012). Lower ammonia levels result in heavier birds, better feed conversion and lower mortality. Alum additions to poultry litter can also precipitate phosphorus. This can aid in P reduction runoff from fields fertilized with poultry litter. Alum additions also reduce the number of pathogens in the litter.
	Nutrients Reduction (Effectiveness): Aluminum from alum reacts with P and forms an insoluble aluminum phosphate compound that is far less susceptible to runoff or leaching. The reduction in ammonia emissions is due to the acid produced when alum is added to the litter. Several studies in the US showed that Alum applications to poultry litter reduced P in runoff by 87% from small plots and by 75% from small watersheds (Moore and Edwards, 2007). Limited studies showed that Ammonia fluxes from alum-treated litter were 70% lower than normal litter (Moore et al., 2000). This results in a higher nitrogen content of the litter, which boosts crop yields.
	Recycling/Recovery: No
	Climate Change Mitigation: More research is needed. Current information is insufficient.
	Operation and Maintenance (O & M): According to Moore (2012), Alum should be applied to poultry litter at a rate equivalent to 5-1 0% by weight (alum/manure). For typical broiler operations growing six week old birds, this is equivalent to adding 0. 1 to 0. 2 lbs alum per bird or 1 -2 tons of alum per house per flock if 20, 000 birds are in each house. The reduction in ammonia emissions is due to the acid produced when alum is added to the litter.
	Cost: According to Moore (2012), this is a cost effective practice. His earlier research showed that the economic returns from this practice were $308 for the grower and $632 for the integrator (company), for a combined return of $940 (Moore et al., 2000).
5.6.	**Phosphorus Immobilizing Amendments to Soil**
NPA Location Finland, Northern Ireland, Republic of Ireland, Scotland	**Description & Purpose:** This practice is included in the cost869 list of practices (Table 1, http://www.cost869.alterra.nl/), however it is not included in the EC guide (2018). The practice has been developed during 1990s, along with the research on the use of industrial by-products and natural materials for P removal from wastewaters pioneered by several researchers in Europe (Drizo et al, 1997; Drizo et al, 1999; Johansson, 1997; Zhu et al, 1997) and Australia (Mann, 1997). Building on the concepts from traditional wastewater engineering they started investigations of various materials rich in Ca, Fe and Al oxides content. Drizo et al (1999) established several additional criteria for the materials selection which included a range of chemical and physical properties such as P retention capacity, hydraulic conductivity, cation exchange capacity, porosity and particle sizes. These investigations established the foundation for the new research field on the industrial and natural by-products use for phosphorus removal from wastewaters and runoff. During the past two decades over 250 industrial by-products and natural materials were investigated in laboratories around the world. Their performance has been described in over 2000 research papers (Drizo, 2019). With the growing recognition of P pollution as the principal trigger of eutrophication, and the need to reduce P loading from agriculture in the US, Chardon and Dorioz (2011) developed Phosphorus Immobilizing Amendments to Soil as one of the BMPs to reduce P. They provided mini review of the materials used and general definition for the practice as 'addition of a substrate that contains P sorbing compounds, with the aim of reducing the risk of dissolved P losses'. Mc Dowell et al (2008) and Drizo et al (2010) investigated the use of industrial by-products to mitigate P pollution from tile drained land. In New Zealand, McDowell et al (2008) suggested that backfilling tile drains with iron melter slag and a small proportion of basic slag could be effective means of decreasing P loss from high P soils. In the USA, Drizo and co-researchers investigated passive filter systems filled with steel slag aggregates for P reduction from agricultural tile drainage in several pilot projects in Vermont and OH (Drizo, 2012). Drizo also developed the very first conservation practice standard for P removal from surface and subsurface flows, known as the USDA Phosphorus Removal System #782 (1.5.1.).
	Nutrients Reduction (Effectiveness): Efficiency: Experience from Finland showed that Aluminum based substances Al $(SO)_4$, $Al(OH)_3$ and $AlCl_3$ with application rate 10 g Al/m^2 achieved 22-90 % reduction in total phosphorus (TP) in spring simulation. Moreover, Fly ash was as effective P-absorber (22 %) as Al $(OH)_3$.
	Recycling/Recovery: Potential for recycling/recovery will depend on the P retention capacity and the quantity of the material used.
	Climate Change Mitigation: None. However, if P sorbing material is vegetated, there could be potential for climate change mitigation. Needs to be investigated.
	Operation and Maintenance (O & M): According to Chardon and Dorioz (2011) no specific skills or technical equipment is needed, other than for application of solid materials like sludge. However, this needs to be revised as the use of basic farm equipment (e.g. backhoe loader) is absolutely necessary in order to place P sorbing material in the field. Also visual inspection of the material after strong rain events or snowmelt is necessary in order to determine potential clogging caused by suspended solids carried in precipitation and snowmelt events. According to the experience from Finland, P-absorbing materials can be applied on fields during autumn to prevent P-runoff on a springtime when frost and snow is melting.

	Cost: Cost will depend on the cost of material sued as well as transportation. In Europe transportation costs are usually in order of 30-40 euro/metric ton (WSSI, 2019).
5.6.1.	**Gypsum**
NPA Location Finland, Northern Ireland, Republic of Ireland, Scotland	**Description & Purpose:** Lime and Gypsum are just few of the materials which have been used as Source Measures to Decrease Phosphorus Loss from Soils to Water for several decades in the USA and other countries (Murphy and Stevens, 2010). Due to the high content of Ca oxides, steel slag aggregates (SSA) have been used as a soil amendment instead of lime for 100 years (New York Times, 1918; White, 1928). In the areas with gypsum production (e.g. USA Gypsum, Pennsylvania (PA), Finland, Ireland) the industry members showed interest to support research on the use of Gypsum to immobilize P from surface runoff. For example Dr. Ray Bryant, a soil scientist with the Agricultural Research Service (ARS) the USDA's chief intramural scientific research agency based in PA was awarded a large Research Grant to investigate potential use of Gypsum. He developed so called gypsum "curtains" (gypsum-filled ditches with the aim to adsorb soluble P from the runoff) and claimed that they could reduce P from the runoff by at least 50% and have a life span of about 10 years (Perry, 2010).
	Nutrients Reduction (Effectiveness): Uusitalo et al (2012) investigated the effects of gypsum on the transfer of P and other nutrients through clay soil monoliths in Finland. They applied gypsum ($CaSO_4$ X 2 H_2O) amendments to 100 m^2 plots within two clay-textured fields, one under shallow cultivation to 10 cm depth and the other ploughed to 20 cm depth. Over the three-year monitoring period, the results from this study showed that gypsum amended soils exhibited substantial decreases in turbidity (45%), PP (70%), DRP (50%) and DOC (35%) relative to control samples. Similar to other P sorbing materials (Drizo, 2002; Drizo, 2019), the ability of gypsum to retain P decreased with time and after 31 months gypsum lost its efficiency in reducing P. The authors concluded that gypsum amendments could have a potential for slowing P loss from agricultural areas.
	Recycling/Recovery: None. Grubb et al (2012) investigated Effect of Land Application of Phosphorus-Saturated Gypsum on Soil Phosphorus under controlled conditions (in a Laboratory Incubation) and showed that applied gypsum be a viable fertilizer source except at the highest P saturation level and application rate, which would be unlikely in agronomic settings.
	Climate Change Mitigation: None.
	Operation and Maintenance (O & M): Similar to any other P immobilizing soil amendment (e.g. 5.6.).
	Cost: Similar to any other P immobilizing soil amendment (e.g. 5.6.), will depend on the quantity of gypsum needed and local labour and transportation costs.
6. Natural Based Systems for Diffuse (Nonpoint) Pollution Sources	
6.1.	**Vegetative Buffer Strips (VBS)**
NPA Location Finland, Sweden, Northern Ireland, Republic of Ireland, Scotland	**Description & Purpose: Vegetative Buffer Strips (VBS), VBS,** also known as filter strips, buffer strips, and buffer zones, have been long accepted as the most common agricultural practice/mitigation measure for nutrient pollution prevention from diffuse/nonpoint pollution sources across the globe (e.g. Richardson et al, 2012; Habibiandehkordi et al, 2018; Drizo, 2019). Buffer Strips are currently mandatory under the Common Agricultural Policy.
	Nutrients Reduction (Effectiveness): highly variable, ranging from below zero up to almost 100%, depending on the number of factors such are width, vegetation (plant species used), nutrients considered, input load, climate, local hydrogeological conditions, and the time period after installation (e.g. Richardson et al, 2012; Georgakakos, 2018). Richardson et al (2012) reviewed history and performance of the fixed-width buffers concluded that despite billions of dollars in investment and 30 years of promotion and implementation on the agricultural lands worldwide there has been very little evidence in their efficiency, in particular in P reduction. In addition, given that P adsorption by soils is a finite process the ability of the VBS to reduce P pollution will diminish with time (Drizo, 2019).
	Recycling/Recovery: No[1]
	Climate Change Mitigation Potential: Has not been investigated. According to the Climate - Adapt (2015) the main potential benefits to climate change adaptation are related to the cooling of water body, increased air humidity and temperature stabilisation, and water retention.
	Operation and Maintenance (O & M): VBS should be inspected after heavy rains/runoff events and checked for debris/litter and sediment accumulation. Depending on the vegetation, harvesting is also required to avoid a build-up of P in the soil.
	Cost: Implementation requires: 1) Investments in term of seeds, plants, soil excavation equipment and labour for construction and planting. 2) Assistance of an extension expert to adapt the design to local conditions of soils, etc. There is not enough information on the costs of implementation and maintenance. It will depend on the location, soil type, difficulty of excavation, type of vegetation used, among other factors. According to data from the US, the implementation costs range from 32-74,000 $/hectare of filter strip. Typical maintenance cost reported for US are 865$/hectare/year. However, this cost is highly variable and depends on the frequency of maintenance needs and

	local costs of labour.
6.2.	**Constructed Wetlands**
NPA Location Finland, Sweeden, Northern Ireland, Republic of Ireland, Scotland	**Definition & Purpose:** Constructed Wetlands (CW) are engineered, man-made wetlands used to remediate waste water or surface water. The principal pollutant removal mechanisms are physical (filtration, sedimentation within the wetland substrate), biological (uptake by vegetation and microorganisms) and chemical (adsorption/precipitation /complexation within the wetland substrate). They have been used extensively and around the world, and in the variety of climates for both point (agricultural effluents) and nonpoint (surface and subsurface runoff) mitigation (e.g. Kadlec and Walace, 2009; Vymazal, 2010; Rozema et al, 2016).
	Nutrients Reduction (Effectiveness): CW's performance in removing P from agricultural sources has been poor regardless from the complexity of design used, especially in cold climates (e.g. Hunt and Poach, 2001; Drizo et al, 2008; Vymazal, 2010; Adera et al, 2018; Drizo, 2019). Knight et al (2000) compiled the Livestock Wastewater Treatment Database for North America containing treatment performance of 38 CW systems. They reported that average TP performance averaged for all livestock management CWs (including cattle feeding, dairy, poultry and swine) was only 42%. Moreover, there is a potential for CWs to become a source of nutrient over time if not managed correctly. Kadlec (2016) recently reviewed large CW for P control which included 66 systems with a median size of 210 ha (2 100 000 m^2). He pointed out that although these very large CW achieved 71% P reduction in average, thanks to at a low median hydraulic loading of only 2.55 cm/day, the amount of P stored has been low, with a median of just 0.77 g P m^{-2} $year^{-1}$. Nitrogen removal can be enhanced by using artificial aeration (Jamieson et al, 2003; Drizo et. al, 2008; Rozema et al, 2016). A review of CWs from Finland showed that the CWs treatment efficiency is highly dependent on the wetland's relative size compared to the upstream catchment area, and on the amount of agricultural land in the upstream catchment (Berninger et al, 2012).
	Recycling/Recovery: No[1]
	Climate Change Mitigation Potential: Current research is limited and non-conclusive. Although wetlands have traditionally been viewed as major carbon sinks due to their dense vegetation, significant quantities of greenhouse gases, in particular CH_4, are released from wetlands due to the processes involved in removing pollutants from the water. Kayranli et al (2009) provided a thorough overview of CH_4 fluxes from different types of wetlands. Twohig (2012) evaluated methane emissions from dairy treatment CW in a cold climate and showed that when treatment of high strength effluents typical of agricultural operations via CW results in the production of the potent greenhouse gas methane (CH4), thus potentially compromising air quality. Methane is released from wetlands via three pathways provided by primary productivity to reach the atmosphere: diffusion through the soil or water profile, plant mediated (aerenchyma), and ebullition when concentrations of CH4 exceed saturation levels (Twohig, 2012).
	Operation and Maintenance (O & M): Operational costs include water quality testing, water level adjustment needs, weed control, flow distribution and level adjustment sumps. O & M costs can range from 400 € per year for surface flow systems to 2,000 € per year for subsurface flow systems.
	Cost of Implementation: The capital costs of CW depend on a variety of factors including detention time, treatment goals, depth of media, type of pre-treatment, distance from the gravel media source. Generally the costs include land, excavation, liners, gravel (subsurface flow systems), plants, distribution and control structures and fencing. In general, the median cost of surface and subsurface flow wetlands is 41,900 € per hectare and 340,000 € per hectare, respectively (SERA, 2019).

[1] None of the current practices provide nutrients recycling/recovery. HOWEVER, they can be retrofitted with P adsorbing materials to provide P recycling/recovery.

Nutrient Recycling/Recovery from Good Agricultural Practices

P Recovery Methods

Drizo (2019) recently reviewed P recycling/recovery technologies from manure and found that unlike at municipal wastewater treatment plants (MWWTPs), the number of technologies/products applied on farms at the full scale are very limited. She suggested that one of the reasons may be in the challenges associated with the high content of organic compounds present both in manure and anaerobic digester effluents (e.g., Desmidt et al., 2015; Tarayre et al., 2016). However that the principal reason is probably in the fact that similar to P removal technologies, the costs of the P recovery process installation and operation on farms cannot be recovered via same mechanisms used for MWWTP's upgrades and installations, e.g., through water tariffs, or a mix of tariffs, transfers, and taxes, because such funding mechanism does not exist for agricultural wastewater treatment. Therefore, it is much harder to sell and/or ensure return on investment if attempting to promote and offer P and/or N recovery technologies in this market, as funding sources would have to come directly from farmers, e.g. private sources. Moreover, as the cost of nutrients recovered from manure is much higher compared to the mineral fertilizer, there are no economic incentives for farmers to invest in recovery processes and technologies on their livestock operations. This situation creates a considerable gap in research and development of novel processes and technologies to achieve more cost-effective nutrient recovery from manure.

Nitrogen Recovery Methods

N Recovery From Air

Szogi et al (2015) described three main approaches to recover NH_3 from air in livestock operations: (1) treating the NH_3 in the exhaust air from the houses using scrubbing or filtration techniques (Ngdewa et al, 2008); 2) to selectively pull and treat the air near the source, using dedicated ventilation systems or systems that are independent of the house ventilation system (Lahav et al, 2008); and (3) the passive use of gas-permeable membrane modules inside the houses (Szogi et al, 2014). The scrubbing methods consist of removal of NH_3 from livestock houses by forcing the house air through an NH_3 trap, such as an acidic solution (scrubbers), or through a porous filter with nitrifying biofilms that oxidize NH3 to nitrate (bio-trickling or organic filters) (Ngdewa et al, 2008). The use of acid scrubber is promising, as it simultaneously mitigates and recovers NH3 emission to form a salt with value as fertilizer. Several novel scrubbers have been reviewed by Szogi et al (2015).

Cost of Implementation

The social aspect of the costs and benefits related to wastewater treatment involves the overlapping generation decision making. Any wastewater treatment system needs time to prove the effectiveness (based on the given sources of information, we use 20-year and 5% social discount rate to assess the value of the treatment systems). There might be one single solution to reduce the N and P runoff once, and every system has a tradeoff benchmark. More often, many decisions of choosing a specific treatment system are based on political orientations, preferences/constraints of funding, and dealing with short term solutions. For any generation, the best practice should be a combination of sustainable treatments that will impose the least costs to yield the highest efficiency of the treatments.

Table 5: Innovative Agricultural Management Practices Tested in the NPA Region

Partners	Pilot Sites	Purpose
Savonia UAS, FIN	Natural Resources Institute Finland, Maaninka	Prevention of P-runoff from grass fields via P binders Testing
Agricultural University of Iceland	Möðruvellir farm	Primary: Design and construct monitoring site for measurements of deep drainage and surface runoff from agricultural fields, operating all year around in arctic conditions, on low budget and minimum attendance. Secondary: to compare effects of different management regimes on N and P losses.
Agricultural Agency, FO	Kollafjörður farm	Nutrients reduction from slurry runoff
Agri-Food and Biosciences Institute, NIR	Hillsborough	A previously constructed trial site has been rejuvenated, modified and prepared to investigate whether the use of SRC willow

		in the agricultural environment can mitigate, and if so to what extent, the ingress of polluting runoffs into the water environment. The experimental Platform consists of six hydrologically isolated plots (each 0.2 ha) with flow proportional monitoring of land drainage water at v-notch weirs. Two different treatments (willows and grass) have been trailed in triplicate.
Lough Neagh Partnership, NIR	South Lough Neagh	Ecosystems services in South Lough Neagh area to examine social, economic and biodiversity benefits of wetland sites.
Heriot Watt University, SCO	Lyell Centre Laboratory, HWU	Phosphorus reduction from agricultural effluents

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APPENDIX 1

Table 1. Good Agricultural Practices Recommended in Iceland

Good management practices ICELAND					
Based on ICELAND GMP-“Starfsreglur um góða búskaparhætti”					
Icelandic	English	**Good Management Practice for nutrients reduction, recycling and recovery**			GMP ref
Hlutverk og ábyrgð bænda og annarra sem vinna við landbúnað	General recommendations on role and responsibility of farmers				**2**
		It is necessary for every farmer to have good overview on what can cause water pollution on their farm			
		In order to prevent pollution, farmers need solid knowledge on substances and processes that can cause pollution.			
		Every on the farm that handle, store, use, spread or discharge materials or substances should be well informed on pollution risk from those items.			
		Check regularly for leakage all container, storages for e.g. oil manure, silage.			
		Ensure that all affluent pipes and closures on the farm are known and mapped.			
Uppsprettur mengunar	Main N and P pollutants in Agriculture	As defined by GMP			**3**
		Manure			
		Synthetic fertilizers			
		silage liquid			
		airborne soil (fokmold)			
Uppspretta mengunar	**Pollution source**	Method/structure			
Dreifður uppruni	**<u>Diffuse sources</u>**				
<u>Útskolun áburðar</u>	N and P leakage from fields				
	2.1. Field Nutrient Budgeting **5. Manure**	Proper timing of manure spreading, Apply recommended amounts [1)] Spread during growing season			

	Management **5.3. Appropriate solid manure storage**	Don´t spread on frozen soil Keep save distance from water pathways Avoid spraying manure in strong sunshine or warm weather.			
Aðstæður sem geta leitt til mengunar	**3. Soil Preparation and Crop Planning**	Avoid situation that can lead to pollution			
Graslendi plægt og notað til akuryrkju	**3. Soil Preparation and Crop Planning**	Leakage connected to ploughing of grassland soil.			
	3.2. Establish cover/catch crops	Don't leave open during Wintertime- (use catch crop)			
Ofbeit	**4. Animal Husbandry**	Overgrazing increase risk of nutrient leaches			
	4. Animal Husbandry	Avoid overgrazing -reduce grazing intensity - especially in the autumn			
Of þéttur jarðvegur	**1.Soil Quality Management** **1.1. Soil Quality Assessment**	Too compacted soil reduces plant uptake of nitrogen			
	1.Soil Quality Management **1.1. Soil Quality Assessment**	Avoid compaction			
Stakar uppsprettur	**Point sources**				
Hauggeymslur	**5. Manure Management**				6.2
	5.2. Appropriate slurry processing and storage systems	Storages should be large enough for maximum manure stock			6.2.1
		Table for expected amount of manure per/head livestock included in GMP			6.2.1
		All manure storages should be designed according to valid regulations			6.2.2
		Location and design of manure storages should be such that it can be easily accessed for emptying			6.2.2
		Manure storages should be located in save distance from surface water			6.2.2
Fljótandi búfjáráburður	Liquid manure storages				6.2.3
	5.2. Appropriate slurry processing and storage systems	All liquid manure should be in storages specially designed for that purpose			
		Storages for liquid manure should have a minimum distance 10 m from any water bodies.			
		The floor of the storage should be impermeable (waterproof)			
		Floor and walls should be protected against corrosion			
		Storages should be designed such that it is easily emptied			
		Designed in accordance with regulations on buildings			
Þurr búfjáráburður	5.3. Appropriate solid manure storage				
		Storages designed especially for solid manure are recommended			
		Effluents from solid manure should be treated as liquid manure			
		If solid manure is stored temporary outdoors it should be ensured that effluents don't pollute water			
		Solid manure should not be stored outdoor closer to water or drainages structures than 10 m			
Leiðbeiningar við	**Manure spreading**				

dreifingu á búfjáráburði	**/discarding**			
	2.1. Field Nutrient Budgeting	Most beneficiary and environmentally friendly way of discarding manure is to use it as fertilizer on cultivated land (hayfields in case of Iceland)		
		Spreading should aim at maximum utilization of nutrients for the plants involved		
		Avoid contamination of rivers and lakes		
		Dumping manure directly to lakes, rivers or drainage ditches is prohibited		
		Define zones where manure spreading should not be practised (This is recommendation to municipal environmental committees)		
		Define zones sensitive to manure spreading needs special precautions. (This is recommendation to municipal environmental committees)		
		Avoid spreading to the edge of lakes and rivers		
	Recommendations and restrictions			6.3
		Spread manure during growing season and preferably, when plants uptake is most active. Autumn spreading on unfrozen soil is also acceptable		
		Avoid spreading on hydrologically saturated soil		
		Avoid spreading on frozen soil specially in sloping landscape		
		Do not spread on known flooding areas		
		Where soil compaction is high do not spread close to surface water		
		Avoid spraying close to surface water especially in sloping areas or if soil is water-saturated		
		Avoid spraying on areas with thin soil (<30 cm) with fissures in the bedrock		
		Avoid spreading on fields mole ploughed within a year and not if soil is collapsed into old mole plough cavities		
Heppilegt áburðarmagn til dreifingar á mismunandi land	Recommended quantities			6.4
Almenn atriði	2.Nutrient Management	General		6.4.1
		The need for fertilizers should be estimated, considering soil type, plants grown and growing conditions on that field		
		Do not exceed 170 kg N ha^{-1}		
Notkun á tún		Table of recommended quantities of manure from different livestock to apply on hayfields, is included	On hayfields	6.4.2
		Recommended quantities for some manure types exceed estimated P needs up to (300 % of what needed)		
Notkun á ógróið land		Manure on un-vegetated land		6.4.3
		Strongly recommended against putting piles of manure on un-vegetated land without spreading properly		
		Mix seeds into the manure before spreading		
Tilbúinn áburður	**Chemical amendments 5.5. – 5.7**	**Synthetic fertilizers**		7
Almennt	General	Estimate the need for nutrients and take into account manure applied		7.1
Geymsla	Storing	Don't store close to water		7.2

Notkun	fertilizing	Keep safety zone of 5-10 m on banks of rivers and lakes, considering types of spreaders used		7.3
Fráveituvatn	**Effluents**			
Frá mjólkurhúsum	From milk houses			9.3
		Do not connect to septic tanks as it contains detergents and sterilizers that may inhibit septic tank processes.		
		Connect effluents directly to drainage pipes where the effluents sip directly into soil.		
Frá votheysgeymslum	Silage storages			9.7
		Connect effluents to corrosion resistant drainage pipe sipping into the soil		

Table 2: Good Agricultural Practices Recommended in Finland

Phosphorus Pollution Source	Good Agricultural Practice	Purpose, e.g. P, N or both nutrients reduction	Field study or mathematical model?	Period of investigation (months/years)	Effectiveness achieved (%)	Reference**
Silage Leachate	Recovery of leachate	P, N				
	Storage of leachate in watertight containers	P, N				
	Use of pre-dried fodder	P, N			Leachate doesn't form when dry content > 29 - 30%	Mikkola et al., 2002 Puumala & Grönroos, 2004
Barnyards and Feed Bunks	Zoning of farmland and minimum distances to water systems					
	Solid foundations (e.g. concrete)					
	Roofed feed bunks					
	Solid and dry (underdrained) ground for passages between shed and grazing lands					
	Decrease of raw protein content in silage	N, P	M			Puumala & Grönroos, 2004
	Decrease of concentrated feed portions and its protein content	N, P	M		Nitrogen utilization increases with lower protein content. For example, a decrease of 2 percentage points in concentrate protein content could increase the nitrogen utilisation by 1 – 2 percentage points. A decrease in nitrogen utilisation results in greater nitrogen content in manure	Puumala & Grönroos, 2004
	Avoiding overfeeding	P, N	M		A decrease of 8.2 g	Yrjänen et al., 2003

					of P intake could reduce the P content in feces by 5.4 g/d	
	Feeding according to animal needs	P				
	Reduction of mineral phosphorus and phosphorus in concentrated feed	P	M			Puumala & Grönroos, 2004
Manure runoff	Ploughing manure into the soil right after distribution	N				
	Dribble bars or trailing shoes for slurry application	N	F	4 years	48% P, 40% N	Puumala & Grönroos, 2004
	Manure application in spring or during growing season in cool, humid, and calmed weather					
	Manure application (forbidden between 15.10 – 15.4) only when snow has melted and ground is no longer frozen or flooded					
	Lower number of animals per hectare to ensure manure absorption					
	Avoiding manure application in areas close to surface water, wells, and main drains as well as in groundwater areas					
	Calculation of nutrient balance					
	Making a manure application plan					
	Manure containers should be impermeable					
	Manure containers should be large enough to store the manure produced in 12 months					
	Tall and narrow manure containers (less area) reduce emissions	N (NH_3)				
	Roofing/covering of manure containers	N (NH_3)			65 – 95%	Puumala & Grönroos, 2004 (1997)
	Removing manure frequently from flooring	N (NH_3)				
	Cooling of manure ducts	N (NH_3)				
	Aeration					
	Separation and fractionation					
	Composting					
	Anaerobic treatment					
Surface and	Solid foundations (e.g.					

subsurface runoff	concrete)					
	Keeping grazing lands covered with plants during winter					
	Restoration and re-creation of wetlands	P, N, TSS	F	1-2 years	30-70 % P, 35 % N	Koskiaho, 2006
	Planting perennial grasses					
	Planting trees and bushes between and around fields					
	Permanent grass buffer zone					
	Calculation of nutrient balance					
	Sedimentation ponds for phosphorus seepage					
	Ploughing manure into the soil right after distribution					
	Dribble bars or trailing shoes for slurry application		F	4 years	48% P, 40% N	Puumala & Grönroos, 2004
Agricultural Tile Drainage	Controlled drainage	N	M	3.5 years	3-13 % N,	Paasonen-Kivekäs et al., 2000
	Underground watering	P, N				
	Runoff recycling	P, N				
Milk Parlor effluents	Storage in manure tanks					
	Sedimentation basin + leach fields	P, N				
	Sedimentation basin + sand filter	P, N	F	1 year >1 year	90 % P; 52 % N 38-88% P; 34-72% N	Kallio & Santala, 2002 Tuhkanen et al., 2005
	Small sewage treatment package plant	P, N	F	 >1 year	95 % P; 75-80 % N 71-97% P; 39-88% N	Kallio & Santala, 2002 Tuhkanen et al., 2005
	Municipal wastewater treatment plant: sewer network	P, N				
	Municipal wastewater treatment plant: cess pool	P, N				
	(Sedimentation basin to ditch)					
	Re-usage of water used for cleaning					
	Usage of cleaning agents with low P	P			90%	Kallio & Santala, 2002
Milk processing effluents						
Cheese processing effluents						
Pig manure	Addition of enzymes in feed, especially phytase enzymes	P			15%	Puumala & Grönroos, 2004
	Feeding monocalcium phosphate instead of dicalcium phosphate	P				
	Liquid feeding	P, N				
	Feeding according to sex and production	P, N			5 – 10 %	Karhapää et al. 2014

	stage (phase feeding)					
	Lower fodder protein and aminoacid equilibrium	N			20%	Puumala & Grönroos, 2004
	Ploughing manure into the soil right after distribution	N				
	Dribble bars or trailing shoes for slurry application	N	F	4 years	48% P, 40% N	Puumala & Grönroos, 2004
	Different piggery floor constructions, with smaller area and more frequent cleaning	N (NH_3)			20 – 75% NH_3	Puumala & Grönroos, 2004
Poultry farms	Addition of aminoacids and enzymes in feed, especially phytase	P, N				
	Feeding monocalcium phosphate instead of dicalcium phosphate	P				
	Feeding according to production stage	P, N				

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Table 3: Good Agricultural Practices Recommended in Northern Ireland

Pollution Source	Good Mgmt Practice for nutrients reduction, recycling and recovery (N3R)		
		Reduction	Recycling/recovery
Diffuse Agric. Pollution	Cover crops	Y	N
	Buffer strips Buffer strips are not mandatory in NI, except in the context of a setback distance from watercourse when spreading manures/fertiliser 20 m form lake shores 10 m from other waterways but may be reduced to 3m it slope is less 10%, or lower emission spreading methods are used. Buffer strips are a voluntary measure implemented through the environmental farming scheme.	Y	N
	Constructed wetlands Wetland are not covered under the CGP in NI, but is mentioned in the Annex. It states that farmers require a discharge consent from the NI Environment Agency if farmer are voluntarily using wetlands to threat dirty water.	Y	N
	Biobeds Biobeds are not mandatory under the CGP but are given as an options for managing the risk posed by pesticides. Farmers require a Waste Management Exemption to use this practice	Y	N
	Trenches Not covered under the CGP	Y	N
	Infiltration Systems Systems such as woodchip corrals, standoff pads and swales not mandatory but are as option in the annex of the CGP, under strict guidelines provide by the NI Environment Agency	Y	N
	Ponds Not covered under the CGP	Y	N
Collection, Storage and Application to Land of Livestock, Slurries & Manures	Slurry must be collected in tanks with a minimum storage capacity of 22 weeks to cover the closed period from Oct 15 to January 30th plus 4 weeks buffer. FYM must be stored un purpose build impermeable stores with liquid seepage from the heaps stored and threated as slurry. Six months storage of seepage from FYM must be available. FYM may also be stored in heaps in the field it will be spread for up to 180 days. (other restriction apply)	Minimise	Y

	Farmer much develop and implement a slurry/manure application plan based on the CGP guidelines.	Y	Y
	Advised but not compulsory to incorporate livestock manures/slurry as quickly as possible after spreading.	N	N
	Spreading rules and bans, e.g. closed period for slurry spreading between Oct 15-Jan 30, do not spread livestock slurries: within 10 m from watercourse, 20m from lake shores and 50 m from drinking water, on slurry application on frozen, waterlogged or steeply sloping ground Minimum standard of construction and maintenance apply to all storage facilities.	N	N
Livestock Yards[2]	Separate clean water from roofs from slurry collection systems and minimise the dirty yard area The dirty yard area should be minimised Runoff from livestock walkways must be management under as pollutant, and direct discharge to water is prohibited	Minimize	N
Parlors and dairies[2]	The drainage from parlour standings and the parlour pit must be collected and contained.	Minimize	N
	Milk is a highly polluting substance and should never enter a watercourse. Waste milk should mixed with slurry before disposing of to agricultural land. Dairy washings should be collected and stored in suitable stores. An exemption under the Waste Management regulation must be obtained before applying milk on it own to land and it must be diluted at ratio of 1:1 with water	Minimize	N
Feed storage and preparation areas[2]	Drainage from feed areas is likely to be highly polluted and must not be discharged to a watercourse.	Minimize	N
Silage Effluent[2]	Minimum standards apply to the siting, design and maintenance of silos Ensure that effluent tanks, channels, silo floors, walls and wall floor joints are inspected annually and any necessary repairs carried out well in advance of the start of silage making.	Minimize	N
	It is prohibited to make silage in freestanding field heaps without an impermeable base and an effluent containment system.	Minimize	N
	Baled silage maybe stored in field at distances of 10 m from a watercources. Where baled silage is stored on concrete any runoff should be captured and stored.	Minimize	N
Silos	Although roofed silos require less management during and after filling, it is essential that frequent checks be made to ensure that the drainage system is free running and that the effluent tank does not overflow.	Minimize	N
Land application and utilisation of livestock manures and slurries	Livestock manures and slurries are a valuable asset and should be applied to agricultural land in accordance with the principles set out in this section. The surface application rate should never exceed 50m3/ha (4500 gallons/acre) although normal application rates should seldom exceed 30m3/ha (2,700 gallons/acre) and any repeat application should not be made within 3 weeks. All applications should take into account the soil conditions and the amount of rain forecast so as to minimise the risk of run off and entry to a field drainage system.	Minimize	N
Soil Protection and Stability	Soil erosion due to livestock - Rivers must be fenced off, if possible alternative watering points provided - Supplementary feed point should be 10m from waterway and minimum of 50 m from a borehole	Minimize	N
	Soil erosion following harvesting. After harvesting and until march 1st either -stubble from harvested crops remains on the land -crop grow grown - or land is left with a rough surface to encourage infiltration	Minimize	N

	Soil Compaction - Trafficability of the soil must be consider before use of equipment or grazing - Compacted soil should be repaired either by ploughing or subsoilling	Minimize	N
Nitrate leaching reduction measures	Northern Ireland has taken a whole territory approach to designation of NVZ - Closed period for slurry spreading from 15th of Oct to 31th of Jan - Closed periods for fertiliser from 15th Sept to 31st Jan - Limit of 170kg Organic N /ha unless under a derogation up to 250 kg N/ha - P an N applications as per RB209 except for soil P index 2 which in NI has been split into P Index 2- and P Index 2+, with the agronomic optimum at 2+ (20-25mg/l Olsen P)	Minimize	N
Sheep Dip	Authorisation to dispose of sheep dip to land must be obtained from the NI Environment Agency	Minimize	N
	In addition farmers must -meet the conditions of a Groundwater Authorisation; • produce, on request, satisfactory written records that indicate that no breach of the legislation has occurred; -ensure the proper siting, operation and maintenance of a sheep dipper; - ensure that there is no evidence of the pollution of groundwater and/or surface water by pesticides, sheep or oil; and -comply with any Notice served by NIEA under the Groundwater Regulations (Northern Ireland) 1998.	Minimize	N
Disposal of Animal caracasses	Disposal to a renderer or incineration plant Local Animal Health Office should be consulted as to renderers or incinerators in the area that are suitable for carcass disposal.	Minimize	N
	On-farm disposal is prohibited. Cacasses must be disposed of via -the national fallen stock scheme -Rendering plant -etc	Minimize	N

Table 4: Good Agricultural Practices Recommended in the Republic of Ireland

Good management practices Ireland N and P pollution reduction					
Based on Irelands Good Agricultural practice for the Protection of waters regulations 2014					
Good Management Practice for nutrients reduction, recycling and recovery					S.I. No. 31/2012 ref
Farmyard Management	Guidelines				**2**
		It is necessary for every farmer to have good overview on what can cause water pollution on their farm			
		In order to prevent pollution, farmers need solid knowledge on substances and processes that can cause pollution. (see Handbook Guidelines)			
		Everything on the farm that handles, stores, uses, spreads or discharges materials or substances should be well informed on pollution risk from those items.			
		Clean water from roofs and unsoiled paved areas should be diverted away from soiled yard areas and prevented from entering soiled storage facilities such as livestock manures, and other organic fertilisers etc.			
		Rain water gutters and down pipes essential for clean water management as stated above, should be well maintained and in good working condition.			
	Soiled water	Check regularly for leakage all containers, storages for e.g. oil manure, silage.			
		Ensure that all effluent pipes and closures on the farm are known and mapped.			
Nutrient Management	Main N and P pollutants in Agriculture	As defined by GMP			**3**
		Manure			
		Chemical fertilizers			
		silage liquid/slurry			
		Sewage Sludge			
		Spent mushroom compost			
Pollution source **<u>Diffuse sources</u>**					
N and P Runoff from fields	General	Incorrect position of Supplementary feeding points.			4
		Incorrect storage of silage bales.			
		Proper timing of the year for specific zones, manure spreading.			
		Incorrect storage of manure prior to landspreading.			

		Apply recommended amounts which do not exceed in a 42 day period, excess of 50m³ per hectare.			
		Keep safe distance from surface waters, boreholes, springs or wells			
Situation that can lead to pollution	General				4
		Waterlogged, flooded, or likely to flood.			
		Don´t spread on frozen soil			
		Avoid spraying manure in heavy rainfall, or warm weather.			
		The use of a tanker with upward facing splash plate.			
	Ploughing	Ploughing to be done within recommended time periods. (When using non selective herbicides).			
Pollution source **<u>Point sources</u>**					
Manure storages	General				2
		Storages should be large enough for maximum manure stock taking into consideration adverse weather conditions.			
		Table for expected amount of manure per/head livestock included in S.I. 31 2014			
		All manure storages should be designed according to valid regulations with relation to type of livestock, rainfall criteria.			
		Location and design of manure storages should be such that it can be easily accessed for emptying.			
		Manure storages should be located in save distance from surface water			
		Storage periods for livestock manure vary, Donegal 20 weeks.			
Manure spreading /discarding					
	General	Most beneficiary and environmentally friendly way of discarding manure is to use it as fertilizer on cultivated lands.			4
		Spreading should aim at maximum utilization of nutrients for the plants involved			
		Avoid contamination of rivers and lakes			
		Dumping manure directly to lakes, rivers or drainage ditches is prohibited			
		Avoid spreading to the edge of lakes and rivers			
	Recommendations and restrictions				4
		Keep safe distance from surface waters, boreholes, springs or wells as distances are specified in S.I. 31 2014			
		Avoid spreading within 15 meters of exposed cavernous or Karstified limestone features.			
		Avoid spreading on waterlogged, flooded or likely to flood saturated soils.			
		Avoid spreading on frozen soil specially in sloping landscape.			
		Avoid spreading if heavy rain is forecasted within 48 hours (have regard for weather forecast issued by Met Eireann).			

	Recommended quantities			
		The need for fertilizers should be estimated, considering soil type, live stock, plants grown and growing conditions on that field. Refer to handbook help sheets.		Refer to Handbook Help sheets
		Do not exceed 170 kg N / ha		
	For example: Maximum fertilization rates on Potatoes crops	Nitrogen- 170kg/ha Phosphorus- 125kg/ha Refer to S.I 31 2014 Schedule 4		Schedule 4
		Strongly recommended against putting piles of manure on un-vegetated land without spreading properly		
Synthetic fertilizers				
	Chemical	Estimate the need for nutrients and take into account manure applied		3
	Storing	Don't store close to water		
	fertilizing	Keep safety zone of 5-10 m on banks of rivers, lakes, boreholes, springs and wells, considering types of spreaders used		
Effluents				
	Unsoiled water	Clean water from roofs and unsoiled paved areas should be diverted away from soiled yard areas and prevented from entering soiled storage facilities such as livestock manures, and other organic fertilisers etc.		2
	Silage storages			
		Connect effluents to corrosion resistant drainage pipe sipping into the soil		

5. Good Agricultural Practices Recommended in Faroe Islands

Regulation regarding fertilizing with slurry in order to avoid runoff. Kunngerð um taðing 2012.
https://logir.fo/Kunngerd/72-fra-29-05-2012-fra-tading
Bellow is a summary of this regulation:

- ✓ Time frame for spraying slurry is 15th March – 15th Oct.
- ✓ No spraying on Sundays and Holy Days
- ✓ Stay at least 50 meters from drinking water sources or supplies
- ✓ Avoid runoff into streams, rivers, lakes, beaches or sea
- ✓ No spraying when raining
- ✓ No spraying when frost or snow
- ✓ No spraying above 250 meters a.s.l.
- ✓ Stay at least 50 meters from living houses
- ✓ Only spraying when wind is heading from living houses
- ✓ No spraying on rocks or stone fences
- ✓ Slurry stores capasity at least for 6 months
- ✓ Slurry stores shall be water tight tanks and equipped with roof
- ✓ Farmers shall have access to at least 0.4 hectares per animal unit
- ✓ A smaller area can be accepted in case of lack of nutrients in the soil