Mechanical Separation of Slurry or Digestate

This technology involves the separation of animal slurry into liquid and solid fractions, that need to be stored and managed separately. Slurry separation is currently not common practice in Northern Ireland (NI), despite having previously been investigated and demonstrated on the CAFRE Estate and through previous research, (AFBI Separator Report 2007) and ongoing research at AFBI, Hillsborough (Lyons et. al., 2021).

There are many different separator systems, ranging from sedimentation lagoons, weeping walls, brushed screen, belt press, screw press and decanting centrifuge. (When the AFBI Global Research Unit was in operation they produced a report on manure treatment systems, (Forbes et. al., 2005) that included a large section on slurry separation, including all the main methods of separation as outlined above. This report will focus on mechanical separation and specifically the screw press and the decanting centrifuge.

As far as N Ireland is concerned, particularly considering the problem of surplus phosphorous on many intensive livestock farms and the issue of algal blooms, it is probable that the screw press and/or decanting centrifuge are the only separation technologies that are likely to gain traction and be able to separate enough phosphorous into the solid fraction to make a difference at individual farm level.

The screw press and decanting centrifuge have a large volume of peer reviewed literature on their use and ability to achieve greater solids amount and concentration of nutrients in the solid fraction and therefore improved P removal efficiencies compared to other lower tech separators. The Agri Food and Biosciences Institute (AFBI) are investigating the application of both these separators within the NI agricultural sector to remove excess P from farms and what this surplus P might be used for.

The screw press separates by particle size, (depends on the mesh size), whilst the centrifuge separates by particle density. Both systems have several variables that can alter separation efficiency. With the screw press the screen size can be altered, the flow rate and the pressure on the solid discharge to change the separation efficiency/dry matter content of the solid fraction. Output decreases as mesh size decreases, but dry matter of solids and partitioning to solid fraction increases. Moller et. al., (2002) found that the screw press could produce a solid fraction with a dry matter content of 25-30%, but a large quantity of small particles ended up in the liquid fraction, (depending on mesh size), leading to a low separation efficiency for N, P and K. With the decanting centrifuge the number of permutations that can be adjusted is almost endless, depending on the desired goal of separation.

Potential benefits of slurry separation

1) Reduction in the volume of liquid requiring storage.
2) Potential to export separated solids and its nutrients, especially phosphorous to soils with a requirement for phosphorous and/or for further processing.
3) Improved efficiency of nitrogen uptake from liquid fraction applied to grassland or arable crops.
4) Less sward contamination (silage and grazing) from application of separated liquid
5) Reduced need for agitation prior to spreading.

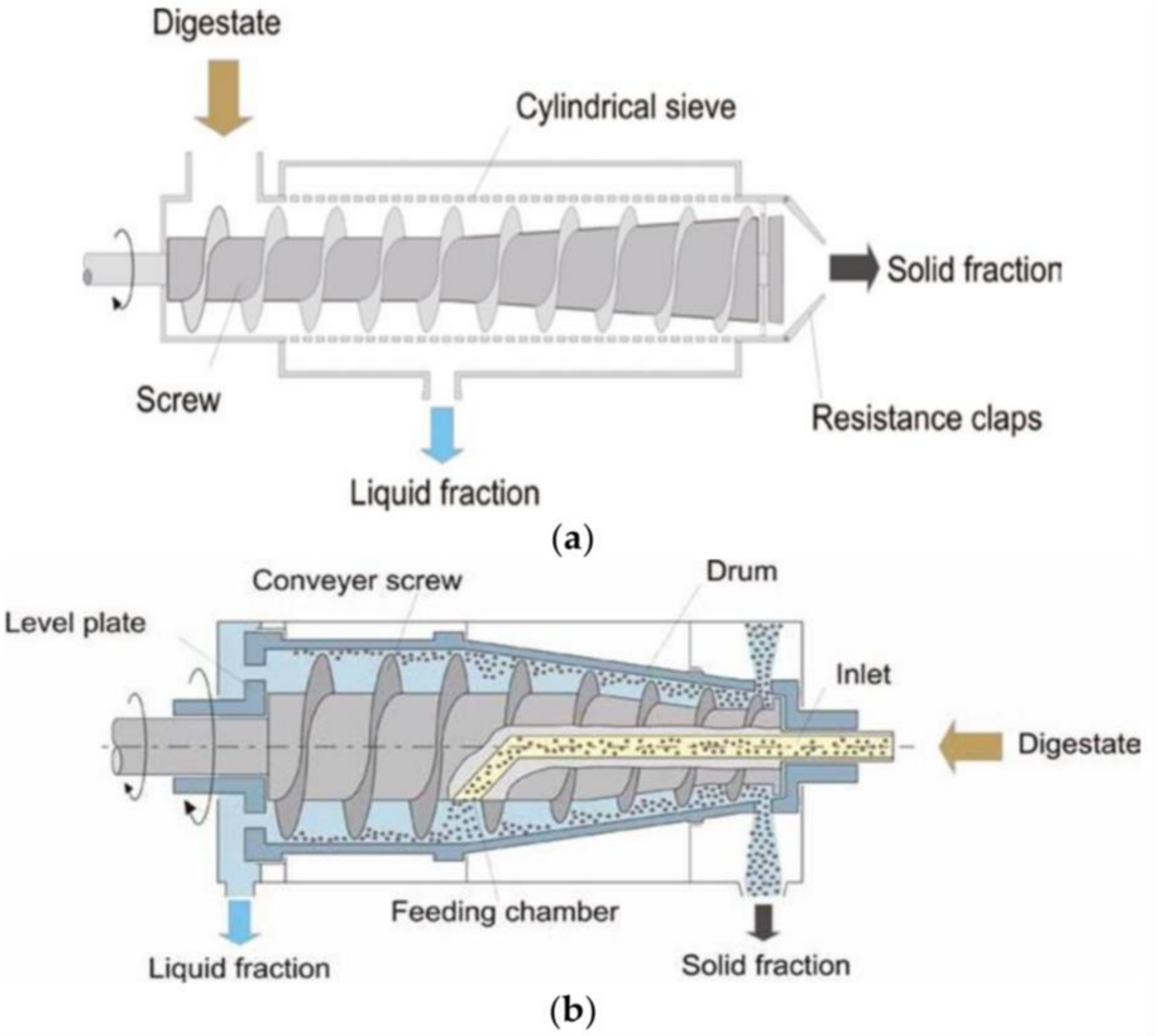


Figure 1: Diagrams with digestate as a feedstock of (a) a screw press separator and (b) a decanting centrifuge separator, showing feedstock input, mode of action, separation chamber, and solid and liquid fraction outlets.

Facilitating the use of Low Emission Slurry Spreading Equipment

The liquid fraction has a lower volume and dry matter concentration than untreated raw slurry (if no additives are used). The benefits of the separated liquid have been documented and investigated previously by CAFRE and AFBI. The liquid fraction is suitable for several methods of application such as irrigation, injection or application by trailing-shoe tanker, as the separation process removes the large fibre particles from the liquid (Lyons et. al., 2021). Low emission slurry spreading equipment struggles with high dry matter slurries. The recommendation for dribble bar is no higher than 9% dry matter and for the trailing shoe this drops to approximately 6% dry matter. Slurry separation offers a solution to these issues. Slurry separation facilitates better use of slurries, coupled with LESSE. However, unless the solid fraction is managed using best available techniques, the combined ammonia emissions of separated liquids and solids may be higher and the overall nitrogen use efficiency no better than for the unseparated slurry, (Pedersen et. al, 2022).

Redistribution of Nutrients across the province, industries, or countries

Mechanical separation has come into sharp focus as potentially part of the solution to the current oversupply of nutrients on many intensive livestock enterprises, coupled with the Lough Neagh algal bloom, with over 60% attributed of to agriculture, (high P soils from high P diets and P applied from inorganic fertiliser plus often less than adequate management of manure spreading – at least before the Nitrates Directive was introduced). Currently NI is sitting with an average P surplus of approximately 12kgs per hectare. However, averages do not adequately paint the whole picture, as some land is likely to be much high in P and some P indexes below optimum for good production. The current soil nutrient health scheme will help to elucidate fields/farms that have soil P indexes above the optimum or need P to bring them to an optimum level.

Depending on the type of separator used, whether or not additives are employed and the update of the technology, there is potential to remove between 275 and 1336 tonnes of phosphate by a screw press and between 2043 and 3653 tonnes with the decanting centrifugation from a possible ~9000 tonnes excess phosphate/year in NI, (Lyons et. al., 2021).

Separation technology is not primarily associated with ammonia reduction or carried out exclusively for that purpose but will help facilitate other potentially impactful ammonia and GHG reduction technologies, as well as an avenue for application of other manure processing technologies, such as anaerobic digestion of the separated solid fraction. Further processing technologies such as the N2 applied system or pelletising the solids requires the separation of manure prior to treatment, so separation forms part of the necessary infrastructure to facilitate such technologies but is not an end in itself.

Separation technology has potential to be utilised on livestock enterprises handling or processing raw slurry and on anaerobic digester sites (pre or/and post digestion). A key objective in the ability to process manure is that excess nutrients can be exported in a more concentrated form (to land that requires P or for further processing). Costs may prove prohibitive depending on the technology employed at farm level. However, with the Lough Neagh issue front and centre with the new DAERA minister, there is likely to be some sort of new legislative framework to tackle the water quality issue, which has been linked to surplus P on farms.

Farm-scale screw presses suitable for slurry and digestate separation are likely to have a combined capital and installation cost of approximately £20,000–£65,000 depending on the number of livestock. Decanting centrifuges at the farm or larger processor level are likely to have capital and installation costs of £50,000–£250,000 (Lyons et. al., 2021). A possible alternative is for mobile separators, (particularly decanting centrifuges) to visit farms on an ongoing basis for slurry separation, although there are biosecurity issues associated with this. Most farms do not have above ground storage, so there are major logistical issues with what to do with the separated liquid: build new stores, put back into existing store from where the raw slurry is being pumped or some alternative, e.g. centralised AD with slurry separation and further processing with the separated digestate going back to farm.

The degree of separation varies widely with the system employed, but generally improves with the more sophisticated systems. To evaluate the performance of separators it is important to consider the reason(s) for separation and what the desired outcome is, (Burton 2007).

In a review of ‘the potential contribution of separation technologies to the management of livestock manure’ Burton (2007) made several conclusions.

What cannot be reasonably expected from farm-based separation processes alone?

- to adequately deal with an offensive odour problem.
- to remove excess ammonical nitrogen.
- to significantly reduce the biological oxygen demand load.
- to achieve a reduction in the overall volume of manure to be handled.

- to change the overall nutrient content — “what goes in must come out”
- to improve or worsen health risks— either to food crops or to livestock.

What can slurry separation processes alone achieve?

- make liquid manure easier to handle — reduced risk of blockages in pipelines (easier to manage LESSE equipment).
- produce solid by-products containing most of the original solid material.
- produce clarified liquids with greatly reduced levels of insoluble organic matter, phosphorous and heavy metals.
- enable the easier targeted application of livestock effluents to cropland.
- enable the easier export of solid concentrates for crop use in other arable farm areas.

In a review of solid-liquid animal slurry separation, Hjorth et. al., (2010) concluded that by combining solid–liquid separation technologies with pre- and post-treatments, end-products having an optimal composition for a specific end-use may be produced.

Separation Efficiency

Separation efficiency can be assessed by measuring the amount of liquids and solids produced in any given period, analysing each fraction for the constituent of interest and then dividing the mass of solids produced by the mass of slurry separated, (liquid volume reduction and/or producing a solid fraction with a high dry matter and with a high proportion of the solids/nutrients in that fraction). The technology employed should reflect the reason(s) for separation. If for example, 20% of the volume and 20% of the solids are transferred to the solid fraction there is no effective separation. Usually, depending on the type of separator employed, dry matter is concentrated in the solid fraction, but phosphate, nitrogen and potassium may not necessarily be.

Typical Example using a screw press: 1000 kg slurry @ 60g/kg DM produces 850kg separated liquid and 150kg solids @ 300g/kg DM. Separation efficiency of dry matter is 150*300/1000/60 = 0.75

Another indicator of separation efficiency is called the reduced separator efficiency index. This is a measure of the increase of the nutrient concentration in the solid fraction. For the example above the equation is (0.75 – 150/1000)/(1-150/1000) = 0.6/0.85 = 0.71. If no differential partitioning takes place the answer is zero. If all the constituent of interest is transferred to the solid fraction the answer is one, (Moller et. al., 2000).

The same calculations can be done for any constituent such as N, P, total ammonia nitrogen etc. Separation efficiency depends on such aspects as species type, diet fed, stage of production, dry matter content of the slurry, age of slurry.

Additives may be used to enhance separation efficiency, especially for P and this can result in over 90% of P being partitioned to the solid fraction, (AFBI separator Report 2007). However, depending on the type and quantity of additives used, the volume of separated liquid could be as great/greater than the original volume of slurry. Chemical additives are divided in coagulating and flocculating agents, according to their reactions in the slurry. In general, they enhance the aggregation of small particles, leading the formation of larger flocs which results in better separation to the solid fraction, (Bolta et. al., 2007).

Type of slurry and storage

An investigation by Zhang et. al., (2022) found that separation efficiency from untreated raw slurry and acidified slurry were consistently greater than those of the digested slurry.

Moller et. al., (2002) found that slurry storage reduced the DM content of manure significantly and consequently, the separation efficiency of TN and DM was significantly reduced, while the separation efficiency of TP was only slightly affected. Slurry storage does not reduce the separation efficiency by centrifuging for nutrients like phosphorus, which are mainly in a suspended form, while separation efficiency of nutrients like nitrogen, which are transformed from an organic to an inorganic form, will be reduced during storage. Centrifugation results in greater solids separation than the other mechanical methods irrespective of animal or slurry type, Zhang et. al., (2022).

Anaerobic Digestion (AD)

Ammonia N concentration, nitrogen content and pH were higher in both unseparated AD material and AD separated liquid storage compared to the undigested separated liquid alone, Baldé et. al., (2018). Holly et. al., (2017) found that slurry separation has a greater mitigation potential for methane in storage than AD, but this likely varies highly depending upon the digester performance. However, combining AD and slurry separation does not further reduce total GHG emissions from storage than AD alone as anaerobically stacking digested solids increased emissions of N2O negating abatement of total GHG. A comprehensive meta-analysis of 45 published articles to evaluate the differences in separation efficiencies of various systems and the changes of gas emissions before and after the separation during on-farm slurry storage was undertaken by Zhang et. al., (2022). Their results indicated that the solids separation efficiency of the untreated raw slurry and acidified slurry were consistently greater than those of the digested slurry.

Greenhouse gas emissions

Both measured and simulated data showed that the centrifuge technology had greater reductions in greenhouse gas (GHG) emissions relative to the screw press, (56.1–58.0% vs. 38.9–40.2% for untreated slurry, and 29.7–30.2% vs. 22.5–23.2% for digested slurry), mainly due to CH4 reduction, (Zhang et. al., 2022). In another experiment Perazzolo et. al., (2015), separation following AD significantly increased GHG emissions for pig slurry, but not cattle slurry. However, it resulted in a significant reduction in NH3 emission potential (9 and 23% for pig and cattle, respectively), with the major contribution to NH3 emissions were the liquid fractions, which accounted for an average of 83 and 75% of the total losses determined by flux measurement or mass balance, respectively (lab-based storage experiment). Considering the whole manure management continuum, if adequate mitigation techniques are adopted to limit the N losses during the storage phase, then mechanical separation may lead to an overall lower impact than untreated slurry.

Dinuccio et. al., (2008) concluded that evidence from their study suggests that mechanical separation of cattle and pig slurries do not reduce GHG emissions but have the potential to increase emissions of CO2 equivalents to the atmosphere during the storage of the separated fractions by up to 30%, when compared with untreated slurries, (30 days of storage measurements). In another experiment by Dinuccio et. al., (2011) storage and soil application of both liquid and solid fractions resulted in an 11% increase in GHG emissions compared to raw cattle slurry, with 70% of the separated solids ammonical N lost following soil application. Both AD and slurry separation can reduce GHG emissions, with the combined AD and slurry separation scenario achieving the highest reduction (41%). AD increases NH3 emissions during storage due to the mineralization process during digestion. Separation alone can achieve significant GHG emission reductions (38%) even greater than AD when using actual performance data from operating systems. Both AD and separation have the potential to reach higher GHG and NH3 emission reductions with improved technology efficiencies and management, (Aguirre-Villegas et. al., 2019). Work by Amon et. al., (2006) concluded that slurry separation reduces GHG emissions (from storage and spreading, solids composted) but is likely to result in an increase in NH3 emissions. The liquid fraction of separated slurry has positive environmental effects and reduces the emission of all gases. Negative environmental impacts from slurry separation are due to emissions from composting of the solid fraction. Centrifuge technology had greater reductions in greenhouse gas (GHG) emissions relative to the screw press for both raw and digested slurry, (Zhang et. al., 2022).

Manure Storage and Ammonia emissions

Gaseous emissions of ammonia are a concern of both raw slurry and following mechanical separation. The liquid fraction has an increased risk of ammonia emissions with the higher concentration of ammonical N in it. Separation by screw press increases TAN/TKN ratio by 9% (Lyons et. al., 2021), which predisposes the liquid fraction to ammonia loss unless additional measures are taken. A literature review of slurry separation data (Pedersen et. al., 2022) shows that slurry separation under some circumstances reduces NH3 loss after field application, but there are very few measurements giving absolute emission factors after field application of the liquid fraction and corresponding raw slurry. The highest emission reductions were obtained with incorporation of the solid fraction after field application. Without incorporation of the solid fraction, overall emission was in some cases larger than for raw slurry.

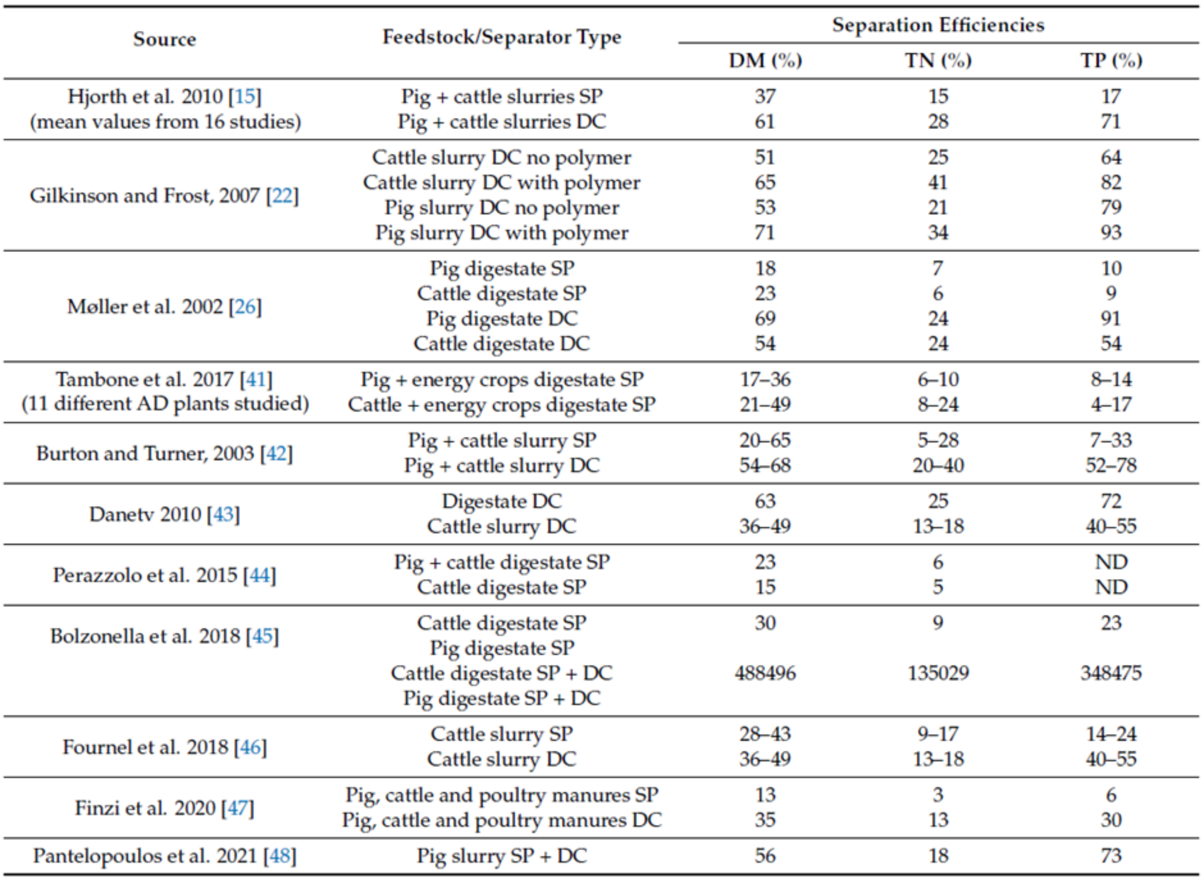
One potential solution for the storage of solids is to cover them with an impermeable cover. In a study by Hansen et. al., (2006) covering solids delayed aeration of the stored manure. This reduced internal heat production, degradation of organic matter, and emission of greenhouse gases and ammonia. Covering the solids reduced the emission of N_2O by 99%, and the emission of NH_3 by 12%. Covering was found to reduce CH_4 emissions by 88%. As the study was not replicated, no statistical significance can be placed on the quoted reductions in gaseous emissions. Petersen et. al., (2008) measured ammonium, total N and carbon losses from separated pig slurry and found that storage reduced the plant-available N and the amount of residual organic N and concluded that the fibrous fraction of separated pig slurry may be characterized as a manure with a high potential for loss and a variable value as fertiliser.

Land Application and fertilising potential

The increased TAN/TN ratio makes the liquid fraction a better organic fertiliser for plant growth with more readily available N. Ammonia volatilisation is reduced from field application of separated liquid due to quicker soil infiltration when finer mesh sizes are used for separation (Lyons et. al., 2021). Work conducted by Frost et. al., (1990) showed that ammonia volatilization decreased with decreasing mesh size to 39% of that from whole slurry for a 0·015mm mesh (for the liquid portion). Slurry acidification to pH 5.5 inhibited the degradation of organic materials during storage and led to an increase in slurry fertiliser value (ammonium and sulphur concentration) whilst mitigating its environmental impacts through a reduction in ammonia losses from storage and soil application. A slight caveat would be that if P partitioning was the goal, acidification would increase its availability, meaning more would be partitioned into the liquid portion. Thus, reducing the effectiveness of separation for this goal, unless acidification was done after separation to the liquid fraction.

Implications for P status and water quality

Separation enables partitioning of the key nutrients, nitrogen, phosphorus, and potassium (NPK). The liquid phase is characterised by a lower DM and will have a higher N to P ratio compared to slurry in its raw state. Ammonical N is mostly in the liquid fraction along with most of the K and this makes for a more balanced organic fertiliser. Decanting centrifuges are more efficient at separating phosphorus than screw presses. Screw press ranges from 4–34% and decanting centrifuge from 30–91% (Lyons et. al., 2021) [Figure 2]. Hence if P removal is the primary objective of separation, then a decanting centrifuge is the preferred option. From the 2007 AFBI separation report by Frost et. al., it was possible to remove almost all of the P to the solid fraction for both cattle and pig slurry with a decanting centrifuge and produce a liquid fraction better suited to land application with already high P soil status.



Source	Feedstock/Separator Type	Separation Efficiencies		
		DM (%)	TN (%)	TP (%)
Hjorth et al. 2010 [15] (mean values from 16 studies)	Pig + cattle slurries SP	37	15	17
	Pig + cattle slurries DC	61	28	71
Gilkinson and Frost, 2007 [22]	Cattle slurry DC no polymer	51	25	64
	Cattle slurry DC with polymer	65	41	82
	Pig slurry DC no polymer	53	21	79
	Pig slurry DC with polymer	71	34	93
Møller et al. 2002 [26]	Pig digestate SP	18	7	10
	Cattle digestate SP	23	6	9
	Pig digestate DC	69	24	91
	Cattle digestate DC	54	24	54
Tambone et al. 2017 [41] (11 different AD plants studied)	Pig + energy crops digestate SP	17–36	6–10	8–14
	Cattle + energy crops digestate SP	21–49	8–24	4–17
Burton and Turner, 2003 [42]	Pig + cattle slurry SP	20–65	5–28	7–33
	Pig + cattle slurry DC	54–68	20–40	52–78
Danetv 2010 [43]	Digestate DC	63	25	72
	Cattle slurry DC	36–49	13–18	40–55
Perazzolo et al. 2015 [44]	Pig + cattle digestate SP	23	6	ND
	Cattle digestate SP	15	5	ND
Bolzonella et al. 2018 [45]	Cattle digestate SP	30	9	23
	Pig digestate SP			
	Cattle digestate SP + DC	488496	135029	348475
	Pig digestate SP + DC			
Fournel et al. 2018 [46]	Cattle slurry SP	28–43	9–17	14–24
	Cattle slurry DC	36–49	13–18	40–55
Finzi et al. 2020 [47]	Pig, cattle and poultry manures SP	13	3	6
	Pig, cattle and poultry manures DC	35	13	30
Pantelopoulos et al. 2021 [48]	Pig slurry SP + DC	56	18	73

Figure 2: Screw press (SP) and decanting centrifuge (DC) separation efficiencies for dry matter (DM), total nitrogen (TN), and total phosphorous (TP) reported in several studies. Separation efficiency is quoted as the percentage of the analyte from the input feedstock that was partitioned to the solid fraction, (Lyons et. al 2021).

Comments

The screw press and decanting centrifuge are well proven methods for slurry separation, with the type employed depending on the goal(s) of separation. The liquid fraction has several factors in its favour. However, the solid fraction presents more of a challenge both to minimise ammonia losses and GHG emissions, whilst also finding a sustainable use for them. As N. Ireland is predominately grassland there is very little availability to export the solids to arable farms locally. AD is a possibility, but the nutrients still need a long-term viable home irrespective of the process employed. Considering that in The Netherlands a lot of farmers must export slurry out of the country to meet legislative requirements, something similar could potentially be in the pipeline locally at some stage, particularly if algal blooms continue to be an ongoing issue.

The cost of installing separators on farm and the logistics of dealing with raw slurry, separated liquid and separated solids cannot be ignored, plus the fact that most slurry is stored beneath animals and not in above ground slurry stores is an issue. While the outcome of the second phase of the SBRI call is unknown, it seems that slurry separation will be part of at least one of the systems employed.

The impact of slurry separation on ammonia mitigation for both fractions is variable (see manure storage section). If both fractions are stored under cover, the liquid fraction is applied using LESSE and the solid fraction incorporated immediately post application there should be some reduction in ammonia emissions, but in many situations this will not be the case and overall ammonia emissions may be greater compared to raw slurry

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