Pig Development Department Research Dissemination Day

Research Results on Alternative Uses for Pig Manure

Teagasc, Pig Development Department, Animal & Grassland Research & Innovation Centre, Moorepark, Fermoy, Co. Cork

Wednesday, 8th June 2011

Teagasc
Agriculture and Food Development Authority

Funding was provided through the Research Stimulus Fund Programme administered by the Department of Agriculture Fisheries & Food under the National Development Plan 2007 – 2013.

Project Number: RSFP 07-543 (RMIS 5823)

Table of Contents

Authors and Affiliations 1

Introduction 2

Research Papers

Methane Production from Anaerobic Co-Digestion of the Separated Solid Fraction of Pig Manure with Dried Grass Silage 4

Solid-Liquid Separation of Pig Manure 10

Composting Separated Solids of Pig Manure 18

Pyrolysis of Separated Solids of Pig Manure 24

Treatment of Piggery Wastewaters Using Constructed Wetlands 30

Treatment of Piggery Wastewaters Using Woodchip Biofilters 36

Composting as a Treatment Strategy for Pathogen Removal from the Solid Fraction of Pig Manure 42

Integrated Constructed Wetlands as a Treatment Strategy for Pathogen Removal from the Liquid Fraction of Pig Manure and Agricultural Wastewater 47

Cost Analyses of the Manure Treatment Options Investigated 53

Summary papers 65

List of Publications to Date 74

Authors and Affiliations

Teagasc, Pig Development Department, Animal & Grassland Research & Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland
Peter Fiska, Caolan Harrington, Peadar Lawlor, Brendan Lynch, Gemma Mc Carthy, Tereza Nolan and Shane Troy

Civil Engineering, College of Engineering and Informatics, National University of Ireland, Galway, Ireland
Kathryn Carney, Mark Healy, Michael Rodgers, Shane Troy, Sihuang Xie, Guangxue Wu and Xinmin Zhan

Agri-Food and Biosciences Institute, Hillsborough, Co. Down, Northern Ireland, UK
Peter Frost and Stephen Gilkinson

Department of Chemical & Life Sciences, Waterford Institute of Technology, Waterford, Ireland
Lee Coffey, Gillian E. Gardiner and Gemma Mc Carthy

Chemical and Environmental Science, University of Limerick, Limerick, Ireland
Witold Kwapinski, James J. Leahy and Shane Troy

Teagasc, Johnstown Castle Environmental Research Centre, Wexford, Co. Wexford, Ireland
Noel Culleton and Caolan Harrington

Central Veterinary Research Laboratory, Department of Agriculture, Fisheries and Food, Backweston Campus, Celbridge, Co. Kildare, Ireland
Montserrat Gutierrez

Institute for Infrastructure and Environment, School of Engineering, the King's Buildings, University of Edinburgh, Scotland, UK
Caolan Harrington and Miklas Scholz

Introduction

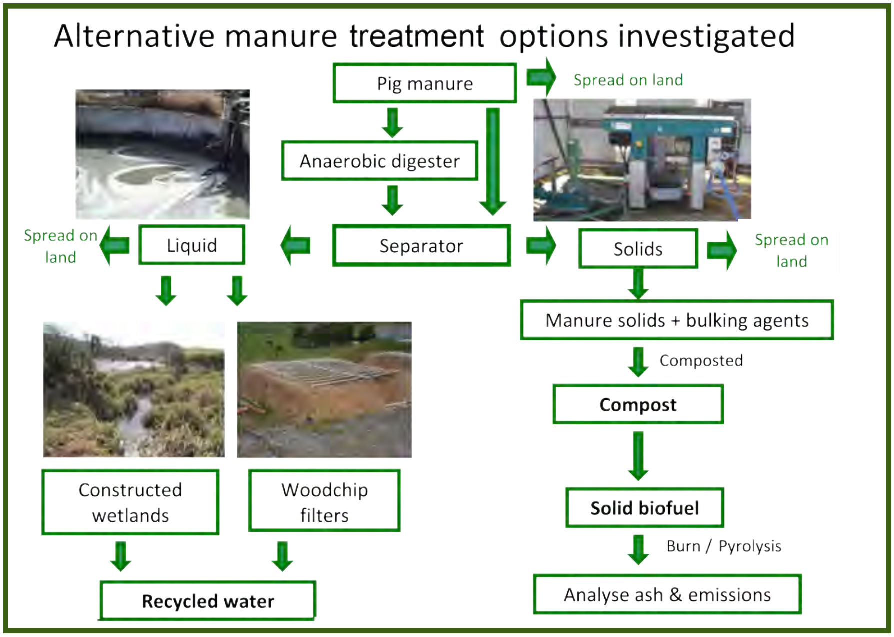
Increasing the amount of energy produced from renewable sources is a stated objective of the EU. Anaerobic Digestion, as investigated in this project, can extract energy from animal and plant biomass, while still retaining the nutritive value of the material as fertiliser. This project looked at reducing the greenhouse gas emissions from stored pig manure, by capturing methane during anaerobic digestion which would otherwise be produced naturally in storage under anaerobic conditions. In addition, production of renewable energy from pig manure is carbon neutral and offsets carbon dioxide that would otherwise be produced by fossil fuels, thus helping to meet Ireland's targets to reduce CO2 emissions. Anaerobic digestion can also help reduce pathogen levels in pig manure. However, it is important to be aware that anaerobic digestion does not reduce the P and N content of manure. Moreover, as the manure will most likely be co digested with other biomass the N and P content of the digested material will likely be even higher than that of the raw manure.

The Nitrates Action plan imposed immense restrictions on the use of pig manure on intensive grassland and cereal farms. Few pig farmers own sufficient suitable land for utilization of the manure generated on the unit and instead supply manure to customer farmers where it replaces chemical fertiliser. However, many of these farms are no longer suitable as the organic N loading from grazing livestock is already at or approaching the 170 kg/ha limit. Post 2017 it is estimated that a further 45-50% land-spread area will be required when soil test P will fully limit the use of pig manure.

Despite the significant financial value of pig manure as a fertilizer, customer farmers may in some instances be reluctant to use pig manure because they fear loss of Single Farm Payment entitlements if they inadvertently make mistakes. Tillage farmers, in particular, were initially concerned about (1) the variable availability of N in pig manure, (2) the short window for application of manure to tillage crops, (3) the effect of manure application on permitted fertiliser N application in subsequent years and (4) a fear that N will become available too late in the season possibly contributing to lodging. However, these concerns have been largely dispelled in recent years.

In addition, concentrated pockets of pig production occur around the country (e.g. Cavan and Mitchelstown) where the quantity of pig manure available exceeds availability of suitable land in the area. Pig manure has to be exported from these areas at considerable cost. The current project examines separation of pig manure into solid and liquid fractions, to explore the potential of the solid fraction as a fuel source and to treat the liquid fraction. A schematic describing the project is given in the figure below.

Despite all the restrictions and difficulties relating to land spreading, this is likely to be the most cost effective method of recycling pig manure nutrients in Ireland for the foreseeable future. While our cost analysis shows that the technologies investigated in this project are not currently cost effective in Ireland, they may have future potential. For example, anaerobic digestion would be cost effective on large units (2000 sows plus) or if centralised treatment plants were developed and if the renewable energy feed in tariff for energy sold to the grid was increased.



Methane Production from Anaerobic Co-Digestion of the Separated Solid Fraction of Pig Manure with Dried Grass Silage

Sihuang Xie, Guangxue Wu, Peadar Lawlor, Tereza Nolan, Peter Frost and Xinmin Zhan

Summary

Anaerobic co-digestion of the separated solid fraction of pig manure (SPM) with dried grass silage (DGS) was studied in three 3-litre capacity continuously stirred digesters at 350C. In each digester four loading rates of volatile solids (VS) were studied: 1.0, 1.5, 2.0 and 3.0 kg VS/m^3 digester/day. Feedstock for each of the digesters had a different percentage of its total volatile solids (solid organic matter) as DGS: digester 1, 20% DGS and 80% SPM; digester 2, 30% DGS and 70% SPM; digester 3, 40% DGS and 60% SPM. Hydraulic retention time in each digester was 30 days. It was found that that co-digestion of SPM with DGS was successful at all three percentage additions and at all four loading rates. Tripling the loading rate of VS increased the volumetric methane yield by an average of 88% and decreased methane production per unit of VS by an average of 38%.

Introduction

Increasing costs of fossil fuels together with decreases in reserves and global warming have led to a growing worldwide need for renewable energy. Anaerobic digestion (AD) of organic matter produces biogas (approximately 60% methane) which is an excellent source of renewable energy. In Ireland, manures from housed livestock could provide an abundant supply of organic matter for AD. For example, it is estimated that 3.1 million tonnes of pig manure are produced in Ireland each year and that this could potentially produce more than 50 million cubic metres of biogas. It is further estimated that this manure contains 13,050 tonnes of N, 2,550 tonnes of P and 6,830 tonnes of K. Therefore, in addition to energy production, pig manure has excellent potential as a fertiliser for grass and other crops and has traditionally been land spread for this purpose. However, environmental legislation, such as the EU Nitrates Directive, has placed constraints on the land application of manures. When compared with traditional pig manure management, AD of pig manure has a number of advantages, for example:

(i) renewable energy production;
(ii) improvement in fertiliser value
(iii) reduction in pathogens and malodours
(iv) reduction in pollution potential

On mainland Europe anaerobic digester systems are common. For example, in Germany there are more than 5,000 on-farm AD systems and in Denmark there are more than 20 large scale centralised AD systems. However, as biomass to feed the larger plants must be transported from the farm to the digester, transport costs can be very high. Reducing the cost of transportation, which is one of the important factors determining whether or not anaerobic digestion of pig manure is economically feasible, can be achieved by separating the solid and liquid fractions of pig manure and then only transporting the solid fraction for digestion. The solid fraction of pig manure produces more biogas per unit volume than raw pig manure due to its higher organic matter concentration. For these reasons AD of the solid fraction of separated pig manures is carried out in some countries such as Denmark.

Grass silage, due to its high digestible organic matter content, is also an excellent feedstock for AD. Ireland has a very suitable climate for grass production and has 4.3 million ha of grassland (15 times the arable area). Much of this grass is conserved as grass silage for use as winter forage for ruminant livestock. For AD, grass silage can be used either as a single feedstock or co-digested with pig manure. Studies have shown that compared to AD of pig manure alone, co-digestion of pig manure with crops can increase biogas yield. Increasing the fraction of grass silage in the feedstock increases the biogas yield.

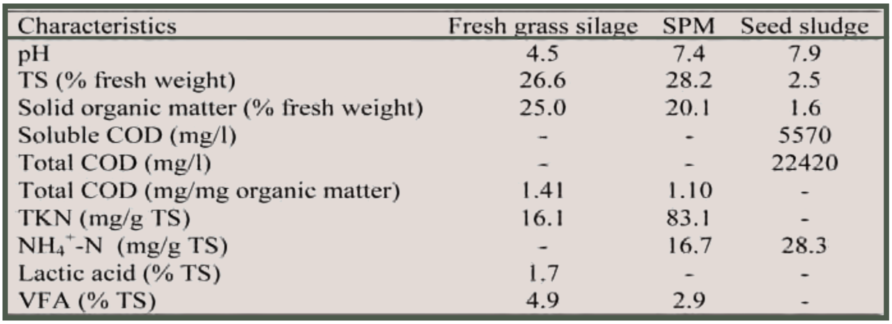
Objective

Anaerobic co-digestion of the separated solid fraction of pig manure and grass silage was investigated in continuously stirred digesters at different loading rates of feedstock and with different proportions of solid organic matter (volatile solids) from solid pig manure and dried grass silage.

Methods

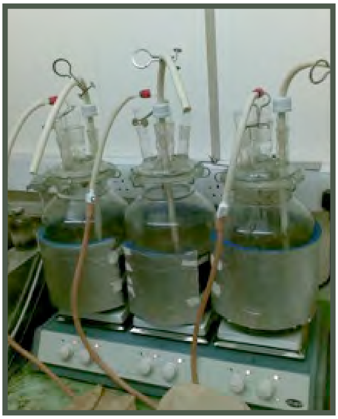
Pig manure was separated using a decanter centrifuge and the solid fraction was collected and frozen. Before use in the experiments the manure was thawed at ambient temperature (~20°C) for one day. Because of difficulties in feeding fresh grass silage into the small laboratory digesters, the grass silage was dried at 60°C for 24 hours and chopped to about 5 mm length. There would have been some losses of volatile fatty acids from the grass silage during drying though these were not measured. The characteristics of fresh grass silage and the separated pig manure are given in Table 1.

Table 1 - Characteristics of fresh grass silage, separated solid pig manure (SPM) and seed sludge used as inoculum.



Characteristics	Fresh grass silage	SPM	Seed sludge
pH	4.5	7.4	7.9
TS (% fresh weight)	26.6	28.2	2.5
Solid organic matter (% fresh weight)	25.0	20.1	1.6
Soluble COD (mg/l)	-	-	5570
Total COD (mg/l)	-	-	22420
Total COD (mg/mg organic matter)	1.41	1.10	-
TKN (mg/g TS)	16.1	83.1	-
NH_4^+-N (mg/g TS)	-	16.7	28.3
Lactic acid (% TS)	1.7	-	-
VFA (% TS)	4.9	2.9	-

Each of the three digesters had a working volume of 3 litres (Fig. 1) which was continuously stirred at 60 rpm. The digesters were maintained at 350C using a hot plate. Each digester was fed once per day with 100 ml of feedstock to give a nominal hydraulic retention time of 30 days. The feedstock for each digester had different proportions of the dried grass silage (DGS) and the separated solid fraction of pig manure (SPM). The proportions used were characterised by the quantities of volatile solids (VS) supplied. In digester 1, 20% of the VS were supplied by DGS and 80% by SPM. In digester 2, 30% of the VS were supplied by DGS and 70% by SPM. In digester 3, 40% of the VS were supplied by DGS and 60% by SPM. Initially, the VS loading rates were equivalent to 1 kg VS/m^3/day, and these were increased stepwise through 1.5 kg VS/m^3/day, 2.0 kg VS/m^3/day to 3.0 kg VS/m^3/day. Each day, prior to feeding, 100 ml of digestate was removed from each reactor and its pH was measured. Remaining digestate was then stored prior to determination of total solids and VS by standard methods.



Picture 1- Anaerobic digestion of pig manure and grass silage in lab-scale continuously stirred tank reactors

The biogas produced by each reactor was collected in a 10 litre biogas storage bag and the volume of biogas was measured by displacement of water. The methane content of the biogas was measured by gas chromatography.

Results/Discussion

1. Methane productivity

Immediately after inoculating the reactors there was a sharp decrease in pH and only small amounts of methane were produced (Fig. 1(a)). For this reason, feeding of the digesters was suspended until methane production increased significantly at day 24. At this point feeding was resumed at a loading rate of 1 kg VS /m^3/day. Thereafter, pH and methane content of the digesters remained constant. The daily mean methane yield from each digester at each of the loading rates is illustrated in Fig 1 (b).

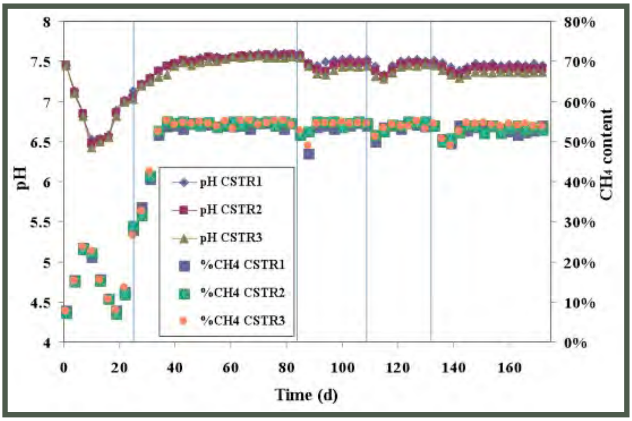


Fig (a)

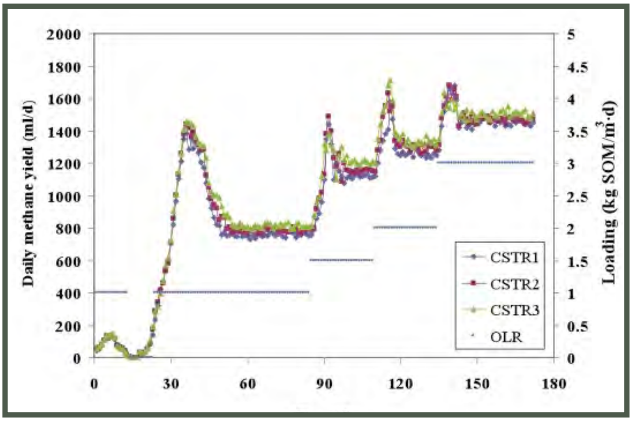
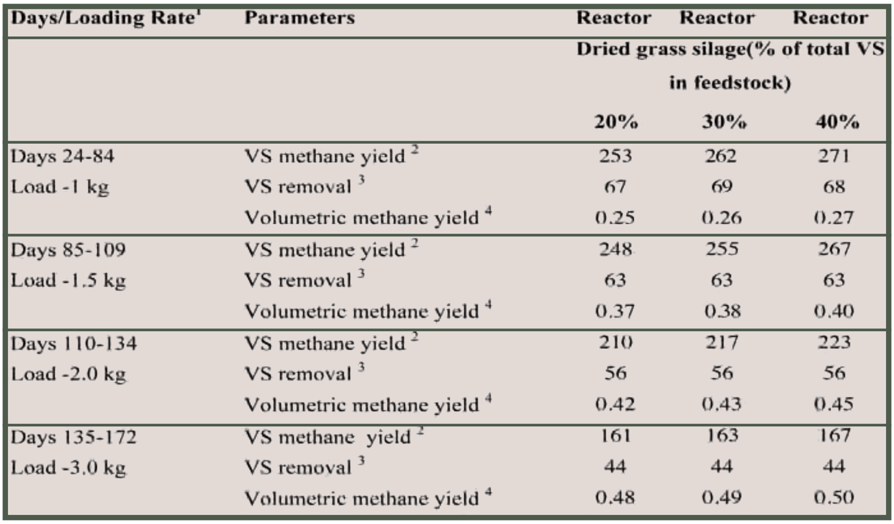


Fig (b)

Figure 1 - (a) pH and methane content in biogas; and (b) daily methane yield over time.

Table 2 summarises further performance. Examination of Fig 1 (b) and Table 2 indicates that increasing the loading rate of VS from 1.0 to 3.0 kg/m^3 of digester increased methane production from an average of 0.26 to 0.49 litres of methane/ litre of digester per day (88% increase). In contrast, for the same increase in loading, methane production per unit of VS decreased by an average of 38% (262-164 ml of methane/g VS added). The lower specific methane yields as VS loading rates increased were reflected in lowered VS removals. At each VS loading rate there was a tendency for specific methane production to increase as the proportion of VS provided by DGS in the feedstock increased. However, this effect was relatively small compared to the effect of increasing overall VS loading rate (Table 2 and Fig. 1 (b)).

Table 2 - Performance of the laboratory digesters at 35^{o}C (average of 10 days in steady state)



Days/Loading Rate[1]	**Parameters**	**Reactor**	**Reactor**	**Reactor**
		Dried grass silage(% of total VS in feedstock)		
		20%	**30%**	**40%**
Days 24-84	VS methane yield [2]	253	262	271
Load -1 kg	VS removal [3]	67	69	68
	Volumetric methane yield [4]	0.25	0.26	0.27
Days 85-109	VS methane yield [2]	248	255	267
Load -1.5 kg	VS removal [3]	63	63	63
	Volumetric methane yield [4]	0.37	0.38	0.40
Days 110-134	VS methane yield [2]	210	217	223
Load -2.0 kg	VS removal [3]	56	56	56
	Volumetric methane yield [4]	0.42	0.43	0.45
Days 135-172	VS methane yield [2]	161	163	167
Load -3.0 kg	VS removal [3]	44	44	44
	Volumetric methane yield [4]	0.48	0.49	0.50

[1] Loading rate is given in kg of solid organic matter (volatile solids)/ m^3 of digester/ day
[2] VS methane yield is given in ml of methane /g volatile solids (VS) added
[3] VS removal is given in % of volatile solids (VS) removed from feedstock
[4] Volumetric methane yield is given in litres of methane per litre of digester per day.

2. Post-methane production potential of digestate

When an anaerobic digester is overloaded with feedstock material, a large amount of feedstock material will be poorly degraded. Therefore, even after digestion this material will still contain high amounts of degradable material with potential to further digest and produce more biogas. The amount of biogas that digestate can yield after digestion is called post-methane production potential.

In the current work it was calculated that at 1 kg VS/m^3 digester loading rate, the post methane production potential would have averaged approximately 11%, 12% and 13% of total methane yield for the DGS addition of 20%, 30% and 40%, respectively. Calculations for the 3 kg VS/m^3/d loading rate indicated an increase in post methane production potential to 38%, 39% and 41% of total methane yield for DGS VS additions of 20%, 30% and 40% respectively.

3. Thermo-chemical pre-treatments of grass silage on methane production

Grass silage has a high lignocellulosic content that can be very resistant to digestion. It is possible to treat grass silage before anaerobic digestion (pre-treatment) to make this lignocellulosic material more available and as a result improve biogas yields.

In the current work two methods of pre-treating grass silage were studied:

- Heating the grass silage (from 60^{o}C to 150^{o}C)
- Adding sodium hydroxide: from 1% to 7.5% by weight of solid organic matter in grass silage

Compared to the methane yield without any pre-treatment, a 39% increase in methane production potential was achieved when grass silage was pre-treated at 100^{o}C along with the addition of sodium hydroxide at 7.5%.

Conclusions

When dried grass silage and the separated solid fraction of pig manure were co-digested in laboratory digesters at 35^{0}C with a hydraulic retention time of 30 days:

- Digestion was successful at all the digester loading rates used (1.0, 1.5, 2.0 and 3.0 kg volatile solids/m^3 of digester).
- Digestion was successful at all of inclusion rates of dried grass silage that were used (20%, 30% and 40% of total volatile solids in the feedstock).
- Tripling the loading rate of volatile solids (1.0 to 3.0 kg volatile solids/m^3 of digester) increased the volumetric methane yield by an average of 88% (0.26 to 0.49 m^3 methane/m^3 of digester/day) and decreased methane production per unit of volatile solids by an average of 38% (262-164 ml of methane per /g volatile solids added).
- Specific methane yield per unit of volatile solids added or per unit of digester volume at each loading rate of volatile solids was little affected by the proportion of dried grass silage in the feedstock.

Solid-liquid separation of pig manure

Tereza Nolan, Peter Fiszka, Brendan Lynch and Peadar Lawlor

Summary

A laboratory experiment was conducted to assess the effect of manure dry matter and chemical (coagulant) addition on the efficiency of separation of pig manure into solid and liquid fractions. An increase in manure dry matter resulted in an increase in the separation efficiency for dry matter and nitrogen, but separation efficiency for phosphorus decreased. Increases in chemical addition resulted in increases in separation efficiency for dry matter, nitrogen and phosphorus. A case study is also presented where 3 different farm-scale separation technologies were analysed.

Laboratory Experiment

Introduction

Separation of pig manure is undertaken to produce two fractions: phosphorus-rich solid fraction and a nitrogen-rich liquid fraction. The solid fraction is cheaper to transport and can be transported relatively long distances for application on tillage land where the requirement for plant available phosphorus is high, or it may be used for composting or as a fuel. The nitrogen-rich liquid fraction can be applied on grassland in the proximity of the pig unit that has a lower requirement for phosphorus. Alternatively, the liquid fraction could potentially be further treated and re-used as wash water.

Methods of solid-liquid separation of pig manure include: (i) natural methods such as sedimentation (ii) mechanical methods such as filtration, pressing, centrifugation; and (iii) separation based on chemical methods which involve the addition of coagulants and flocculants.

On farm manure separation usually involves mechanical methods. However, chemicals are often used with mechanical methods to enhance the separation process and the optimal dosage will vary. Chemical treatments include the use of coagulants and flocculants. The most commonly used coagulants are metal salts. The ions of these metal salts react with ions in the slurry forming very small settable flocks and by sweeping action, suspended particles in the slurry can be made to settle together within these small flocks. Flocculants are then used to agglomerate these small coagulated particles into large, rapidly settling flocks.

It is recommended that the optimal dosage of chemicals is determined before field application. This is particularly important since adding coagulants and/or flocculants above the optimum dosage is very expensive and may not necessarily improve separation efficiency. Another factor that can affect the separation process is the dry matter of the manure. It is expected that a higher dry matter manure can produce a drier solid fraction compared to manure of lower dry matter.

Objective

The objective of this study was to assess the effect of manure dry matter and different doses of coagulant addition on the separation efficiency of pig manure into solid and liquid fractions.

Methods

Twenty litres of manure with high dry matter content (~ 8%) were collected from the under-slat tank in a finishing pig house with a dry feeding system. This sample was continuously mixed, and sub-samples were collected and diluted with tap water to produce material of 7.7%, 5.2%, 3.3% and 1.6% dry matter sub samples. Six 500-ml samples at each dry matter content manure were treated with 0.4% flocculant solution (C1900P, Celtic Watercare, Cork) and 6 different doses of coagulant addition (PC31, Celtic Watercare, Cork): 0.0, 0.5, 1.0, 1.5, 2.0 and 2.5 ml. The addition rate for coagulant recommended by the suppliers for use with the Westfalia UCD 205 decanting centrifuge at Moorepark is 2 to 3 litres per m^3 (1.0 to 1.5 ml per 500 ml). The samples were then centrifuged for 10 minutes at 3000 rpm in a laboratory centrifuge. After separation, the liquid and the solid fraction were weighed and analysed for dry matter, nitrogen and phosphorus content.

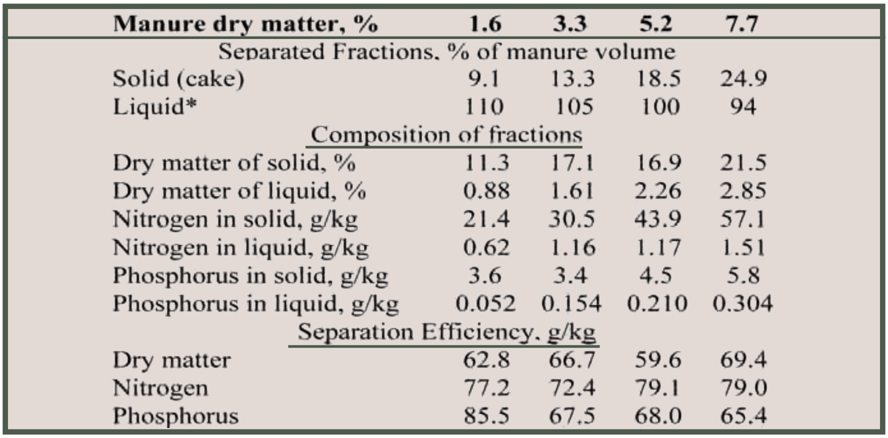
Results/Discussion

Effect of manure dry matter

Increasing the manure dry matter resulted in a larger solid fraction and smaller liquid fraction (expressed as a percentage of initial manure). The dry matter of both the solid and liquid fractions increased with increasing dry matter. An increase in manure dry matter from 1.61 to 7.71% resulted in a 90% increase in the dry matter content of the solid fraction (from 11.3% to 21.5%) and a 224% increase in the dry matter of the liquid fraction (from 0.88 to 2.85%). These results demonstate that obtaining a clear diluted liquid fraction is often achieved at the expense of obtaining a low dry matter separated solid phase (Table 1).

Nitrogen and P content in both the solid and liquid fraction also increased with increasing manure dry matter. A 61% increase in the P content of the solid fraction was observed when the dry matter of the manure was increased from 1.61% to 7.71%.

Table 1 - Effect of manure dry matter percentage on the separation process



Manure dry matter, %	**1.6**	**3.3**	**5.2**	**7.7**
Separated Fractions, % of manure volume				
Solid (cake)	9.1	13.3	18.5	24.9
Liquid*	110	105	100	94
Composition of fractions				
Dry matter of solid, %	11.3	17.1	16.9	21.5
Dry matter of liquid, %	0.88	1.61	2.26	2.85
Nitrogen in solid, g/kg	21.4	30.5	43.9	57.1
Nitrogen in liquid, g/kg	0.62	1.16	1.17	1.51
Phosphorus in solid, g/kg	3.6	3.4	4.5	5.8
Phosphorus in liquid, g/kg	0.052	0.154	0.210	0.304
Separation Efficiency, g/kg				
Dry matter	62.8	66.7	59.6	69.4
Nitrogen	77.2	72.4	79.1	79.0
Phosphorus	85.5	67.5	68.0	65.4

** The solid and liquid fraction add up to more than 100% because the percentage shown is expressed as percentage of initial manure, before the addition of chemicals. The addition of chemicals resulted in the addition of ~ 18% more liquid (flocculant + coagulant + water).*

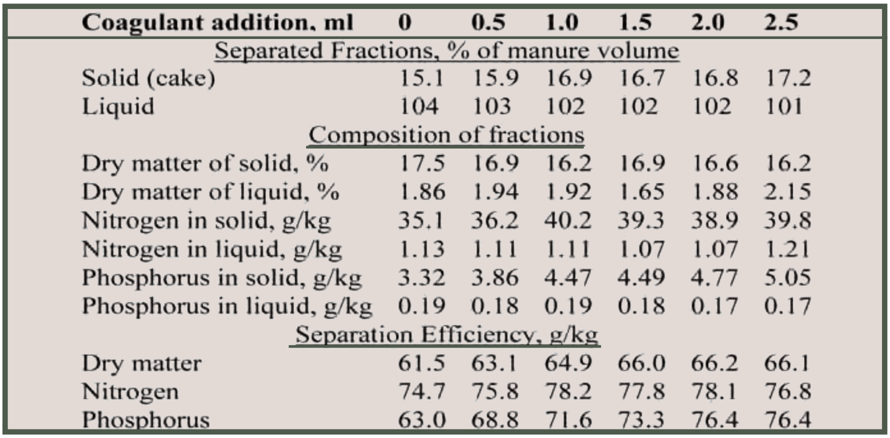
Effect of chemical addition

Results are given in composition of fractions and also in efficiency of separation. The composition of fractions gives us the amount of a specific nutrient (or dry mater) in each fraction produced (liquid and solid). Efficiency of separation accounts not only for the amount of nutrients or dry matter in each fraction but also takes into account the final amount of each fraction produced.

Adding more conditioner resulted in a larger cake (solid) fraction and smaller liquid fraction. There was an increase of 11.9% in cake percentage as coagulant addition varied from 0 to 1.0 ml and only a 1.8% increase when coagulant addition increased from 1.0 to 2.5 ml, suggesting a declining benefit as coagulant addition increased past 1.0 ml. The dry matter of the cake fell slightly with increasing coagulant dosage; however there was only a 1.3 point percentage difference between the higher addition (16.2% dry matter) and the smaller addition (17.5%) of coagulant. However, efficiency of dry matter separation, tended to increase with increased coagulant addition.

Adding more coagulant resulted in an increase in phosphorus content of the solid fraction. However, the benefit seemed again to decline as the dose rate increased. There was a 34.6% increase in phosphorus in the solid fraction when coagulant addition was increased from 0 to 1.0ml, and only a 13% further increase when the coagulant dosage was further increased from 1.0 ml to 2.5 ml.

Table 2 - Effect of coagulant addition on separation process



Coagulant addition, ml	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**
Separated Fractions, % of manure volume						
Solid (cake)	15.1	15.9	16.9	16.7	16.8	17.2
Liquid	104	103	102	102	102	101
Composition of fractions						
Dry matter of solid, %	17.5	16.9	16.2	16.9	16.6	16.2
Dry matter of liquid, %	1.86	1.94	1.92	1.65	1.88	2.15
Nitrogen in solid, g/kg	35.1	36.2	40.2	39.3	38.9	39.8
Nitrogen in liquid, g/kg	1.13	1.11	1.11	1.07	1.07	1.21
Phosphorus in solid, g/kg	3.32	3.86	4.47	4.49	4.77	5.05
Phosphorus in liquid, g/kg	0.19	0.18	0.19	0.18	0.17	0.17
Separation Efficiency, g/kg						
Dry matter	61.5	63.1	64.9	66.0	66.2	66.1
Nitrogen	74.7	75.8	78.2	77.8	78.1	76.8
Phosphorus	63.0	68.8	71.6	73.3	76.4	76.4

** The solid and liquid fraction add up to more than 100% because the percentage shown is expressed as percentage of initial manure, before the addition of chemicals. The addition of chemicals resulted in the addition of ~ 18% more liquid (flocculant + coagulant + water)*

Statistical analyses (not presented) showed that dry matter and nitrogen content of the liquid fraction was not affected by the addition of coagulant, while phosphorus content decreased. Separation efficiency for phosphorus increased with increasing coagulant addition and, once again, the benefit seemed to decline with additions above 1.0 ml. There was a 13.7% increase in efficiency when coagulant addition was increased from 0 to 1.0 ml and only a further 6.7% increase in P separation efficiency when coagulant addition was increased from 1.0 ml to 2.5 ml.

Nutrients in pig slurry are mostly found in very fine suspended particles that are not easily separated by mechanical separators alone. Studies have shown that as much as 80% of the suspended solids, 78% of the N, and 93% of the phosphorus that are potentially removable by solid-liquid separation alone, are contained in very fine particles that would pass through a 0.3 mm screen. Moreover, most of the P in pig slurry is in particles < 10 µm in diameter. For this reason chemicals are used to enhance the separation process. The ions present in the coagulant react with ions present in the slurry to form settable flocks. Consequently, by a sweeping action, suspended particles in the slurry can be made to settle together with these flocks. Flocculants are used to agglomerate these coagulated particles into large, rapidly settling flocks. The result, as seen in our study, is that more solids and P are transferred to the solid fraction after separation.

Based on this study, we would suggest adding coagulant at a rate of 1.0 ml per 500 ml of manure or 2 litres per m^3.

Conclusions

Separation efficiency for dry matter and nitrogen increased with increasing manure dry matter, however separation efficiency for phosphorus was reduced. Coagulant addition should be in the order of 2 litres per m^3 of manure when 0.4% diluted solution of flocculant is added at 17% (by volume). The cost per m^3 of liquid pig manure for this recommended chemical addition is €3.55 (2 litres of coagulant at €0.46/litre = €0.92 and 0.68 litres of flocculant at €3.87/litre = €2.63).

Case Study

Introduction

Transportation of dilute liquid manure over long distances to suitable spread lands is expensive. Separation of manure into a solid fraction high in P and a liquid fraction high in N provides the possibility of utilizing the two fractions on different sites. However, to be commercially viable, separation of manure and utilizing it as above must be a lower cost option than transporting and spreading of raw manure. The cost of handling and disposal or utilisation of the solid fraction of manure will be greatly influenced by its dry matter content. If separation of manure is to become a feature of manure management in Ireland, then it will be necessary to achieve more than 30% dry matter in the solid fraction.

Methods

Three separation systems were analysed: (i) the Geotube® (TenCate Industrial Fabrics Europe), (ii) a fixed decanter centrifuge (GEA Westfalia Separator UCD 205, GEA Westfalia Surge GmbH, Bönen, Germany) and (iii) a contractor mobile decanter centrifuge (Centriquip CQ5000, Clay Cross, Derbyshire, United Kingdom). The pig manure used in all 3 systems was sourced from a storage tank of c. 1.1 million-litre capacity, which is used to collect manure from all stages of production. Manure was added to this storage tank weekly and the contents were agitated using vertically-mounted electrical propeller agitators located close to the base of the tank. Some characteristics of the systems are described below:

Geotube® - The Geotube® is a high-strength permeable fabric with a fine pore structure designed to retain particles above a certain size while the liquid seeps through the pores, resulting in volume reduction of the contained material. This volume reduction allows for the repeated filling of the Geotube® container. After the final cycle of filling and dewatering, the retained fine grain materials can continue to consolidate by desiccation because the residual water vapour escapes through the membrane. The Geotube® used was a sealed sack 8 m-long by 4 m-wide when laid flat. The liquid manure was first transferred to a 20 m^3 storage tank. Flocculant and coagulant were added and the material was thoroughly mixed. The manure was then fed by gravity into the Geotube® through a filling port on top. The sack inflated temporarily to a height of about 45 cm as manure was added before subsiding as water seeped from the porous membrane. Four such batches were prepared and added to the Geotube®. The tube was left in place for 6 months. The sack was laid outdoors on a 10 cm-deep bed of coarse gravel, placed on an impermeable plastic sheet designed to collect the run-off liquid which was collected in an underground tank.

GEA Westfalia UCD 205 – This fixed decanter centrifuge is a continuously operating horizontal solid wall bowl centrifuge. Its maximum capacity is 5 m^3/h, but the effective capacity is lower and at most 2.5 – 3.0 m^3/h. Manure was pumped into a small (2.5 m^3) vertical cylinder-shaped tank fitted with a slow moving paddle agitator. Coagulant (PC31, Celtic Watercare, Cork) was added at a rate of 2.5 L/m^3 and the contents of the tank were agitated for at least five minutes before being fed into the separator. The manure was fed into the separator by way of a variable speed seepex pump system with a fitted macerator. The rate of flow to the separator varied from c. 0.3 m^3 per hour up to 2.0 m^3 per hour. Flocculant (C1900P, Celtic Watercare, Cork), diluted with water (0.4% dilution) was added to the manure as it entered the centrifugal chamber at a rate of 240 to 360 litres per hour. The centrifuge had an operating speed of 5,600 rpm. The separated solid was discharged into a container, while the separated liquid was discharged to a storage tank.

Centriquip CQ5000 - The mobile decanter centrifuge was a truck-mounted integrated unit incorporating a mixing chamber, polymer dosing unit and centrifuge. This plant contained its own generator and only required connection to a water supply. The solid was discharged by a side-mounted auger, while the separated liquid was discharged by gravity to a store. The nominal capacity of this unit is 15 - 50 m^3 per hour.

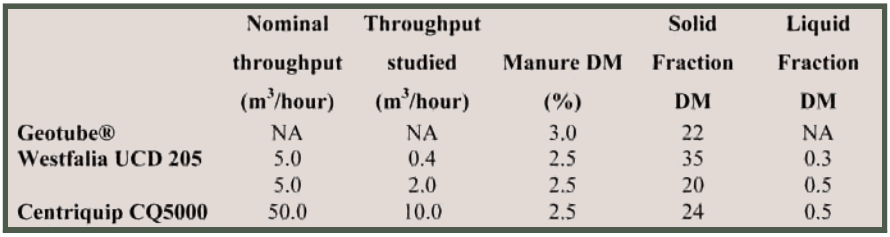
Results/Discussion

Water was discharged rapidly from the Geotube® (most within two hours) and after 24 hours there was little additional seepage. The dry matter content of the solid fraction was c. 22% on the day after filling and changed little over the next six months reaching a maximum of 24%. Removal of the solid required ripping of the Geotube® and because of this it could not be reused. The Geotube® represents a relatively effective, low cost technology method of manure separation, but recovery of the cake from the tube and subsequent handling are laborious.

For the fixed decanter centrifuge, the dry matter content of the solid cake was closely related to the throughput and also to the dry matter content of the manure. The highest dry matter material was produced when throughput was greatly reduced. When the manure dry matter was in the region of 2.5% and a throughput of 2.0 m^3 per hour was attained, the dry matter of the cake was c. 20%. A dry matter content of 32 to 35% was achieved when throughput was reduced to 0.4 m^3/hour. However, in a farm-scale scenario, a 0.4 m^3/hour throughput is not realistic; considering that a 500 unit sow produces c. 30 m^3 of manure daily, it would take 75 hours to separate the manure produced in 1 day. Costs associated with the fixed decanter centrifuge can be found in the cost analyses paper in this proceedings.

The dry matter content of the solid fraction from the mobile decanting centrifuge reached 22 to 24% when throughput was reduced to c. 10 m^3 /hour. The contractor claimed that had he more time to adjust the coagulant/flocculant dose, the dry matter of the solids could reach 28-30%. At the moment, this system achieves 28-30% dry matter in the cake from municipal sludge separation.

Table 3 - Comparison of the dry matter (DM) content of the solid and liquid fractions of pig manure for the three separation systems



	Nominal throughput (m^3/hour)	**Throughput studied (m^3/hour)**	**Manure DM (%)**	**Solid Fraction DM**	**Liquid Fraction DM**
Geotube®	NA	NA	3.0	22	NA
Westfalia UCD 205	5.0	0.4	2.5	35	0.3
	5.0	2.0	2.5	20	0.5
Centriquip CQ5000	50.0	10.0	2.5	24	0.5

The contract charge for the mobile decanting centrifuge was in excess of €100/hour. Assuming that the throughput to yield a high dry matter cake will be about 10 m^3/hour, the cost of separation is conservatively estimated at €10/m^3. After separation, the cost of haulage and spreading the two separated fractions must still be incurred.

According to Treanor (2008), €10/m^3 is equal to the cost of transport and spreading manure about 45 km by farm tractor and tanker (capacity 12 m^3) or about 100 km by truck tanker (capacity 26 m^3).

Conclusions

The three methods of manure separation examined yielded solid and liquid fractions capable of being used for separate land application. However, separation (+ transport and spreading) of the separated solid and liquid fractions of pig manure is unlikely to be an economical alternative to the transport and spreading of raw manure.

References

Treanor, 2008 *Managing Composition and Handling Costs of Pig Manure*. Thesis (M.An.Sc.), University College Dublin, 2008.

Fiszka, 2010 *Management of pig manure including variation in composition and aspects of manure separation into solid and liquid fractions*. Thesis (M.An.Sc.), University College Dublin, 2010.

Composting Separated Solids of Pig Manure

Shane Troy, Tereza Nolan, James Leahy, Mark Healy, Witold Kwapinski and Peadar Lawlor

Summary

Four trials were conducted to investigate composting of the separated solid fraction of pig manure. In the first two trials separated solids of pig manure and various different readily available carbon rich bulking agents (woodchip, chopped straw, shredded green waste, sawdust and sawdust + woodchip together) were used. Sawdust was the most suitable of these bulking agents. The small particles in sawdust have a very large surface area. Therefore they mixed best with the pig manure and produced the most stable compost. Straw was found to be too bulky and would have to be chopped very finely to be used, while the particle sizes in woodchip and green waste were too big to mix homogenously with the pig manure.

Trials 3 and 4 were undertaken to investigate composting of the separated solid fraction of pig manure with incremental proportions of sawdust. Trial 3 used separated solids of raw manure while in Trial 4 the separated solids of manure after anaerobic digestion was used. The literature suggests that the optimum initial carbon to nitrogen (C:N) ratio for effective composting is 25-30. A C:N ratio of 30 corresponds to a separated manure to sawdust ratio of approximately 3:2. However we found that stable compost could be produced using a C:N ratio of only 16. This corresponds to a separated manure to sawdust ratio of approximately 4:1. Approximately 60% less sawdust is required at this rate to compost similar quantities of manure. Reducing the amount of sawdust required to produce stable compost reduces the cost for farmers.

Introduction

Since August 2006, in accordance with S.I. 378 of 2006 and its amendment (S.I.610 of 2010), the quantity of livestock manure that can be applied to land in Ireland has been greatly reduced. Currently manure application is curtailed to a maximum limit of 170 kg of organic nitrogen (N) per hectare per year. Land availability for spreading pig manure will be further restricted in the coming years, when the plant available phosphorus (P) will also have be considered. It is estimated that an additional 45% spreadlands will be required by 2017 when the full restrictions on P application come into full effect. This will increase the cost of manure handling, as manures in livestock dense areas will have to be transported to less livestock dense areas for landspreading.

This increased cost for farmers, has resulted in the need to investigate practical and economically viable on-farm solutions for pig manure management.

Composting has the potential to stabilise the organic N fraction of the manure and increase its fertiliser value. In addition, the volume and water content of the manure are greatly reduced, and there is a reduction in malodour. This makes the product easier to transport, store and use. Composting also destroys pathogens and weed seeds found in untreated manures.

Stabilisation of the organic matter in the composting materials determines the effectiveness of the composting process. For stabilisation to occur, key factors, such as temperature, aeration, water content (WC), pH and structure must be at an optimum level both initially and throughout the composting process. The WC of a compost pile, for example, should be in the range of 40-60% throughout the composting process. The dry matter content of liquid pig manure in Ireland can vary from 0.6 to 15.9%, with a mean of 4.8% (Fiszka, 2010). For this reason, it is essential that it is separated and mixed with a dry material (bulking agent) to reduce its moisture content before composting.

The carbon: nitrogen (C:N) ratio is one of the most important factors influencing the quality of compost produced. The microorganisms involved in the composting process require C as an energy source and N for reproduction and development. The optimum C:N ratio for composting is 20 – 30. Since the C:N ratio of pig manure is around 11, the addition of C-rich bulking agents is essential. These bulking agents increase the C:N ratio, decrease WC, and improve the structure and porosity of the composting mix. Many different types of bulking agents have been used including straw, sawdust, woodchip, peat, peanut shells, rice hull, paper and chicken litter. However, the addition of these bulking agents adds an extra cost to the composting process.

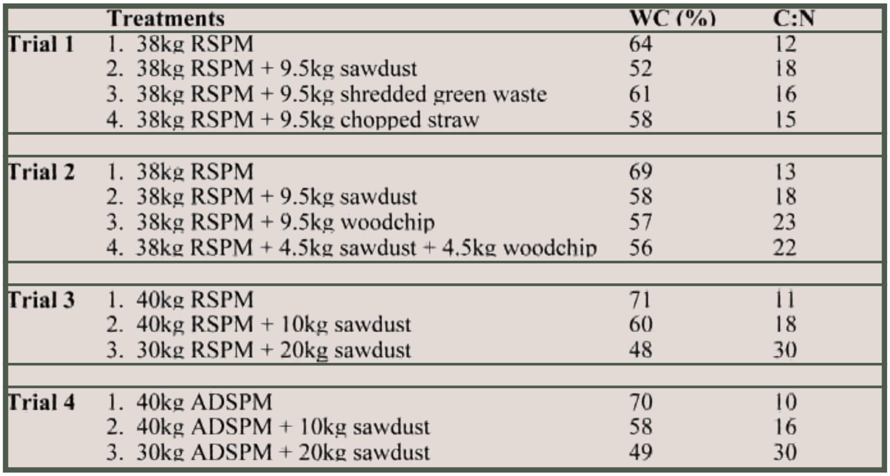
Objective

The overall aim was to investigate how effective farm-scale composting of the separated solids of pig manure could be achieved using readily available bulking agents at least cost to the farmer. A number of readily available bulking agents were investigated to determine which produced the best quality compost. Having decided on sawdust as the most suitable bulking agent, we investigated the effect of incremental additions of sawdust (incremental increase to the C:N ratios) on the quality of compost produced.

Methods

For Trials 1, 2 and 3, raw pig manure was sourced from an uncovered over ground storage tank of c. 1.1 million litre capacity which is used to collect manure from stock of all ages (Teagasc, Moorepark, Fermoy, Co. Cork). Fresh manure is added to this storage tank weekly and agitation was by vertically-mounted electrical propeller agitators located close to the base of the tank. In Trial 4, anaerobically digested pig manure was collected from another pig farm and transferred to the site of the study before separation. This manure also came from all stages of production and was aerated prior to anaerobic digestion. A decanter centrifuge (GEA Westfalia Separator UCD 205, Bönen, Germany) was used to perform the mechanical separation of the pig manure in all trials. A coagulant, aluminium salt (alum) in liquid form (PC31, Celtic Water Care, Cork) was added at c. 2.5 litres per m^3 and a flocculant, a water soluble polyacrylamide (PAM) (C1900P, Celtic Water Care, Cork), after dilution with water to 0.4 % by volume was added to the manure at approximately 17 % by volume to increase the efficiency of separation. Carbon rich bulking agents were added to adjust the C:N ratio and to reduce the WC. The bulking agents and separated manure were thoroughly mixed by hand to ensure homogeneity before being placed in insulated compost tumblers (Jora JK270 composter, Joraform AB, Mjölby, Sweden) and composted for 56 days. The trials and treatments are listed in table 1. All treatments were replicated 4 or 5 times.

Table 1 - Details of compost mixtures with initial water content (WC) and initial Carbon to Nitrogen ratio (C:N) for the 4 trials



	Treatments	WC (%)	C:N
Trial 1	1. 38kg RSPM	64	12
	2. 38kg RSPM + 9.5kg sawdust	52	18
	3. 38kg RSPM + 9.5kg shredded green waste	61	16
	4. 38kg RSPM + 9.5kg chopped straw	58	15
Trial 2	1. 38kg RSPM	69	13
	2. 38kg RSPM + 9.5kg sawdust	58	18
	3. 38kg RSPM + 9.5kg woodchip	57	23
	4. 38kg RSPM + 4.5kg sawdust + 4.5kg woodchip	56	22
Trial 3	1. 40kg RSPM	71	11
	2. 40kg RSPM + 10kg sawdust	60	18
	3. 30kg RSPM + 20kg sawdust	48	30
Trial 4	1. 40kg ADSPM	70	10
	2. 40kg ADSPM + 10kg sawdust	58	16
	3. 30kg ADSPM + 20kg sawdust	49	30

RSPM - raw separated pig manure; ADSPM - anerobically digested separated pig manure.

The temperature of each compost pile was recorded daily. Aeration of the tumblers was provided by manually turning the tumblers twice daily (morning and afternoon) during the first week of the trial and once-a-day thereafter. Samples weighing approximately 0.5 kg were taken from the compost piles on Days 0, 3, 7, 14, 21, 28, 42 and 56 and tested for pH and WC. Ash content, organic matter (OM) and C, N, and hydrogen (H) contents were measured in samples collected on Day 0 and Day 56. Two tests were undertaken to evaluate the compost as a growth medium. An Oxygen Uptake Rate (OUR) test was conducted on Day 0 and Day 56 samples to determine the aerobic biological activity of the compost at the beginning and end of the composting process. The OUR test measures the respiration rate of microorganisms within the compost. Stable compost will have a lower OUR than unstable compost. A cress seed germination test was undertaken on samples taken on Day 56 to determine the germination index (GI). The GI test is a measure of root growth and length and is used to determine compost maturity.

Results/Discussion

For all trials, the temperatures in the tumblers increased rapidly after mixing. For all treatments, temperatures of greater than 50°C were achieved in the first few days of composting. All treatments except the manure only treatments (Treatment 1 in each trial) remained above 50°C for at least one week after mixing. The temperature in the manure only treatments tended to drop much sooner than the treatments with added bulking agents in all of the trials. This was because of the poor composting conditions in the manure only treatments. Figure 1 shows an example of the temperature profile of the treatments for trial 4.

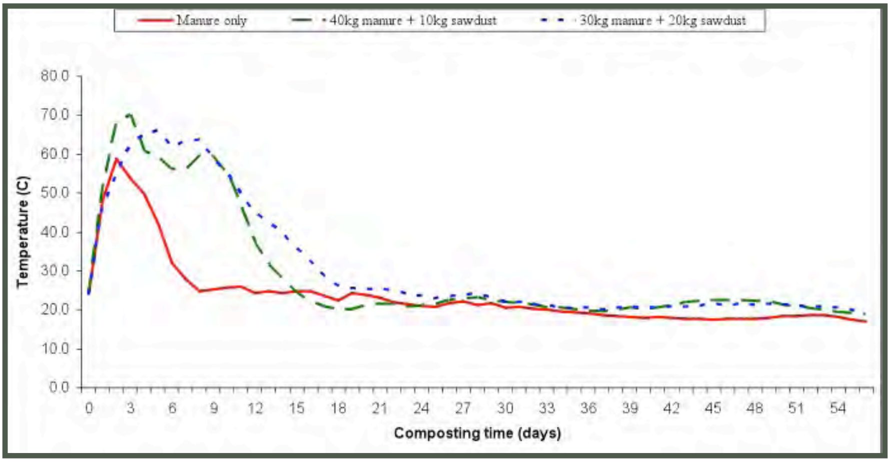


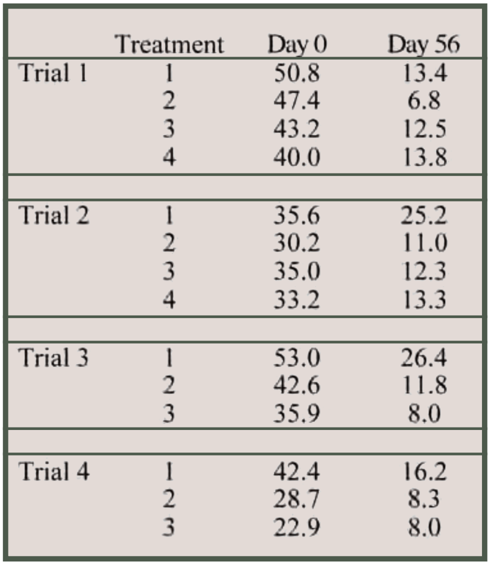
Figure 1 - Temperature profile for all three treatments in Trial 4

The pH of the mixtures showed a similar pattern for all treatments. pH rose when the temperature of the compost was high due to the production of ammonia. When temperatures returned to ambient levels, the pH of the mixtures decreased due to ammonification and nitrification.

The water content of the mixtures showed no significant reduction over the period of composting. This was because our studies were conducted using enclosed tumblers. With the rise in temperature, the water which evaporated from the piles could not easily escape the tumblers. Much of the water vapour condensed on the inner walls of the tumbler, replacing the water that was initially lost through evaporation. This would not occur in large farm-scale compost piles where water would be easily lost to the atmosphere. In some cases water may have to be added to the compost to keep the water content above 40%.

All treatments had high initial organic matter contents (OM). Organic matter varied from approximately 75% for manure only treatments to 80-90% for treatments with added bulking agents. The OM decreased from Day 0 to Day 56. Losses in OM were lowest in treatments which contained sawdust and woodchip (<18% loss of OM). These treatments contained high amounts of lignin which is extremely resistant to breakdown. Organic matter losses in the other treatments ranged from 21-43%. The C:N ratio also decreased over the composting process as carbon was degraded by the composting microorganisms.

Table 2 - Results of the Oxygen Uptake Rate test (mmol O_2/kg OM/hour).



	Treatment	Day 0	Day 56
Trial 1	1	50.8	13.4
	2	47.4	6.8
	3	43.2	12.5
	4	40.0	13.8
Trial 2	1	35.6	25.2
	2	30.2	11.0
	3	35.0	12.3
	4	33.2	13.3
Trial 3	1	53.0	26.4
	2	42.6	11.8
	3	35.9	8.0
Trial 4	1	42.4	16.2
	2	28.7	8.3
	3	22.9	8.0

Results of the OUR tests are shown in table 2. For all treatments the OUR on Day 56 was significantly lower than that on Day 0. The proposed Irish OUR threshold for a stable compost is $\leq$13 mmol O_2/kg OM/hour. The manure only treatment in the four trials failed to achieve this value after composting. All sawdust-amended treatments achieved this value along with the green waste-amended treatment in Trial 1 and the woodchip-amended treatment in Trial 2. However in both of these trials the treatment with added sawdust achieved the lowest OUR value.

Conclusions

The addition of a carbon-rich bulking agent is required when composting separated solids of pig manure. Of the bulking agents investigated sawdust produced the best quality compost. When composting the separated solids of pig manure and sawdust, stable compost can be produced using a C:N ratio as low as 16:1. This corresponds to a separated manure solids to sawdust ratio of 4:1 (fresh weight).

References

Fiszka, 2010 *Management of pig manure including variation in composition and aspects of manure separation into solid and liquid fractions.* Thesis (M.An.Sc.), University College Dublin, 2010.

Pyrolysis of Separated Solids of Pig Manure

Shane Troy, Tereza Nolan, James Leahy, Mark Healy, Witold Kwapinski and Peadar Lawlor

Summary

Two pyrolysis trials were performed to investigate the biochar produced from composted and non-composted separated solids of pig manure. Trial 1 investigated the effect of adding five different carbon-rich bulking agents to the separated solids of pig manure on the characteristics of pig manure biochar. The effect of composting pig manure before pyrolysis, on the biochar produced, was also investigated. In most samples, composting before pyrolysis had a negative effect on higher heating value and the fixed carbon content of the biochar. However, in the samples containing sawdust and woodchip, prior composting resulted in increased fixed carbon contents. Sawdust and woodchip were the bulking agents which gave the greatest higher heating values and fixed carbon contents.

Trial 2 investigated the effect of adding incremental levels sawdust to the separated solids of pig manure after anaerobic digestion on the characteristics of the biochar produced following pyrolysis. The higher heating values, fixed carbon contents and surface areas of the biochars increased as the percentage of sawdust in the feedstock increased. Composting before pyrolysis had a negative effect on higher heating value, fixed carbon content and surface area of the biochar.

Introduction

Pyrolysis is a process whereby a biomass feedstock, such as woodchip or livestock manure, is heated to very high temperatures in an oxygen-free atmosphere. The organic portion of the feedstock is converted to biochar and volatile gases. These volatile gases contain tars which can be condensed to form a combustible bio-oil. Many modern systems use the gas produced during pyrolysis to provide all the energy requirements of the pyrolysis unit. The bio-oil produced can be burned directly to generate heat or refined to produce transportation fuels. However, the main topic of our investigation was to analyse the biochar produced.

The two main potential uses for the biochar are as a fertiliser or a fuel. Biochar can be used as a feedstock for coal combustion and gasification plants. It can also be applied to the soil as a soil addendum to improve fertility or to sequester carbon in the soil, earning income in the future through carbon credits.

Studies in soils with low organic matter have shown increased biomass yield and plant growth using biochar additions in conjunction with another nutrient source.

However, even in relatively fertile soils with higher organic matter (OM) content, biochar may be used to increase the efficiency of fertilisers, thus reducing fertiliser applications. Due to its high absorptive capacity, biochar reduces nutrient leaching and maintains the improvements due to the application of mineral fertiliser over a longer period of time than that achieved by the fertiliser application alone. The nutrient retention capabilities of soil amended with biochar are a result of greater cation exchange capacity and increased populations of mycorrhizal fungi. This leads to greater nutrient availability for plants. Plant uptake of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and some micronutrients has been shown to be increased with the addition of biochar to soil. Biochar also increases soil pH and reduces soil density, thereby increasing drainage, aeration and root penetration.

The use of biochar produced through the pyrolysis of manures can have some benefits to farmers. It can be used to alleviate the problems of nitrogen (N) leaching from soils which can be a problem when manure is landspread. The P and K content of the manure are almost completely recovered in the biochar, leading to higher concentrations in the biochar than in the original manure. Due to the higher N, P and K concentrations in biochar from manure when compared with biochar from wood wastes, the manure-based biochar may offer additional benefits as a low grade fertiliser, even when used without other forms of fertilisation.

Soil carbon sequestration is another benefit from using biochar. This works by sequestering the carbon removed from the air by plants during photosynthesis. These plants are harvested to produce the biomass feedstock for pyrolysis, producing energy from the gases and bio-oil. Meanwhile, the biochar is applied to soil where it acts as a long-term carbon sink. Organic matter added to soil as manure and compost will be quickly mineralised and released to the atmosphere as carbon dioxide (CO_2). However, the carbon in biochar has been found to persist in soil for millennia. This process removes carbon from the atmosphere, therefore mitigating the effects of global warming.

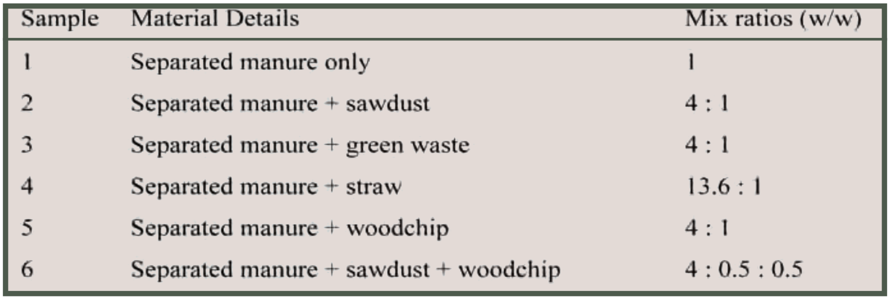
Objective

The overall aim was to investigate the characteristics of biochar produced from the composted and non-composted separated solids of pig manure. The effect of the addition of different types of bulking agent and the addition of incremental levels of sawdust to the separated solids of pig manure before pyrolysis was also investigated.

Methods

Two trials were undertaken. In each, samples were analysed (A) pre-composting and (B) post-composting to examine the effect of composting before pyrolysis on the quality of the biochar formed. In Trial 1, the effect of different carbon rich bulking agents on the characteristics of pig manure biochar was investigated. Six different materials consisting of separated solids of pig manure mixed with different bulking agents were studied (Table 1).

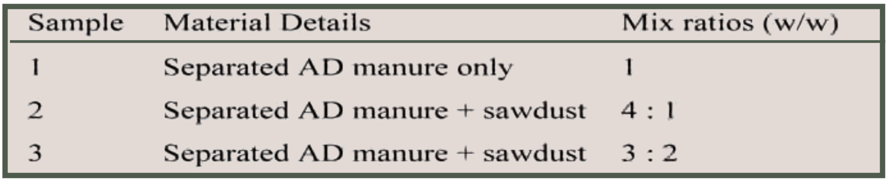
Table 1 - Details of the materials analysed in Trial 1



Sample	Material Details	Mix ratios (w/w)
1	Separated manure only	1
2	Separated manure + sawdust	4 : 1
3	Separated manure + green waste	4 : 1
4	Separated manure + straw	13.6 : 1
5	Separated manure + woodchip	4 : 1
6	Separated manure + sawdust + woodchip	4 : 0.5 : 0.5

Trial 2 investigated the effect of incremental levels of sawdust addition to the separated solids of anaerobically digested pig manure on the characteristics of the biochar produced following pyrolysis (Table 2).

Table 2 - Details of the materials analysed in Trial 2



Sample	Material Details	Mix ratios (w/w)
1	Separated AD manure only	1
2	Separated AD manure + sawdust	4 : 1
3	Separated AD manure + sawdust	3 : 2

AD – anaerobically digested

All materials were dried at 60^{o}C for 48 hours and milled before storage in a refrigerator prior to pyrolysis and analysis. Milling ensured samples were homogenous. A laboratory-scale pyrolysis unit (Figure 1) was used to pyrolise each sample.

During pyrolysis, samples were heated to 600±10^{o}C. A flow of 30mL/min nitrogen ensured that the atmosphere inside the unit was oxygen free. The residence time for pyrolysis was 15 minutes. Gases produced were cooled at a temperature of -7±1^{o}C to form bio-oil. The mass of the biochar and bio-oil was determined after pyrolysis in order to calculate % yield of biochar and bio-oil.

Duplicate samples of each biomass and their resulting biochar following pyrolysis were subjected to proximate analysis for Water Content (WC), ash content, Volatile Matter content and Fixed Carbon. Each biomass sample and resultant biochar also underwent ultimate analysis for C, N and H contents.

Higher Heating Value was calculated from the ultimate analyses using equations.

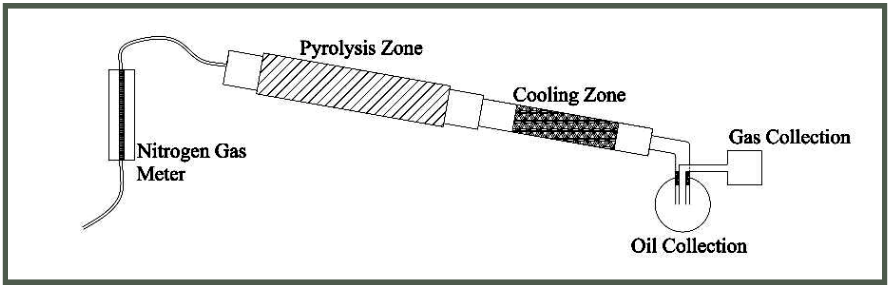


Figure 1: Laboratory scale pyrolysis unit

Results/Discussion

Trial 1

Details of the selected proximate and ultimate analyses results for the biochars are given in Table 3.

Table 3 - Proximate and ultimate results for biochars for trial 1

Sample	Yield char (%)	Ash (%)	VM (%)	FC (%)	N (%)	C (%)	H (%)	HHV (MJ/kg)
1A	42.3	61.2	19.5	19.3	2.6	35.4	1.2	16.7
1B	53.1	62.6	21.8	15.6	2.8	32.0	1.2	16.5
2A	33.8	45.4	17.9	36.8	2.0	54.5	1.7	19.7
2B	39.7	42.3	19.1	38.7	2.3	50.6	1.7	18.9
3A	38.5	43.2	19.8	37.1	2.4	50.7	1.7	18.9
3B	48.9	47.0	18.6	34.4	2.9	39.4	1.5	17.1
4A	37.7	57.6	17.0	25.4	2.4	44.7	1.4	17.7
4B	52.2	60.6	19.9	19.6	2.9	33.6	1.3	16.5
5A	33.9	52.5	18.7	28.8	2.0	55.4	1.9	20.0
5B	37.0	47.0	17.3	35.7	2.3	49.5	1.5	18.6
6A	34.2	48.3	19.6	32.1	2.0	48.2	1.2	18.2
6B	39.8	41.9	18.9	39.2	2.3	46.9	1.5	18.1

All analyses preformed on a dry basis; A=before composting; B=after composting; HHV=higher heating value; VM=volatile matter content; FC= fixed carbon content.

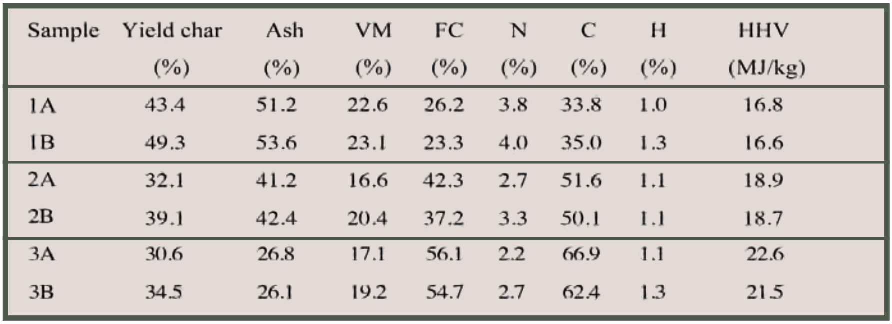
Composting increased the biochar yield after pyrolysis. These increases were greatest in samples 1, 3 and 4 (26-39%), but lower in samples 2, 5 and 6 with lignin rich bulking agents (9-18%).

For samples 1, 3 and 4, the ash content was higher in the composted samples while the Fixed Carbon content was lower. The opposite was true for samples 2, 5 and 6, the samples which contain lignin rich bulking agents (sawdust and woodchip). Here, composting before pyrolysis reduced ash content and increased Fixed Carbon content in the biochar. If high Fixed Carbon content is considered an important component of the biochar to be produced, then composting before pyrolysis should be considered for biomass containing manure with sawdust or woodchip. Highest Fixed Carbon contents were found in samples 2 and 3 before composting and samples 2, 5 and 6 after composting. Composting reduced the Higher Heating Value. Therefore, if the biochar was to be used as a fuel, composting would not be advisable. The highest Higher Heating Values were found in samples 2 and 5 before composting.

Trial 2

Details on the selected proximate and ultimate analyses results for the biochars produced in Trial 2 are given in Table 4.

Table 4 - Proximate and ultimate results for biochar for trial 2



Sample	Yield char (%)	Ash (%)	VM (%)	FC (%)	N (%)	C (%)	H (%)	HHV (MJ/kg)
1A	43.4	51.2	22.6	26.2	3.8	33.8	1.0	16.8
1B	49.3	53.6	23.1	23.3	4.0	35.0	1.3	16.6
2A	32.1	41.2	16.6	42.3	2.7	51.6	1.1	18.9
2B	39.1	42.4	20.4	37.2	3.3	50.1	1.1	18.7
3A	30.6	26.8	17.1	56.1	2.2	66.9	1.1	22.6
3B	34.5	26.1	19.2	54.7	2.7	62.4	1.3	21.5

All analyses preformed on a dry basis; A=before composting; B=after composting; HHV=higher heating value; VM=volatile matter content; FC= fixed carbon content.

Biochar yield was significantly higher for samples which had been composted. This is due to the decreased Volatile Matter content in composted samples. Biochar yield decreased as the level of sawdust addition was increased. Again this decrease was to due to increased Volatile Matter in the sawdust, which resulted in more gas formation and less biochar formation.

The Fixed Carbon content was lower in all composted samples. In this instance,

composting before pyrolysis would not be advised if high Fixed Carbon content was an important component of the biochar to be produced (i.e. if it is to be used as a soil addendum). The ash content was reduced and the Fixed Carbon content increased as the percentage of sawdust in the samples increased.
The C content and Higher Heating Value decreased after composting for all samples. The Higher Heating Value values increased as the amount of sawdust added to the samples increased.

Conclusions

Composting of samples resulted in a:

- higher yield of biochar. However, the loss of mass during composting must be taken into consideration when assessing the increased biochar yield
- reduction in the Higher Heating Value of the biochar produced
- higher Fixed Carbon contents when composting raw pig manure and lignin-rich bulking agents (such as woodchip)

Of the bulking agents investigated, sawdust and woodchip resulted in the best heating values and Fixed Carbon contents when mixed with separated raw pig manure. Increasing the percentage of carbon-rich bulking agent in the sample mix resulted in increased Higher Heating Values and Fixed Carbon contents and surface areas.

Further studies

- An energy balance is being carried out to investigate the feasibility of a farm-scale pyrolysis unit producing biochar for land application while using the bio-oil and gases produced to power the process.
- The fertiliser potential (NPK values) of the biochar will be investigated
- Nutrient leaching from soil amended with liquid pig manure, composted pig manure solids and chemical fertiliser, with and without the addition of biochar from pig manure, will be investigated. The addition of biochar to the soil should decrease nutrient leaching for all three amendments due to the high nutrient retention capacity of biochar, thus allowing for reduced fertiliser application rates and reduced costs for farmers.

Treatment of Piggery Wastewaters Using Constructed Wetlands

Caolan Harrington, Miklas Scholz, Noel Culleton and Peadar Lawlor

Summary

A series of small, replicated ‘meso-scale’ Integrated Constructed Wetland (ICW) systems were built in Moorepark, Fermoy, Co. Cork to examine the use of ICW systems for the treatment of anaerobically digested swine wastewater over an 18-month period. These systems examined key operations in the ICW design to investigate the possibility of tailoring the ICW approach to successfully treat piggery wastewaters. The results showed potential for this technology to be applied to large scale swine wastewater treatment.

Introduction

The EU Nitrates Directive and the Water Framework Directive (WFD) place significant pressure on member states to focus on the quality of their water bodies. The WFD requires that all surface and ground water bodies achieve ‘good status’ by 2015. The Nitrates Directive places a restriction on the amount of nitrogen and phosphorus that can be applied to spreadlands over the course of a year (170 kg of nitrogen per hectare per year in Ireland). Agriculture is potentially a large contributor to non-point source diffuse pollution (such as surface run-off), yet there are very few viable approaches available to farmers to tackle such problems.

The use of constructed wetlands has been growing around the world as an approach for the treatment of a range of wastewaters, including agricultural yard wastewaters, slurries, manure, run-off and soiled water. Their popularity has been gaining momentum in the last 20 years in Ireland with the development of Integrated Constructed Wetlands (ICW). These were pioneered in the Anne Valley, Co. Waterford to treat agricultural wastewaters. The result of this has been an improvement in water quality in the River Anne, which was previously labelled “a dirty ditch” by the EPA, to a river with a Q-rating (based on small invertebrate diversity) of 4 (clean). These ICW systems have been shown to be cost effective, require low maintenance and are capable of treating a wide range of wastewaters. In addition, they have enhanced local biodiversity and environmental conditions, as well as providing a social amenity to the local area. Over the last 20 years, the ICW initiative has shown these systems to be a fully capable approach to the treatment of agricultural wastewaters. However, their efficacy in piggery wastewaters has not been examined. The latter are generally more troublesome to treat than cattle wastewaters due to their highly concentrated and variable characteristics.

Moreover, piggeries generally have limited available spreadlands and consequently, the manure produced on the unit is often used by other farmers as fertilizer. However, implementation of the Nitrates Directive has limited the amount of manure that can be spread on these traditional spreadlands. Therefore, providing a cost-effective method for the treatment of wastewater/ liquid manure on piggeries could give greater flexibility in the management of pig manure.

Objective

The primary objectives of this study were to examine the key operating procedures in ICW systems and examine them individually for their effect on the removal of nutrients (nitrogen and phosphorus) from the wastewater being treated. The examination and determination of their impact on the efficiency of ICW systems treating swine wastewaters would allow the improvement/ adaptation of the current ICW design to be applied on pig units.

Methods

From December 2008 to June 2010, 16 meso-scale ICW systems were operated in Teagasc, Moorepark, Co. Cork. These systems were directly scaled down from full-scale ICW systems found elsewhere in Ireland. The layout of these 16 systems is shown in Figures 1 and 2.

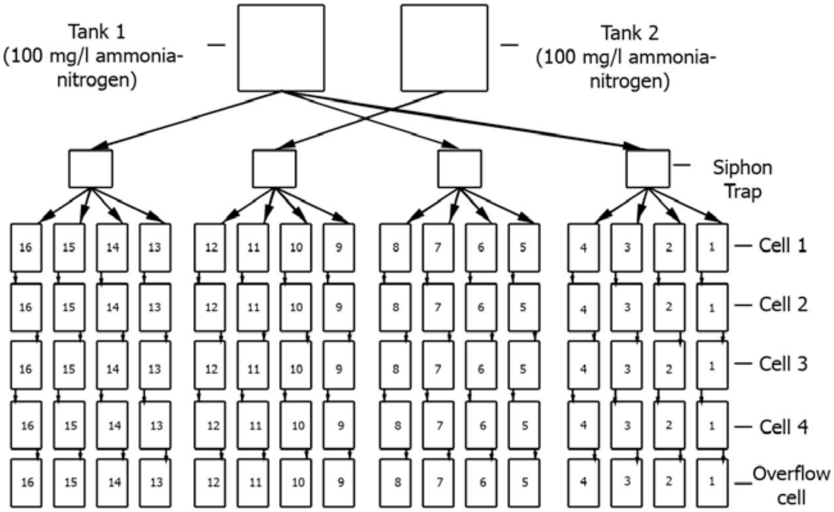


Figure 1 – Schematic drawing of the meso-scale ICW systems

Figure 2 – Meso-scale ICW systems in June of 2009

Each system comprised a series of 4 cells in sequence with each cell receiving gravity-fed flow from the preceding cell (Figure 1). Each system was planted with *Glyceria maxima* (Reed Sweet Grass) in relatively dense groups to ensure complete coverage by the plants once established (Figure 3.). Each system was fed dilute anaerobically digested swine wastewater by means of a small submersible pump from 1 m^3 storage units. Two storage units contained the influent material that was pumped to each of the systems.

Figure 3 – Bare-root Glyceria maxima planted in each cell

The 16 systems comprised 4 key operations, with 4 replicates of each system (Figure 1.) The operational parameters of each system are presented in Table 1. The initial loading of the systems (110 m^3 per hectare per day) was deemed too high due to the small scale of the units and the high ammonium-nitrogen (NH_3-N) loading, which had a significant effect on the establishment of the plants in each of the systems. Ammonium is a toxic substance to many plants and can be the limiting factor in the establishment of ICW plants. Due to this fact the initial loading was decreased from 110 to 37 m^3 per hectare per day. Once the loadings were decreased, the removal rates across all systems improved considerably and were maintained throughout the remainder of the experiment. Each tank was filled with the liquid fraction of spent anaerobically digested pig manure and the nutrient loading rate was adjusted by dilution with water. Each system was examined and maintained each week throughout the study period.

Table 1 - Key operational parameters of each system.

System	Ammonium – N (mg per litre)	Hydraulic loading (m^3/hectare/day)	Effluent recycling
Normal (cells 1 to 4)	100	37	No
Recycling (cells 5 to 8)	100	37	Yes (100%)
High nutrient load (cells 9 to 12)	200	37	No
High flow rate (cells 13 to 16)	100	74	No

Results/Discussion

The overall average removal efficiencies of these 4 systems for ammonium-nitrogen, molybdate reactive phosphorus (MRP) and other nitrogen species (nitrite, nitrate and total oxidised nitrogen) is shown in Table 2. Over the full 18-month experimental period, they averaged an ammonium removal rate of >99%. High removal rates were also found for MRP and total oxidised nitrogen.

Table 2 - Average removal rates (%) for each system.

	Normal	Recycling	HNL	HFR
Ammonium	100	100	100	99
Molybdate reactive phosphorus	98	96	95	89
Nitrite	95	96	98	84
Nitrate	93	92	82	76
Total Oxidised Nitrogen	93	93	93	77

HNL-High Nutrient Load. HFR-High Flow Rate

The variability of these removal rates was quite low throughout the 18-month period, regardless of weather conditions or time of year. This consistent removal shows the capacity of these systems to deal with variable inflow as well as small fluctuations in volume due to weather (heavy rain, storm events).

The only periods where removal was negatively affected was during the winter periods where heavy frost and sub-zero temperatures affected the small-scale systems. However, this is not typically a problem in large-scale ICW systems and was considered an effect of scale. Despite these conditions, removal rates were high, but not quite as high as during the summer months.

Some seasonal changes, however, were found for ammonium-nitrogen removal rates (Figure 4).

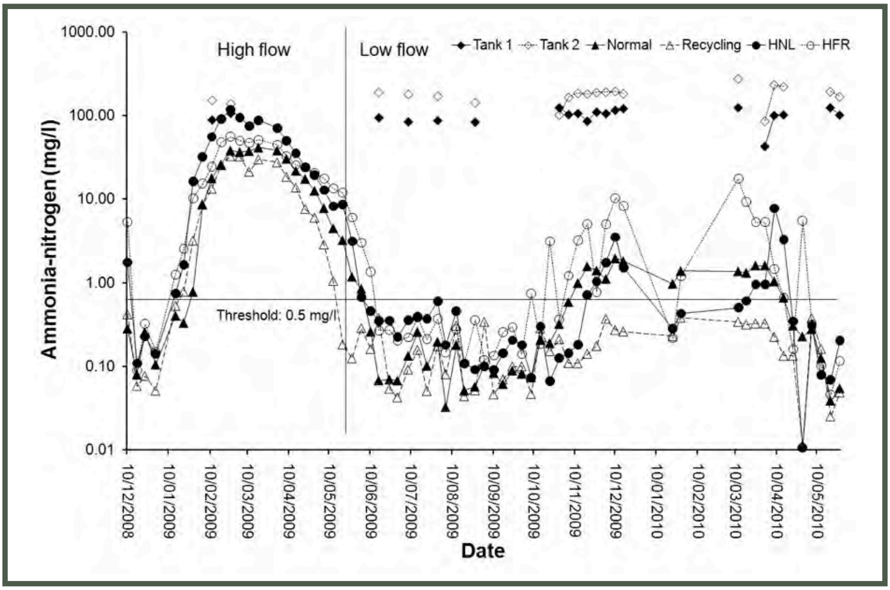


Figure 4 – Average ammonium-nitrogen levels recorded in the outflow of the 4 systems

The effluent collected at the end of each system typically had ammonium concentrations lower than 1mg per litre (Figure 4.). The only instances where this was not the case was during the winter months, which during this experiment were exceptionally harsh and resulted in the freezing over of all of the cells.

Throughout the summer months, there was little to no outflow from the majority of the systems with the exception of the high flow rate (HFR) systems which received twice the volume of the other operations. This “zero-outflow” is a design aspect that is replicated in full-scale systems as well, ensuring that outflow from any system is typically only during periods of extended or heavy rain.

The overall removal of nutrients through the systems was similar to removal levels recorded from ICW systems in the Anne Valley in Co. Waterford as well as other full-scale ICW systems in use throughout Ireland.

Conclusions

- Despite the low initial removal rates of nutrients, the performance of all of the ICW systems improved dramatically when the inflow was reduced from 100 to 37m^3 per hectare per day.
- Based on our results with the meso-scale systems, an average pig unit of 500 sows integrated would require a land area of ~ 10 hectares to construct an ICW to treat the separated liquid fraction of the pig manure it generates. This calculation is based on a hydraulic loading rate of 74m^3 per hectare per day and a maximum ammonium level in the influent of 200mg/litre (the highest level studied in our system). However in a full –scale ICW, some other features need to be considered (soil liners, bigger size of system etc). These other features and recycling of water could potentially increase the ammonia tolerance of the system. This might potentially halve the land area required to ~5 hectares, however this would have to be proven.
- Wastewater recycling has a 3-fold benefit; it reduces the water necessary to dilute the influent wastewater to a manageable level, it increases the hydraulic retention time and it helps to reduce or even eliminate an outflow.
- The volume of water leaving each system compared to the volume of influent is greatly reduced due to evapotranspiration. In full-scale systems, this is further increased with water being retained in the wetland soils and limited ground infiltration. This helps reduce any potential risk to the receiving waterbody.
- Additional benefits of ICWs are their low maintenance costs, low energy requirements and their enhancement of local biodiversity and environment.
- Guidelines for farmyard soiled water and domestic wastewater are available in the ICW guidance manual on the EPA and Department of Environment, Heritage and Local Government websites.

Treatment of Piggery Wastewaters Using Woodchip Biofilters

Kathy Carney, Michael Rodgers, Peadar Lawlor and Xinmin Zhan

Summary

The Nitrates Action Plan has restricted the amount of land area suitable for the landspreading of pig manure. Treatment of pig manure would reduce the need for extensive landspreading. This study investigates the use of woodchips as biofilter media in two parts: a laboratory study and a pilot scale study. The laboratory study consisted of twelve woodchip biofilters treating the separated liquid fractions of (i) raw pig manure (SR) and (ii) pig manure after anaerobic digestion (SAD). Two loading rates (low and high) were examined: 5 L/m^2/day and 10 L/m^2/day. Results from the laboratory study indicated that organic matter (in terms of chemical oxygen demand –COD) and ammonium removals were higher at the low loading rate. More nitrification occurred at the lower loading rate as indicated by the lower ammonium and higher nitrate production in both the SR and SAD woodchip biofilters. The pilot scale biofilter design was based on the results of the laboratory study. Analysis of the performance of laboratory and pilot scale woodchip biofilters will aid in the development of design guidelines for a smart, efficient, low maintenance treatment system that can be adapted by the Irish pig industry.

Introduction

The Nitrates Action Plan requires the Irish pig industry to investigate new methods of treating pig manure that reduce the need for extensive landspreading. Pig manure contains high concentrations of nutrients with the potential to cause environmental damage to receiving waters; for instance, ammonium nitrogen is toxic to fish, and can lead to eutrophication and consequent depletion of dissolved oxygen levels in water.

Previous studies suggest woodchips can supply biodegradable carbon substrates that can be used for the balanced growth of beneficial heterotrophic microorganisms in the treatment of wastewaters where excess nitrogen and phosphorus are present. This balanced growth ensures that additional nitrogen is incorporated into microbial cells thus: (i) reducing nitrogen concentrations in the filter effluent and (ii) leading to beneficial slow release of nitrogen when the woodchips are spread on land as a soil conditioner.

The use of out-wintering woodchip pads has become popular in Ireland and Scotland as an environmentally beneficial means of over-wintering cattle. Effluent passing through these shallow biofiltration woodchip pads is treated, to a limited degree, due to the physical, chemical and biological processes that occur in the pads. Analysis of these woodchip pads suggests that successful treatment of high strength piggery wastewater could be achieved using woodchips as biofilter media. The spent woodchips from the biofilters could be beneficially land-spread, leading to reduced transport costs.

Objective

The objective of this study is to investigate the use of native woodchips as a biofilter media for the treatment of (i) the separated liquid fraction of raw pig manure (SR) and (ii) the separated liquid fraction of digestate after anaerobic digestion of pig manure (SAD). The study is divided into two parts: (i) a laboratory study and (ii) a pilot scale study. Successful treatment of piggery wastewater using woodchip biofilters could reduce: (i) nutrients released into ground and surface waters, (ii) transportation costs and (iii) mains water requirements on a pig farm through reuse.

Methods

Design and construction of the laboratory woodchip biofilters

The laboratory study provided controlled conditions for examining the nutrient removal efficiency of the woodchip biofilters at two different hydraulic loading rates. Two steel frame units (Figure 1), each supporting six identical woodchip filters, were placed in a controlled temperature room at 11 ± 1 ºC .The woodchips were contained within 225 mm diameter polyethylene pipes (CorriPipe). A 10 mm wire mesh was attached to the base of the CorriPipe. The filters were open at the bottom to allow air flow through the filters in order to maintain an aerobic environment for the microorganisms.

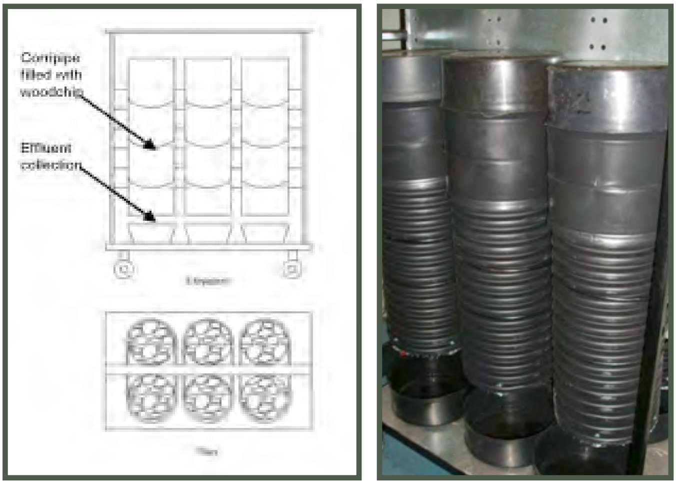


Figure 1 – Laboratory scale biofilters in NUI Galway

Lodgepole pine (*Pinus contorta*) woodchips were chosen as the biofilter media. Lodgepole pine is the second most popular conifer in Ireland, growing on over 65,000 hectares of the Irish Forestry Company (Coillte Teo.) holding land. The lodgepole pine logs were freshly cut, debarked and chipped with an industrial wood chipping machine. The filters had a total depth of 600 mm; 400 mm of course woodchips (14 – 28 mm) and 200 mm of fine woodchips (0 – 8 mm). Before operation, each filter was seeded with two litres of activated sludge taken from a local wastewater treatment plant.

Influent wastewater; source and characteristics

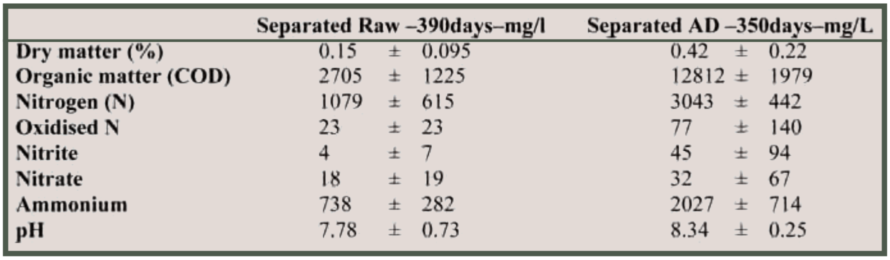
The wastewaters treated by the biofilters were:

(i) the separated liquid fraction of raw pig manure (SR). It was sourced from Teagasc, Moorepark, Fermoy, Co. Cork, and separated using a decanter centrifuge (GEA Westfalia Separator UCD 205, Germany).

(ii) the separated liquid fraction of pig manure after anaerobic digestion (SAD). The anaerobic digestate was generated in a mesophilic anaerobic digester and separated by a belt press separator.

Both liquid fractions were collected and stored in a controlled temperature room at 11 ± 1˚C. Solid and nutrient values are shown in Table 1.

Table 1 – Mean ± standard deviation of various parameters over 390 and 350 days of operation for separated raw and AD influents, respectively



	Separated Raw –390days–mg/l	Separated AD –350days–mg/L
Dry matter (%)	0.15 ± 0.095	0.42 ± 0.22
Organic matter (COD)	2705 ± 1225	12812 ± 1979
Nitrogen (N)	1079 ± 615	3043 ± 442
Oxidised N	23 ± 23	77 ± 140
Nitrite	4 ± 7	45 ± 94
Nitrate	18 ± 19	32 ± 67
Ammonium	738 ± 282	2027 ± 714
pH	7.78 ± 0.73	8.34 ± 0.25

Hydraulic loading rates

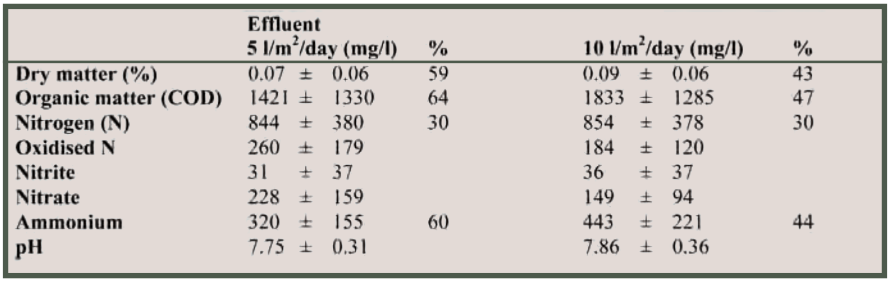
The SR and SAD influents were applied manually twice daily at 9 am and 6 pm. 99 ml for the low loading rate and 199 ml for the high were added to the top surface of the filter media over 2 and 4 minutes, respectively. This loading represented hydraulic loading rates of 5 L/m^2/day (low) and 10 L/m^2/day (high). Three replicates were examined for each loading rate and each influent type. Samples of influent and effluent were taken twice weekly and tested within 24 hours of sampling.

Results/Discussion

Separated raw manure

Table 2 shows the average concentrations of solids and nutrients in the SR biofilter effluents at the low and high loading rates over the study period of 390 days. The presence of oxidized nitrogen was observed after 60 days of operation. This was assumed to be the end of the start-up period. Therefore percentage removals are calculated from this point onwards. The results are shown in table 2.

Table 2 – Mean ± standard deviation of various parameters over 390 days of operation and average removal rates (%) after start up period for separated raw biofilter effluent

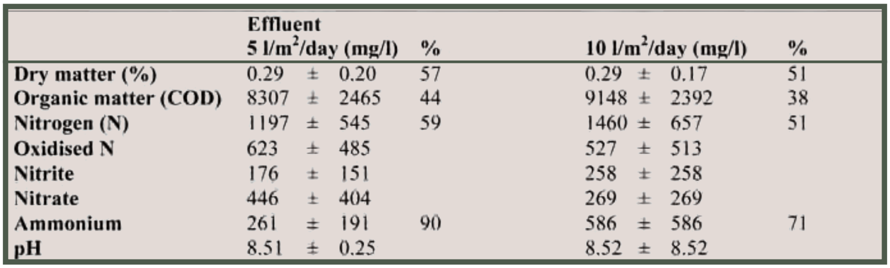


	Effluent 5 l/m^2/day (mg/l)	%	10 l/m^2/day (mg/l)	%
Dry matter (%)	0.07 ± 0.06	59	0.09 ± 0.06	43
Organic matter (COD)	1421 ± 1330	64	1833 ± 1285	47
Nitrogen (N)	844 ± 380	30	854 ± 378	30
Oxidised N	260 ± 179		184 ± 120	
Nitrite	31 ± 37		36 ± 37	
Nitrate	228 ± 159		149 ± 94	
Ammonium	320 ± 155	60	443 ± 221	44
pH	7.75 ± 0.31		7.86 ± 0.36	

Separated AD manure

Table 3 shows the average concentrations of suspended solids and nutrients in the biofilter effluent for the SAD wastewater over 350 days of operation. The occurrence of nitrification was observed after 70 days of operation; therefore percentage removals calculated from this point onwards (days 70 – 350), which was assumed as the end of the start-up period, are shown in Table 3.

Table 3 – Mean ± standard deviation of various parameters over 350 days of operation and average removal rates (%) after start up period for separated AD biofilter effluent



	Effluent 5 l/m^2/day (mg/l)	%	10 l/m^2/day (mg/l)	%
Dry matter (%)	0.29 ± 0.20	57	0.29 ± 0.17	51
Organic matter (COD)	8307 ± 2465	44	9148 ± 2392	38
Nitrogen (N)	1197 ± 545	59	1460 ± 657	51
Oxidised N	623 ± 485		527 ± 513	
Nitrite	176 ± 151		258 ± 258	
Nitrate	446 ± 404		269 ± 269	
Ammonium	261 ± 191	90	586 ± 586	71
pH	8.51 ± 0.25		8.52 ± 8.52	

Dry matter

The addition of two 100 mm layers of fine woodchips above the coarse woodchip layer increased the dry matter removal capacity of the biofilters. Higher removal occurred at the low loading rate for the SR biofilters. Loading rate did not influence dry matter removal in the SAD biofilters, possibly due to the small particle size.

Organic matter (Chemical oxygen demand)

COD removal was higher at the low loading rate when compared to the high loading rate. The SR and SAD biofilters were successful in removing an average of 64 % and 44 % of the COD, respectively, at the low loading rate.

Nitrogen

Table 2 and Table 3 show the average concentrations of ammonium, nitrate and nitrite in the SR and SAD biofilter effluents. Nitrogen removal occurred through a number of mechanisms: (i) filtration, (ii) simultaneous nitrification and denitrification, (iii) volatilisation of ammonia and (iv) biomass assimilation. At the low loading rate, an average of 30 % and 59 % of total nitrogen was removed by the SR and SAD biofilters, respectively. Higher complete nitrification occurred at the low loading rate, indicated by the lower ammonium and higher nitrate production in both the SR and SAD biofilters. An average of 60 % (SR) and 90 % (SAD) removal of ammonium occurred at the low loading rate following the respective start-up periods.

Pilot scale woodchip biofilters

Following on from the laboratory work pilot scale biofilters were constructed at Moorepark to demonstrate effects of scale, variations in temperature and rainfall. As the majority of nitrogen in the aerobic biofilter effluent in the laboratory study was in the form of nitrate and nitrite, the pilot scale biofilters incorporate a saturated layer of woodchips at the base of the filter (Figure 2); supplying an anoxic environment for the conversion of nitrate to nitrogen gas, thereby increasing the total nitrogen removal of the system.

Figure 2 – Pilot scale filters at Moorepark

Conclusions

Results from the laboratory-scale study indicate that:

(i) woodchip biofilters are successful in removing an average of 59 % (SR) and 57 % (SAD) of dry matter at a lading rate of 5 L/m^2/day

(ii) for both piggery wastewaters (SR and SAD) COD and ammonium concentrations in biofilter effluents were lower at the low loading rate (5 l/m^2/day).

(iii) the lower loading rate resulted in higher complete nitrification in biofilters treating both SR and SAD liquids.

(iv) a number of mechanisms were responsible for nitrogen removal; filtration, simultaneous nitrification and denitrification, ammonium volatilisation, and biomass assimilation.

(v) the majority of ammonium removed in the system was converted to nitrite and nitrate. The addition of a saturated layer of woodchips in the pilot scale woodchip biofilters could improve the nitrogen removal performance of the system as this anoxic zone encourages denitrification, thereby reducing the oxidised nitrogen in the effluent.

(vi) analysis of the performance of laboratory and on-site woodchip biofilters will aid in the development of design guidelines for a smart, efficient, low maintenance treatment system that can be adapted by the Irish pig industry.

References

S.I.610.2010., *European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010.*

Composting as a Treatment Strategy for Pathogen Removal from the Solid Fraction of Pig Manure

Gemma Mc Carthy, Peadar Lawlor, Lee Coffey, Tereza Nolan, Montserrat Gutierrez and Gillian Gardiner

Summary

The aim was to investigate survival of pathogens and enteric indicator micro-organisms during composting of the separated solid fraction of pig manure. Findings showed that *Salmonella*, when present, was removed by composting. *Enterococcus* and *E. coli* counts were reduced and were undetectable in the final compost. Coliform, although reduced were still present at counts of 3.66-4.43 $\log_{10}$ CFU/g in the final compost. Overall, the pig manure-derived compost complied with EU regulations for marketable processed manure products, as it was free from *Salmonella*, with *E. coli* or *Enterococcus* counts not exceeding 3.0 $\log_{10}$ CFU/g.

Introduction

Considerable quantities of manure are generated on farms each year in Ireland. Land spreading is the least expensive and most widespread use for pig manure and supplies grassland and crops with valuable nutrients and organic matter to increase soil fertility. However, intensification of pig production in Ireland has resulted in large numbers of pigs concentrated in specific geographic locations (e.g. Co. Cavan and Co. Cork). This often means that in these ‘pig dense’ areas the amount of nutrient rich pig manure produced is well in excess of the quantity needed to meet agronomic requirements. The Nitrates Directive (91/676/EEC, 1991) of 12 December 1991 first implemented in Ireland in 2006 and currently interpreted in Ireland by S.I. No. 610 (2010) has imposed restrictions on land spreading of manure in the European Union. This has forced the Irish pig industry to investigate alternative management strategies for pig manure. One option is composting.

Composting is an inexpensive, sustainable method of treating waste materials which converts organic matter into a humus-like product. Pig manure-derived compost could potentially be used as an organic fertilizer or further processed into added-value products, such as a solid biofuel. However, to market a processed manure product it must comply with microbiological criteria as set out in the EU animal by-product regulations to ensure risks to users are minimized. For example, *Salmonella*, a pathogen which is commonly found in pig manure, should be absent in 25 g samples. In addition, the compost should have a maximum of 1,000 *E. coli* or enterococci per gram (3.0 $\log_{10}$ CFU/g) and spore-forming bacteria must be reduced. Furthermore, an industry compost quality standard has been proposed for Ireland and includes similar limits for pathogenic bacteria. Therefore, it is evident that microbiological analysis of pig manure-derived compost is essential for biosafety assessment and to determine regulatory compliance.

Objective

To investigate survival of pathogens and indicator micro-organisms during composting of the separated solid fraction of pig manure with various bulking agents.

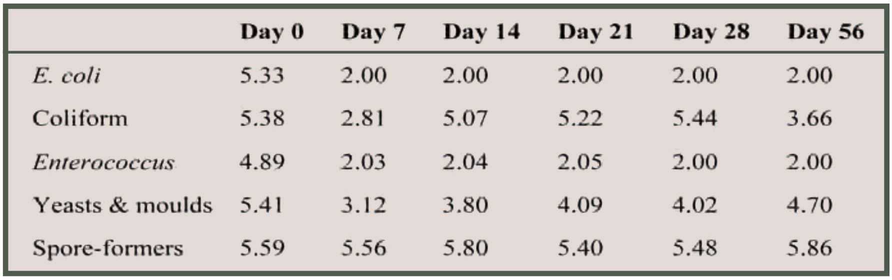
Methods

Two composting trials, each lasting 56 days, were performed at Teagasc, Moorepark, Fermoy, Co. Cork and are described in these proceedings. In Trial 1 the separated solid fraction of pig manure was composted alone (treatment 1; T1) or mixed with the following bulking agents; sawdust (T2), shredded green waste (T3), or chopped barley straw (T4). In Trial 2, the pig manure solids were composted alone (T1) or mixed with sawdust (T2), Sitka spruce woodchips (T3) or sawdust + woodchips (T4). For each treatment there were three replicates. Microbiological analyses were performed on the manure, the separated solids, the bulking agents and on compost samples at days 0, 7, 14, 21, 28 and 56. Samples were serially diluted (10-fold), pour-plated on selective media and incubated at appropriate temperatures to enumerate *Enterococcus, E. coli*, total coliforms, aerobic spore-forming bacteria and yeasts and moulds. For spore-forming bacteria, samples were heated to 80 °C for 10 min prior to plating. All counts were recorded as colony forming units (CFU) per gram and then log-transformed. Representative aerobic and anaerobic spore-formers were isolated from the Trial 2 compost samples at day 56 and identified using 16S rRNA gene sequencing. In addition, the presence/absence of *Salmonella* in 25 g samples was determined according to standard ISO procedures and representative *Salmonella* isolates were identified by serotyping and tested for antibiotic resistance.

Results/Discussion

An antibiotic sensitive isolate of *Salmonella* Livingstone was detected in the sawdust and straw used as bulking agents in compost Trial 1 but was not detected in the manure or in the compost at any time point. In the second trial, *Salmonella* was only recovered from one of the compost tumblers from T4 on day 0. The two isolates recovered were identified as *Salmonella* Schwarzengrund but one was fully sensitive to all 13 antibiotics tested, while the other was resistant to nine, which is worrying. However, *Salmonella* was undetectable on day 7, indicating that it was inactivated, most likely by the heat generated during the composting process.

Table 1 - Mean[1] microbial counts ($\log_{10}$ CFU/g) in pig manure-derived compost from Trial 1



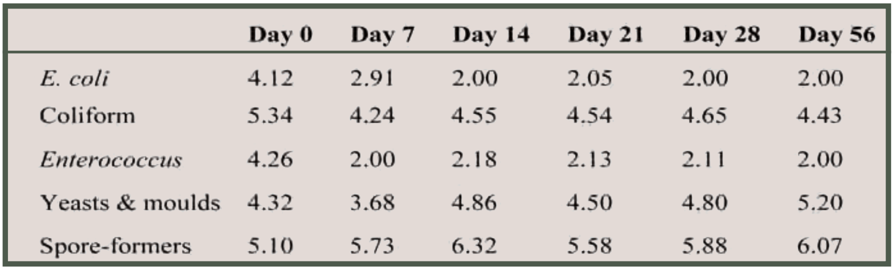
	Day 0	Day 7	Day 14	Day 21	Day 28	Day 56
E. coli	5.33	2.00	2.00	2.00	2.00	2.00
Coliform	5.38	2.81	5.07	5.22	5.44	3.66
Enterococcus	4.89	2.03	2.04	2.05	2.00	2.00
Yeasts & moulds	5.41	3.12	3.80	4.09	4.02	4.70
Spore-formers	5.59	5.56	5.80	5.40	5.48	5.86

[1] Mean counts from Treatments 1, 2, 3 and 4. The limit of detection was 100 CFU/g (values below the limit of detection were recorded as $\log_{10}$ 2.0 CFU/g)

By day 7 the *E. coli* count in the Trial 1 compost had decreased to below the limit of detection (Table 1), probably because the mean temperature during composting had increased to a maximum of 66 °C on day 4. *E. coli* remained undetectable thereafter. However, *Enterococcus*, which also declined on day 7, remained slightly above the limit of detection until day 21, but was undetectable thereafter. Coliform decreased by day 7, increased on day 14 but had declined again by day 56 (Table 1). The increase observed at day 14 is most likely due to the fact that although the mean temperature of the compost increased to a maximum of 66 °C on day 4, it had decreased to 38 ºC by day 14. This temperature decrease would have allowed re-growth of any residual coliform. No significant reductions in aerobic spore-former counts were observed over time; counts remained stable throughout composting and the mean count at day 56 was 5.86 $\log_{10}$ CFU/g (Table 1). In addition, the mean yeast and mould count declined initially but increased at day 14 (Table 1). Despite this increase, yeast and moulds were lower in the final compost than on day 0.

Table 2 shows the mean microbial counts in compost from Trial 2 over the 56 day composting period. Similar to the first trial, mean *E. coli* and *Enterococcus* counts were reduced by day 7 of composting, most likely because the temperature had increased to a maximum of 65 °C on Day 2. Thereafter, *E. coli* counts declined further and together with *Enterococcus*, they were non-detectable at day 56. Coliform counts were reduced by day 7 and remained stable thereafter. Interestingly, the day 7 decrease and subsequent increase in coliform counts observed in Trial 1 was not seen in this trial. However, the reduction in coliform was not as great as that achieved in Trial 1 (Table 2), probably because high temperatures were not maintained for as long in Trial 2. Contrary to the findings for Trial 1, yeast and mould counts were higher on day 56 than initially found on day 0. Furthermore, unlike Trial 1, counts of aerobic spore-formers actually grew during composting, with mean counts higher at days 14, 28 and 56 than at day 0 (Table 2).

Table 2 - Mean[1] microbial counts ($\log_{10}$ CFU/g) in pig manure-derived compost from Trial 2



	Day 0	Day 7	Day 14	Day 21	Day 28	Day 56
E. coli	4.12	2.91	2.00	2.05	2.00	2.00
Coliform	5.34	4.24	4.55	4.54	4.65	4.43
Enterococcus	4.26	2.00	2.18	2.13	2.11	2.00
Yeasts & moulds	4.32	3.68	4.86	4.50	4.80	5.20
Spore-formers	5.10	5.73	6.32	5.58	5.88	6.07

[1] Mean counts from Treatments 1, 2, 3 and 4. The limit of detection was 100 CFU/g (values below the limit of detection were recorded as $\log_{10}$ 2.0 CFU/g)

Most importantly, the compost from both trials complied with EU regulations and the proposed quality standard for compost, as it was free from *Salmonella*, with *E. coli* or *Enterococcus* counts not exceeding 3.0 $\log_{10}$ CFU/g. However, no reductions in aerobic spore-forming bacteria were observed (Tables 1 & 2). This is not surprising, as spore-formers are resistant to temperatures of up to 100 °C and the maximum temperature achieved in the compost was 65-66 °C. Representative isolates were identified as *Bacillus* or closely related genera. As none were pathogenic species, they should pose no risk to end users of the compost. On the other hand, *Clostridium sporogenes* and *Clostridium perfringens* were identified as the predominant anaerobic spore-forming bacteria. As C. *perfringens* spores can cause fatal wound infections, precautions may be necessary for end users handling the manure-derived compost. Yeast and mould counts were also relatively high in the final compost (Tables 1 & 2) and may be potentially hazardous to humans as a result of exposure to fungal spores. However, identification of moulds is required in order to determine potential risks.

Conclusions

Reductions in pathogenic and enteric indicator bacteria were observed during composting of pig manure solids, with *E. coli*, *Enterococcus* and *Salmonella* non-detectable in the final compost. The pig manure-derived compost complies with EU regulations, as it was *Salmonella*-free and counts of enteric indicator bacteria were below limits. Although a reduction in spore-forming bacteria was not achieved *B. licheniformis* was the dominant aerobic spore-former recovered and should pose no risk to end-users. However, the discovery of *Clostridium perfringens*, which can cause wound infections, may be of concern. Overall, composting of pig manure can be considered an alternative to landspreading, which could be used by producers to generate a marketable product.

Integrated Constructed Wetlands as a Treatment Strategy for Pathogen Removal from the Liquid Fraction of Pig Manure and Agricultural Wastewater

Gemma Mc Carthy, Peadar Lawlor, Montserrat Gutierrez and Gillian Gardiner

Summary

The aim was to evaluate the removal of pathogens and enteric indicator micro-organisms in integrated constructed wetlands (ICW's) treating agricultural wastewater and the liquid fraction of pig manure. Findings showed that *Salmonella*, when present in the influent, was removed by treatment through ICW's. *Enterococcus* and *E. coli* were undetectable in the final ICW effluents, while coliform were reduced. Overall, this study demonstrates that on-farm ICW's are a viable treatment strategy for pathogen removal from agricultural wastewater.

Introduction

Considerable quantities of wastewater are generated on farms each year. Wastewater contains animal faeces and urine as well as yard run-off and milking parlour washings if originating on a dairy farm. In addition, although manure separation is not commonly practiced on Irish farms, it generates a liquid fraction which also requires treatment or disposal. In Ireland, land spreading is the least expensive and most widespread disposal option for wastewater. However, it requires sufficient land area in close proximity to the farm, especially considering restrictions imposed by the EU Nitrates Directive. This has forced the pig industry in particular to investigate alternative wastewater management strategies. For the liquid fraction of manure and other wastewater, treatment in constructed wetlands (CW's) may offer a viable alternative to landspreading. Integrated constructed wetlands (ICW's) are horizontal, surface flow CW's specifically designed to incorporate the surrounding landscape (Fig. 1). They consist of a series of linked ponds or 'cells'. The influent material is pumped directly into the first cell and from there it flows sequentially through the other cells. The treated effluent is usually discharged to waterways.

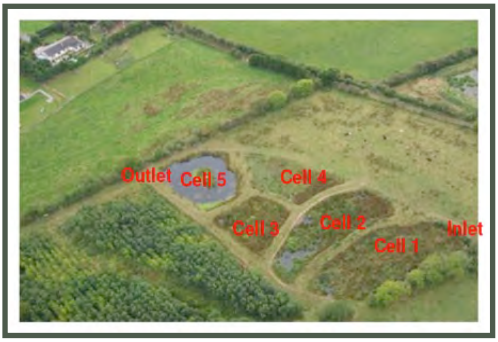


Figure 1 - Aerial view of a five year old surface flow integrated constructed wetland in the Anne Valley, Co. Waterford, Ireland (Carty et al., 2008).

On-farm ICW's used in the Anne Valley in Co. Waterford to treat agricultural wastewater have been shown to reduce nitrogen, phosphorus, suspended solids and chemical and biological oxygen demand. However, like manure, agricultural wastewater is also likely to contain pathogens, such as *Salmonella*. Therefore, information is required on the removal of enteric pathogens, in particular *Salmonella*, from agricultural wastewaters treated in Irish ICW systems.

Objective

To investigate the removal of pathogenic and indicator micro-organisms in ICW's treating wastewater from dairy and pig farms.

Methods

The influent and effluent from the first cell and the effluents from the mid- and final cells were sampled from nine on-farm ICW's on two occasions. These comprised six ICW's in Co. Waterford each with 4-5 cells, treating dairy wastewater and two with 10 and 12 cells, respectively treating piggery wastewater. One other ICW with 10 cells, treating the liquid fraction of anaerobically digested (AD) pig manure was also sampled. Influent and effluent samples were serially diluted (10-fold), pour-plated on selective media and incubated at appropriate temperatures to enumerate *Enterococcus, E. coli* and total coliforms. All counts were recorded as colony forming units (CFU) per ml and then log-transformed.

Results/Discussion

Mean coliform, *E. coli* and *Enterococcus* counts across all nine ICW's from two sampling time-points were significantly lower in the mid-cell effluent than in the effluent from the first cell (Fig. 2). However, no decreases were observed downstream of the mid-cell. Most notably, counts of all three indicator bacteria were lower in the final effluent than in the effluent from Cell 1 and both *E. coli* and *Enterococcus* were non-detectable. Comparing counts in the final effluent with those in the influent, mean removal rates across all nine ICW's were greatest for coliform (81.5 %), with *E. coli* and *Enterococcus* reduced by 55.9 % and 66.9 %, respectively (Fig. 2).

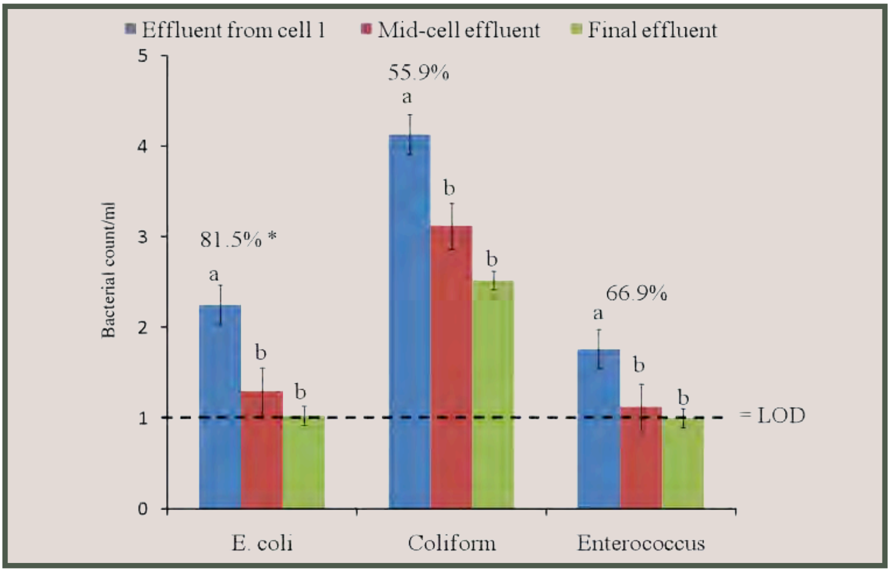
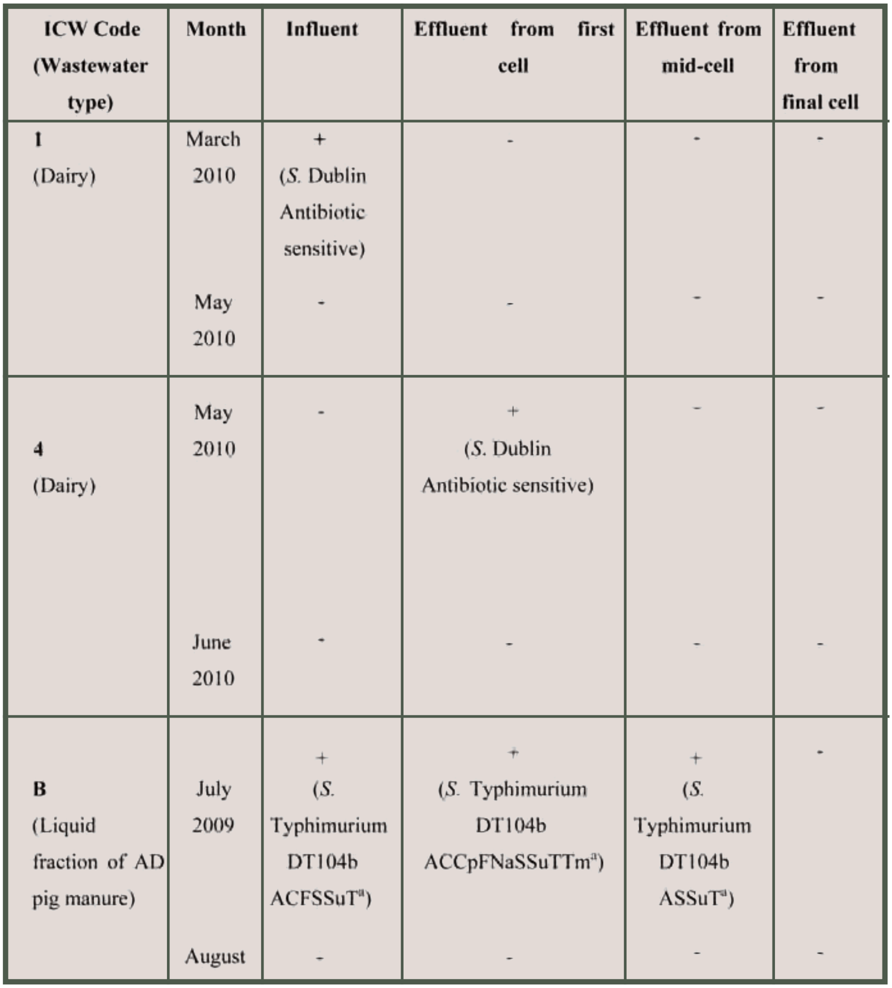


*Figure 2 - Effect of flow through cells on mean bacterial counts ($\log_{10}$ CFU/mL) from nine ICWs treating wastewater from dairy or pig farms, sampled on two occasions. Bars with different letters are significantly different. The limit of detection (LOD) was $\log_{10}$ 1.0 CFU/mL. *Percent reductions obtained when the influent and effluent counts were compared*

Salmonella was detected in three of the nine ICW systems; two treating dairy wastewater and one treating the liquid fraction of AD pig manure (Table 1).
In one dairy farm ICW an antibiotic sensitive isolate of *Salmonella* Dublin was detected in the influent in March 2010 but not in any of the other ICW cells or the effluent (Table 1). *S*. Dublin is most frequently recovered from cattle, to which it is host-adapted, correlating with the fact that this ICW treated dairy wastewater. However, *Salmonella* was not detected in this ICW when re-sampled in May. Surprisingly, in the other *Salmonella*-positive dairy ICW, *Salmonella* was undetectable in the influent to Cell 1 but the Cell 1 effluent was positive for *S*. Dublin which was also fully antibiotic sensitive. This may be because *Salmonella* had grown to detectable levels within Cell 1 due to the nutrient-rich nature of the influent material.

Table 1 - Presence (+) or absence (-) of *Salmonella* in the influent, effluent from the first and mid cells and the final effluent of integrated constructed wetlands treating wastewater from dairy or pig farms.



ICW Code (Wastewater type)	Month	Influent	Effluent from first cell	Effluent from mid-cell	Effluent from final cell
1 (Dairy)	March 2010	+ (*S.* Dublin Antibiotic sensitive)	-	-	-
	May 2010	-	-	-	-
4 (Dairy)	May 2010	-	+ (*S.* Dublin Antibiotic sensitive)	-	-
	June 2010	-	-	-	-
B (Liquid fraction of AD pig manure)	July 2009	+ (*S.* Typhimurium DT104b ACFSSuT[a])	+ (*S.* Typhimurium DT104b ACCpFNaSSuTTm[a])	+ (*S.* Typhimurium DT104b ASSuT[a])	-
	August	-	-	-	-

[a] Antibiotic resistance pattern: A, ampicillin; C, chloramphenicol; Cp, ciprofloxacin; F, florfenicol; Na, nalidixic acid; S, streptomycin; Su, sulfamethoxazole; T, tetracycline; Tm, trimethoprim

This is backed up by the fact that counts of enteric indicator bacteria were observed to increase within Cell 1 in a number of the ICW's (data not shown). However, *Salmonella* was non-detectable in subsequent cells. It was also absent from all cells of the same ICW when re-sampled in June. The fact that *Salmonella* was absent from both ICW's when re-sampled in May and June may be accounted for by seasonal effects. Repeated sampling is required to obtain a complete data set across all seasons.

In the ICW treating the liquid fraction of AD pig manure, *Salmonella* Typhimurium DT104b, which is pathogenic to both humans and animals, was detected in the Cell 1 influent and effluent and the mid-cell effluent when sampled in June 2009 (Table 1). However, it was absent in the final effluent. The isolates recovered had different antibiotic resistance profiles; some were resistant to as many as nine antibiotics, while others were less resistant. In August 2010, *Salmonella* was not detected in any of the ICW cells (Table 1). This is most likely because it was absent from the influent material (the liquid fraction of AD manure). This is because, although the manure itself contained *Salmonella* Derby, no *Salmonella* was detected after AD. These results may demonstrate that AD inactivated the *Salmonella*. This was not the case the previous year, as the manure, both prior to and after AD, contained *Salmonella* Typhimurium, which was carried over to the liquid fraction following separation. These data may suggest that the Derby serotype is more sensitive to inactivation by AD than Typhimurium. Overall, *Salmonella*, when present in the influent material, appeared to be removed by the ICW's. However, repeated sampling is required on a regular basis in order to investigate the effect of hydraulic retention time on bacterial removal.

Conclusions

Reductions in pathogenic and enteric indicator bacteria were observed across nine ICW systems treating agricultural wastewater, including the liquid fraction of AD pig manure. Most notably, *E. coli*, *Enterococcus* and *Salmonella* were non-detectable in the final ICW effluent. This study suggests that on-farm ICW's are effective in reducing indicator bacteria and in eliminating pathogens from agricultural wastewater. There are currently no microbiological standards for discharge waters. However, the findings of this study suggest that the treated wastewater would be suitable for release to waterways or for use as a wash-water on-farm. However, repeated sampling is required. ICW's can therefore be considered an alternative treatment option for the liquid fraction of pig manure and other agricultural wastewater, which could be used by producers to help overcome land-spreading restrictions.

References

Carty, A., Scholz, M., Heal, K.V., Keohane, J., Dunne, E.J., 2008. *Farm Constructed Wetland Design Manual for Northern Ireland and Scotland.*

Department of Environment (Northern Ireland) and Scottish Environment Protection Agency, United Kingdom.

Cost Analyses of the Manure Treatment Options Investigated

Tereza Nolan, Stephen Gilkinson, Peter Frost, Caolan Harrington, Kathryn Carney, Shane Troy, Sihuang Xie, Xinmin Zhan, Mark Healy and Peadar Lawlor

Objective

The objective here was to perform a cost analysis of the non-land spread technologies investigated in our project. Cost analysis was performed for anaerobic digestion of pig manure and grass silage, solid-liquid separation of the digested material, composting of the solid fraction and treatment of the liquid fraction by means of integrated constructed wetlands (ICW) and woodchip filters.

Methods

Costs were calculated based on a case study of a 500 sow integrated pig farm unit producing 16m^3 liquid pig manure per sow per year (8000 m^3 in total per year), at 4.5% dry matter. For comparison sake, the Nitrates Directive action plan assumes that 20.7m^3 liquid pig manure is produced per sow per year (10350 m^3 in total per year) at 4.3% dry matter. Where appropriate, examples of different sized units are given to demonstrate economies of scale.

The costs for each technology are given separately. However most of the technologies must be used in combination. For example, composting can only be performed after the pig manure has been separated into its solid and liquid fractions. The solid fraction after separation is used for composting. Consequently, to calculate the full cost of composting, the costs associated with the separation process must also be included. Furthermore, because the initial manure has been separated into its solid and liquid fractions, the liquid fraction must also be dealt with. The liquid fraction will be either treated or land spread, and the associated costs cannot be ignored.

The same can be said for the treatment of the liquid fraction using ICW or woodchip filters. Treatment is only possible after the liquid manure has been separated into its solid and liquid fractions. In this case the solid fraction also needs to be dealt with, either by composting or land spreading, and the associated costs must be accounted for.

Results/Discussion

Anaerobic digestion of pig manure and grass silage

1. Initial investment costs

The investment costs for an anaerobic digester will vary from case to case, depending on the specific needs and size of the installation. As a result, it is difficult to specify general investment costs without a comprehensive list of basic assumptions. Therefore, expert advice should always be sought so that individual requirements are taken into consideration early in the planning process.

An example of the investment costs associated with the co-digestion of pig manure and grass silage is given in Table 1. Some important assumptions include:

- 500 sow unit, producing 8000 m^3 manure per year with 4.5% dry matter
- Dry matter of grass silage: 25%
- Grass silage to pig manure ratio of 1 to 20 on a fresh weight basis [3:1 volatile solid (VS) basis]
- Retention time of 30 days
- Digester volume: 767m^3 (10 metres high by 10 metres diameter)
- Daily load of 25.2 m^3 of fresh material (33.3 kg of fresh material per m^3 of digester volume - 1.5 kg VS/m^3/day)
- Combined Heat and Power (CHP) efficiency of 30% for electricity and 50% for heat with a run time of 90%
- The biogas production for pig manure was assumed as 300 m^3/tonne VS and as 550 m^3/tonne VS for grass silage

Total project costs (excluding connection to the grid and other fees) associated with construction of the unit are calculated at €332,839. For the above example connection to the grid and other fees costs were estimated at €145,500. The latter is only an estimate and will vary greatly from case to case depending on the farm's so called 'import infrastructure'. If you are lucky enough to already have a large import infrastructure, your grid connection agreement may only require 'metering infrastructure' and no cable updates may be required. In this case you would be able to export on the same cables that are used for electricity supply. Therefore, an individual farm could be charged anything from a nominal charge if located in a favourable situation (< €10,000) up to €250,000+ if cables, transformer upgrades etc are required.

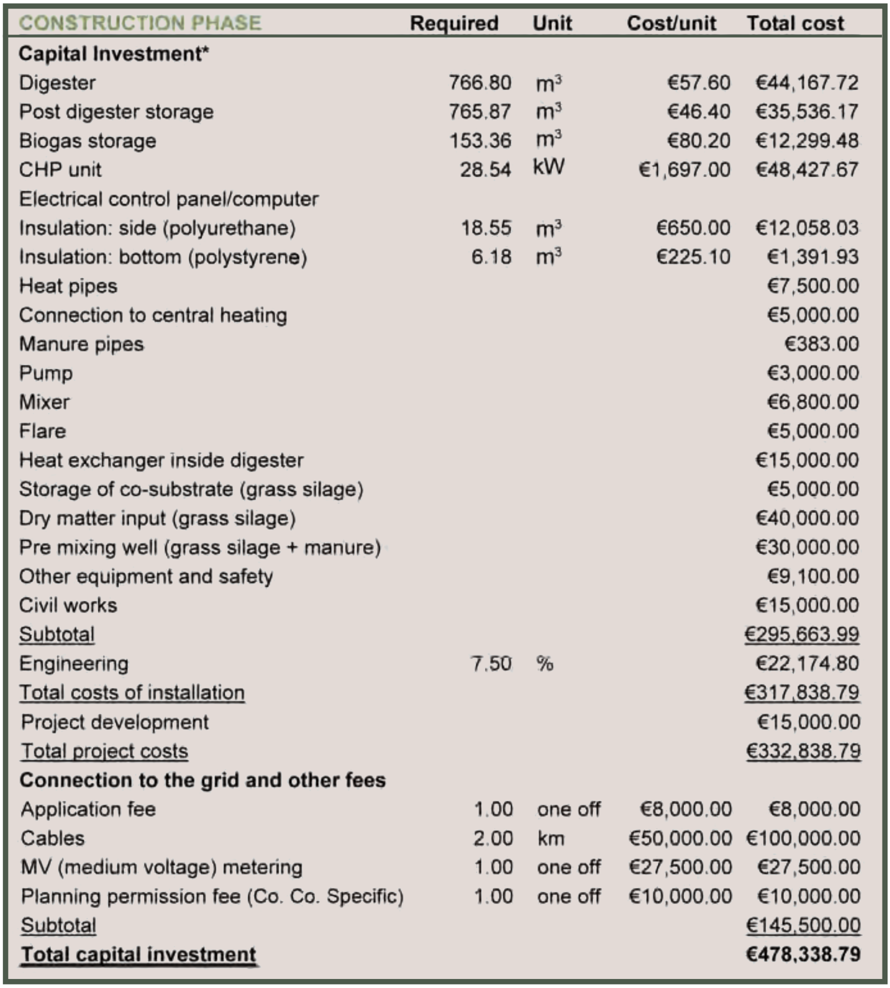
Total capital investment (capital investment plus fees) for the AD unit described above is calculated at €478,339.

2. Cost-benefit analyses

Table 2 shows the costs and benefits and the pay back time calculations for the AD unit described in Table 1 and includes:

- The annual repayment for the AD unit (inclusive of interest) per €1000 borrowed is €111, assuming an interest rate of 7% on a loan period of 15 years which is the average lifetime of an anaerobic digester. Therefore the annual capital and interest repayments will be €36,945 (€332,839/1000 x €111),

Table 1 - Investment costs associated with the co-digestion of pig manure and grass silage



CONSTRUCTION PHASE	Required	Unit	Cost/unit	Total cost
Capital Investment*				
Digester	766.80	m³	€57.60	€44,167.72
Post digester storage	765.87	m³	€46.40	€35,536.17
Biogas storage	153.36	m³	€80.20	€12,299.48
CHP unit	28.54	kW	€1,697.00	€48,427.67
Electrical control panel/computer				
Insulation: side (polyurethane)	18.55	m³	€650.00	€12,058.03
Insulation: bottom (polystyrene)	6.18	m³	€225.10	€1,391.93
Heat pipes				€7,500.00
Connection to central heating				€5,000.00
Manure pipes				€383.00
Pump				€3,000.00
Mixer				€6,800.00
Flare				€5,000.00
Heat exchanger inside digester				€15,000.00
Storage of co-substrate (grass silage)				€5,000.00
Dry matter input (grass silage)				€40,000.00
Pre mixing well (grass silage + manure)				€30,000.00
Other equipment and safety				€9,100.00
Civil works				€15,000.00
Subtotal				€295,663.99
Engineering	7.50	%		€22,174.80
Total costs of installation				€317,838.79
Project development				€15,000.00
Total project costs				€332,838.79
Connection to the grid and other fees				
Application fee	1.00	one off	€8,000.00	€8,000.00
Cables	2.00	km	€50,000.00	€100,000.00
MV (medium voltage) metering	1.00	one off	€27,500.00	€27,500.00
Planning permission fee (Co. Co. Specific)	1.00	one off	€10,000.00	€10,000.00
Subtotal				€145,500.00
Total capital investment				**€478,338.79**

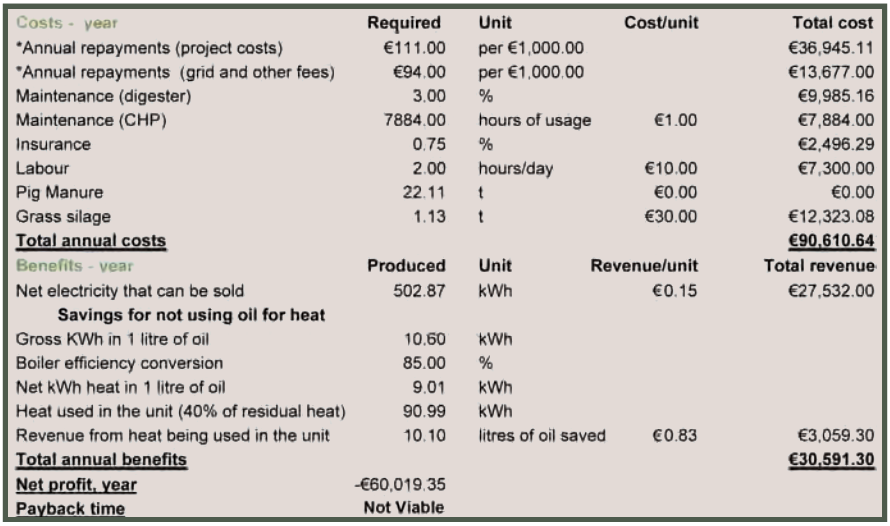
**Reference: Planning and Installing Bioenergy Systems: A Guide for Installers, Architects and Engineers. Earthscan Publications Ltd., 2005*

- The annual repayment for the connection to the grid and other fees (inclusive of interest) per €1000 borrowed is €94, assuming an interest rate of 7% on a loan period of 20 years. Therefore the annual capital and interest repayments will be €13,677 (€145,500/1000 x €94),
- The annual maintenance costs are about 2-4% of the investment costs

(assume 3%), excluding the maintenance of the CHP, which is arranged separately,

- Maintenance of the CHP: between €0.80 and €1.1 per operational hour (assume €1/hour),
- The annual insurance costs will be 0.5-1.0% of the total installation costs (assume 0.75%),
- Labour costs: calculated at €10 per hour
- Price of the grass silage: calculated at €30 per tonne

Table 2 - Calculation of costs and benefits and the pay back time for AD unit



Costs - year	Required	Unit	Cost/unit	Total cost
*Annual repayments (project costs)	€111.00	per €1,000.00		€36,945.11
*Annual repayments (grid and other fees)	€94.00	per €1,000.00		€13,677.00
Maintenance (digester)	3.00	%		€9,985.16
Maintenance (CHP)	7884.00	hours of usage	€1.00	€7,884.00
Insurance	0.75	%		€2,496.29
Labour	2.00	hours/day	€10.00	€7,300.00
Pig Manure	22.11	t	€0.00	€0.00
Grass silage	1.13	t	€30.00	€12,323.08
Total annual costs				**€90,610.64**
Benefits - year	**Produced**	**Unit**	**Revenue/unit**	**Total revenue**
Net electricity that can be sold	502.87	kWh	€0.15	€27,532.00
Savings for not using oil for heat				
Gross KWh in 1 litre of oil	10.60	kWh		
Boiler efficiency conversion	85.00	%		
Net kWh heat in 1 litre of oil	9.01	kWh		
Heat used in the unit (40% of residual heat)	90.99	kWh		
Revenue from heat being used in the unit	10.10	litres of oil saved	€0.83	€3,059.30
Total annual benefits				**€30,591.30**
Net profit, year	-€60,019.35			
Payback time	**Not Viable**			

** Reference: Management data for farm planning 2006/2007*

Benefits can be calculated by adding the revenue generated from the sale of the electricity produced and the savings made by displacing a portion of the oil normally used on the unit (by using the residual heat from the CHP unit).

In May 2010 the Renewable Energy Feed in Tariffs (REFIT) were announced but the terms and conditions are not yet finalised as they are subject to the states aids clearance which has yet to be obtained from the European Commission. As it stands electricity generated from an anaerobic digestion combined heat and power (AD-CHP) unit smaller than 500kW will be paid €0.15/kWh, while an AD-CHP >500kW will be paid €0.13/kWh.

From the calculations above a 500 sow integrated unit digesting grass silage and pig manure would reduce profitability by €60,019 per year. However, it is important to remember that, in the case of an anaerobic digestion plant, economies of scale will apply. For example, a 2000 sow unit with an investment cost of ~ €958,579 would have a payback time of 32.6 years. Furthermore, if the price paid for the electricity was to increase from €0.15/kWh to €0.22/kWh the payback time would be around 12 years for the 2000 sow unit but the investment would still not be viable for the 500 sow unit (138 years).

Also, the digestion process is dependent on many variables and changing one of them will impact the whole process. For example, if feeding the digestor at a grass silage to pig manure ratio of 1 to 6.5 (instead of 1 to 20 as before) we would have a pay back time of ~27 years (at €0.15kWh) for the 2000 sow integrated unit. Moreover, if the price paid for electricity was to increase to €0.22kWh, the payback time for the 2000 sow integrated unit would be 8.7 years.

Anaerobic digestion has some marginal benefits in terms of improvement in the fertiliser value of the manure [increased nitrogen (N) availability]. However, anaerobic digestion will have no impact on the amount of N and phosphorus (P) to be dealt with from the pig unit. Moreover, because the manure will most likely be co digested with another biomass, grass silage in our example, the N and P content of the digested material will be higher than that on the raw manure.

Consequently the costs associated with spreading/treating the digestate still have to be incurred after anaerobic digestion.

Solid-liquid separation of pig manure by decanter centrifuge

The costs associated with solid and liquid separation of the anaerobically digested pig manure (+ grass silage) are described in Table 3. Some important assumptions made for these calculations include:

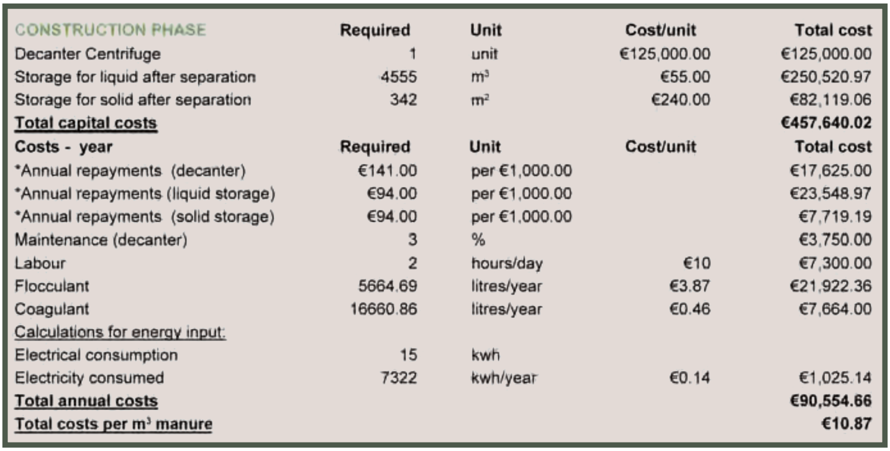
- 500 sow unit, producing 8000 m^3 manure/year with 4.5% dry matter
- Manure digested with grass silage as described above
- Decanter centrifuge running at 20m^3/hour, 2.0 hour/day, 255 days/year
- Separation efficiency for dry matter of 70%
- Coagulant addition: 2.0 litres per m^3
- Flocculant solution (0.4% in water) addition: 17% by volume of slurry

Calculations show that a total investment cost of €457,640 is necessary.

Table 3 also shows the calculation for annual operating costs and includes:

- Annual repayment for decanter centrifuge: the annual repayment (inclusive of interest) per €1000 borrowed is €141.00, assuming an interest rate of 7% on a loan period of 10 years which is the average lifetime of a decanter centrifuge. Therefore the annual capital and interest repayments will be €17,625 (€125,000/1000 x €141),

Table 3 - Costs associated with solid-liquid separation



CONSTRUCTION PHASE	Required	Unit	Cost/unit	Total cost
Decanter Centrifuge	1	unit	€125,000.00	€125,000.00
Storage for liquid after separation	4555	m^3	€55.00	€250,520.97
Storage for solid after separation	342	m^2	€240.00	€82,119.06
Total capital costs				**€457,640.02**
Costs - year	**Required**	**Unit**	**Cost/unit**	**Total cost**
*Annual repayments (decanter)	€141.00	per €1,000.00		€17,625.00
*Annual repayments (liquid storage)	€94.00	per €1,000.00		€23,548.97
*Annual repayments (solid storage)	€94.00	per €1,000.00		€7,719.19
Maintenance (decanter)	3	%		€3,750.00
Labour	2	hours/day	€10	€7,300.00
Flocculant	5664.69	litres/year	€3.87	€21,922.36
Coagulant	16660.86	litres/year	€0.46	€7,664.00
Calculations for energy input:				
Electrical consumption	15	kwh		
Electricity consumed	7322	kwh/year	€0.14	€1,025.14
Total annual costs				**€90,554.66**
Total costs per m^3 manure				**€10.87**

** Reference: Management data for farm planning 2006/2007*

- Annual repayment for the liquid storage: the annual repayment (inclusive of interest) per €1000 borrowed is €94.00, assuming an interest rate of 7% on a loan period of 20 years which is the average lifetime of the installation. Therefore the annual capital and interest repayments will be €23,549 (€250,521/1000 x €94),
- Annual repayment for the solid storage: the annual repayment (inclusive of interest) per €1000 borrowed is €94.00, assuming an interest rate of 7% on a loan period of 10 years which is the average lifetime of the installation. Therefore the annual capital and interest repayments will be €7,719 (€82,119/1000 x €94),
- Maintenance of decanter centrifuge: calculated as 3% of the investment costs per year
- Labour costs: calculated at €10 per hour
- Chemicals used during separation (coagulant and flocculant)
- Electrical consumption of decanter, based on the amount of hours it is being used.

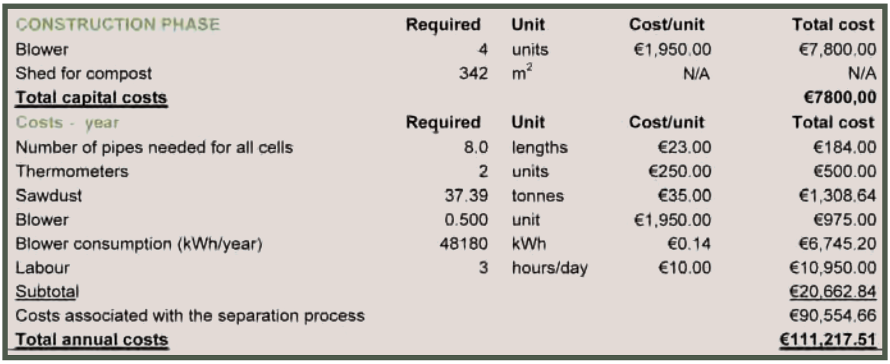
Therefore, without grants available, the annual operating costs for the separation process would be €90,555 (€10.87 per m^3 of manure).
After separation the liquid and solid fractions will have to be dealt with, either by further treatment or land spread, and there will be costs associated with this.

Composting the solid fraction of pig manure

The costs associated with composting the solid fraction generated by the decanter centrifuge described above are shown in Table 4. Some important assumptions made for these calculations include:

- 500 sow unit, producing 8000 m^3 manure/year with 4.5% dry matter
- Manure digested with grass silage and subsequently separated by decanter centrifuge as described above
- Dry matter of solid fraction: 28%
- Bulking agent used: sawdust
- Separated manure to sawdust ratio (fresh weight): 6 to 1, C/N ratio =18.9
- Composting done by aerated static piles with blowers attached to perforated pipes to provide aeration. No mechanical turning of the pile required.
- The composting is performed indoors. The cost associated with the shed construction is not accounted for in the totals in Table 4. This has already being accounted for in the costs associated with the separation system (described above, Table 3), as the manure will have to be separated before composting
- It is assumed that a bucket loader is available to the farmer to construct the compost pile
- Compost decomposition rate: 40%

Table 4 - Costs associated with composting



CONSTRUCTION PHASE	Required	Unit	Cost/unit	Total cost
Blower	4	units	€1,950.00	€7,800.00
Shed for compost	342	m^2	N/A	N/A
Total capital costs				**€7800,00**
Costs - year	**Required**	**Unit**	**Cost/unit**	**Total cost**
Number of pipes needed for all cells	8.0	lengths	€23.00	€184.00
Thermometers	2	units	€250.00	€500.00
Sawdust	37.39	tonnes	€35.00	€1,308.64
Blower	0.500	unit	€1,950.00	€975.00
Blower consumption (kWh/year)	48180	kWh	€0.14	€6,745.20
Labour	3	hours/day	€10.00	€10,950.00
Subtotal				€20,662.84
Costs associated with the separation process				€90,554.66
Total annual costs				**€111,217.51**

The capital costs associated with composting include the blowers and the shed construction. However, as explained above, costs associated with the shed construction are accounted for in the costs associated with separation. It is assumed that one blower will have to be replaced every two years (life expectancy of eight years).

The total annual costs for the composting alone (including pipes, thermometers, sawdust, blowers, electrical consumption and labour) are calculated as €20,663.

However, for a complete cost analysis, the cost of the separation process (€90,555 described in Table 3) also needs to be included as the solid fraction of the manure can only be composted after separation. The total annual cost is therefore €111,218.

Assuming 40% decomposition rate, a total of 156,837 litres of compost will be produced annually. Therefore, to break even, the compost would have to be sold at €0.71/litre. In comparison a 50 litre bag of peat based compost is sold at €6.00 (€0.12/litre).

For a 2000 sow unit the total annual costs would be €297,040 and in this case the price achieved for the compost would have to be €0.53/litre to break even.

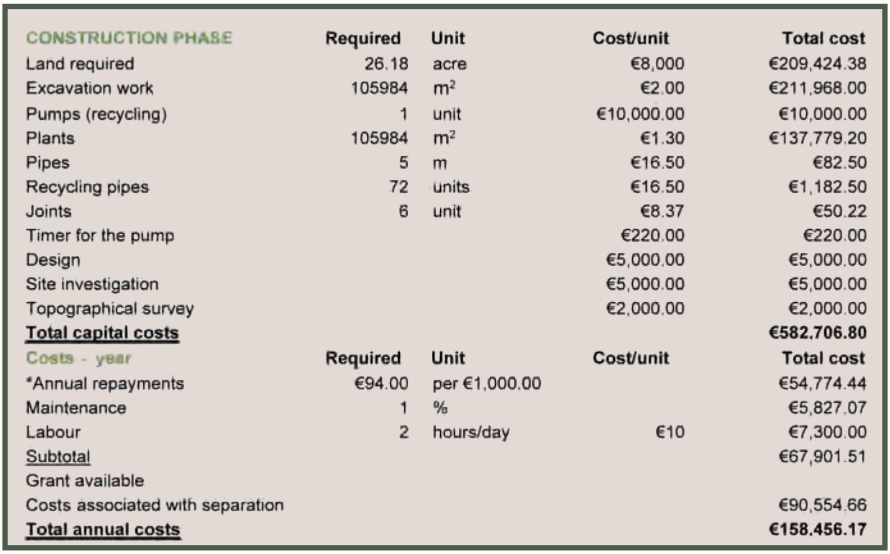
Treatment of the liquid fraction by integrated constructed wetlands

The costs associated with using ICW to treat the liquid fraction generated by the decanter centrifuge system described above are shown in Table 5. Some important assumptions made in these calculations include:

- 500 sow unit, producing 8000 m^3 manure/year with 4.5% dry matter
- Manure digested with grass silage and subsequently separated by decanter centrifuge, as described above.
- The cost associated with storage of the separated liquid fraction is not accounted for in the totals in Table 5. This is because the cost for this storage has already being accounted for in the costs associated with the separation system (described above), as the manure will have to be separated before being treated.
- It is assumed that the system can cope with a maximum ammonium level of 200 mg/litre. This is based on results from the meso-scale system in Moorepark. However, while the meso-scale approach endeavours to mimic a full-scale ICW, it lacks certain features, like a soil liner etc. Therefore, a full-scale ICW might have the potential to treat liquid with even higher ammonium levels. In any case, the separated liquid fraction coming from the separator needs to be diluted before pumping to the first ICW pond.
- 424 m^3 of water is needed daily to bring the ammonium levels to 200 mg/litre (to bring ammonium levels to 400 mg/litre, 200 m^3 of water per day would be required).

The land area required for the ICW construction is around 26 acres (10.6ha). This could potentially be halved (13.6 acres; 5.5 ha) if the amount of water required to dilute the influent was reduced (this would be the case if the influent only had to be diluted to 400 mg/litre instead of the 200mg/litre assumed in our example).

Table 5 - Costs associated with Integrated Constructed Wetlands



CONSTRUCTION PHASE	Required	Unit	Cost/unit	Total cost
Land required	26.18	acre	€8,000	€209,424.38
Excavation work	105984	m^2	€2.00	€211,968.00
Pumps (recycling)	1	unit	€10,000.00	€10,000.00
Plants	105984	m^2	€1.30	€137,779.20
Pipes	5	m	€16.50	€82.50
Recycling pipes	72	units	€16.50	€1,182.50
Joints	6	unit	€8.37	€50.22
Timer for the pump			€220.00	€220.00
Design			€5,000.00	€5,000.00
Site investigation			€5,000.00	€5,000.00
Topographical survey			€2,000.00	€2,000.00
Total capital costs				**€582.706.80**
Costs - year	**Required**	**Unit**	**Cost/unit**	**Total cost**
*Annual repayments	€94.00	per €1,000.00		€54,774.44
Maintenance	1	%		€5,827.07
Labour	2	hours/day	€10	€7,300.00
Subtotal				€67,901.51
Grant available				
Costs associated with separation				€90,554.66
Total annual costs				**€158.456.17**

** Reference: Management data for farm planning 2006/2007*

Total investment costs for the construction of an ICW system capable of treating the separated/diluted liquid fraction is calculated at €582,707.

The annual repayment (inclusive of interest) per €1000 borrowed is €94.00, assuming an interest rate of 7% on a loan period of 20 years which is the projected lifetime of an ICW. Therefore, the annual capital and interest repayments will be €54,774 (€582,707/1000 x €94).

Maintenance is calculated at 1% of the investment costs and labour (€10.00/hour) is also accounted for. This gives a total annual cost for the ICW alone of €67,902.

However, for a complete cost analysis, the cost of the separation process (€90,555, described in Table 3) also needs to be included as the liquid fraction of the manure can only be put through the ICW after separation. The total annual cost is therefore €158,456.

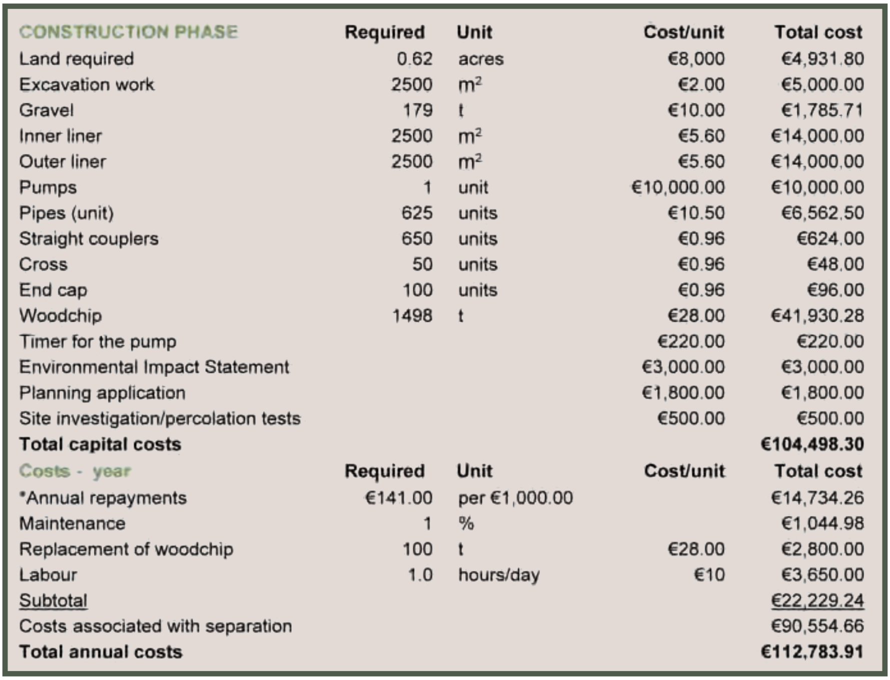
Treatment of the liquid fraction by woodchip biofilters

The costs associated with using a woodchip filter to treat the liquid fraction generated by the decanter centrifuge system described above are shown in Table 6. Some important assumptions made for these calculations include:

- 500 sow unit, producing 8000 m^3 manure/year with 4.5% dry matter
- Manure first digested with grass silage and subsequently separated by

decanter centrifuge as described above
- The cost associated with storage of the separated liquid fraction is not accounted for in the totals in Table 6. This has already being accounted for in the costs associated with the separation system (described previously, Table 3), as the manure will have to be separated before being treated
- Application rate of 10 litres of separated liquid per m^2 of filter
- Filter dimensions: 50 m by 50 m
- Filter depth: 1.5 m

Table 6 - Costs associated with woodchip biofilters



CONSTRUCTION PHASE	Required	Unit	Cost/unit	Total cost
Land required	0.62	acres	€8,000	€4,931.80
Excavation work	2500	m^2	€2.00	€5,000.00
Gravel	179	t	€10.00	€1,785.71
Inner liner	2500	m^2	€5.60	€14,000.00
Outer liner	2500	m^2	€5.60	€14,000.00
Pumps	1	unit	€10,000.00	€10,000.00
Pipes (unit)	625	units	€10.50	€6,562.50
Straight couplers	650	units	€0.96	€624.00
Cross	50	units	€0.96	€48.00
End cap	100	units	€0.96	€96.00
Woodchip	1498	t	€28.00	€41,930.28
Timer for the pump			€220.00	€220.00
Environmental Impact Statement			€3,000.00	€3,000.00
Planning application			€1,800.00	€1,800.00
Site investigation/percolation tests			€500.00	€500.00
Total capital costs				**€104,498.30**
Costs - year	**Required**	**Unit**	**Cost/unit**	**Total cost**
*Annual repayments	€141.00	per €1,000.00		€14,734.26
Maintenance	1	%		€1,044.98
Replacement of woodchip	100	t	€28.00	€2,800.00
Labour	1.0	hours/day	€10	€3,650.00
Subtotal				€22,229.24
Costs associated with separation				€90,554.66
Total annual costs				**€112,783.91**

** Reference: Management data for farm planning 2006/2007*

The total investment costs for the construction of a woodchip biofilter system capable of treating the separated liquid fraction from a 500 sow integrated unit are calculated at €104,498.

It is hard to predict a lifetime for this system as this is a novel technology. We can assume a life time of 10 years and consider that the top layer (20 cm) of woodchips would have to be replaced every two years. Assuming a life time of 10 years and an interest rate of 7.0% on the money borrowed, the annual repayment costs would be €141.00 per €1000 borrowed. Therefore the annual repayment (including interest) will be €14,735 (€104,498/1000 x €141). Maintenance is calculated as 1% of the investment costs and labour at €10.00/hour is also accounted for. This gives a total annual cost for the biofilters alone of €22,229.

However, for a complete cost analysis, the cost of the separation process (€90,555, described in Table 3) also needs to be included, as the liquid fraction of the manure can only be put through the bio filters after separation. The total annual cost is therefore €112,784.

However, the effluent from this system is not suitable for discharge as it is still high in P. Therefore additional costs will be associated with further treatment for P removal (perhaps ICW), before the effluent can be safely discharged into a water body.

Transport and Landspread

Table 7 shows the annual costs for transporting and spreading raw pig manure by tractor and vacuum tanker or by truck, according to Treanor (2008). Calculations are for a 500 integrated sow unit, producing 8000 m^3 manure/year with 4.5% dry matter.

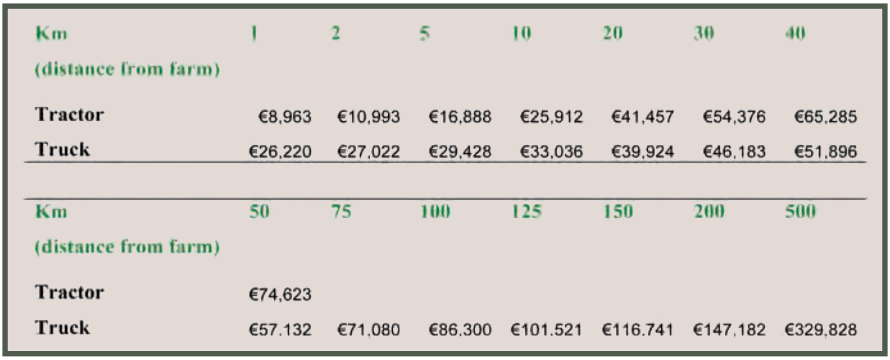
The following assumptions are made for the tractor and vacuum tanker:

- Load size 11.8 m^3 (2,600 gallons)
- Loading time six minutes
- Travel speed while loaded increases with distance
- Return speed is 5 km/hr more than the outward journey
- Hire cost for tractor, tanker and operative is €35 per hour
- Unloading time is approximately twice the loading time if land spread (equal to loading time if discharged into a store but this will incur a spreading charge at a later stage).

Assumptions for the truck are:

- Load size 27 m^3 (6,000 gallons)
- Loading time 15 minutes
- Travel speed while loaded increases with distance
- Return speed is 5 km/hr more than the outward journey
- Hire cost for truck and operative is €65 per hour
- Unloading time is equal to loading time
- Cost of spreading is €2 per m^3

Table 7 – Annual costs associated with raw manure haulage (transport and spreading) for a 500 sow integrated pig farm.



Km (distance from farm)	1	2	5	10	20	30	40
Tractor	€8,963	€10,993	€16,888	€25,912	€41,457	€54,376	€65,285
Truck	€26,220	€27,022	€29,428	€33,036	€39,924	€46,183	€51,896

Km (distance from farm)	50	75	100	125	150	200	500
Tractor	€74,623						
Truck	€57.132	€71,080	€86.300	€101.521	€116.741	€147,182	€329,828

Conclusions

While our cost analysis shows that the technologies investigated in this project are not currently cost effective in the Republic of Ireland, compared to conventional land spreading, they may have future potential. Anaerobic digestion for example, would be cost effective on large units (2000 sows plus) or if centralised treatment plants were developed and if the renewable energy feed in tariff for energy sold to the grid was increased.

The separation and treatment of the liquid fraction might become an alternative for large or centralised units in the future if the necessity for hauling manure longer distances becomes necessary. The efficacy of ICW in treating the liquid fraction of separated pig manure is limited by the amount of extraneous water needed for dilution. One solution in this case may be to pre-treat the liquid fraction using woodchip filters to first reduce levels of ammonium-nitrogen and solids in the liquid. This would reduce the volume of water required for dilution before discharge into the ICW and consequently reduce the land area required for these systems.

References

German Solar Energy Society (DGS), Ecofys, 2005. *Planning and Installing Bioenergy Systems: A Guide for Installers, Architects and Engineers.* Earthscan Publications Ltd.

Teagasc, 2006/2007. *Management Data for Farm Planning.* Printed and published by Teagasc, Oak Park, Carlow, Co. Carlow, Ireland

Treanor, 2008 *Managing Composition and Handling Costs of Pig Manure*. Thesis (M.An.Sc.), University College Dublin, 2008.

Summary Papers

Methane Production from Anaerobic Co-Digestion of Pig Manure and Grass Silage

Increased demand for energy, depletion of fossil fuel reserves and concern regarding greenhouse gas emissions have resulted in increased interest in renewable energy. Anaerobic digestion of organic matter, such as animal manure and energy crops, produces methane, which is a clean and renewable fuel suitable for use in the generation of heat and electricity.

Animal manure is a resource material for biogas production. The Irish pig production sector contributes 6% to the gross agricultural output and is the third most important agricultural sector. It is estimated that 3.1 million m^3 of pig manure is produced in Ireland annually, containing 13,050 tonnes of N, 2,550 tonnes of P and 6,830 tonnes of K. It is therefore an excellent fertiliser for grass and other crops and has traditionally been land spread for this purpose. Anaerobic digestion of pig manure has advantages over traditional pig manure management (i) methane production, which can be used to displace fossil fuels; (ii) improvement in fertiliser value through increased nutrient availability; and (iii) reduction in pathogens load and malodour.

Ireland has a very suitable climate for grass production. Conserved grass silage is in high digestible organic matter and volatile solids making it an excellent feedstock for anaerobic digestion, either as a single feedstock or co-digested with pig manure. Compared to anaerobic digestion with pig manure as the sole feedstock, co-digestion of pig manure with grass silage can increase biogas yield by: (i) maintaining an optimal pH for methanogens; (ii) decreasing ammonia/ammonium inhibition, which may occur with anaerobic digestion of manure alone; and (iii) providing a higher carbon to nitrogen ratio (C/N) in the feedstock.

It is estimated that 3.1 million tonnes of pig manure are produced in Ireland each year and that this could potentially produce more than 50 million cubic metres of biogas.

Solid-Liquid Separation of Pig Manure

As a result of the Nitrates Directive, traditional spread lands in close proximity to areas of concentrated pig production may no longer be able to take all the manure produced in these areas. Therefore, transportation of liquid pig manure from these areas may become a major cost in the future.

Dry matter content is the single most important factor determining the cost of manure transportation. One way of increasing the dry matter of manure is through separation. Manure separation fractionates the phosphorus from the liquid manure into the solid fraction. When using a decanter centrifuge and chemical addition, for example, up to 90% of P (and 30% of N) can be partitioned to the solid fraction. This solid fraction can either be transported longer distances to suitable spreadlands more cheaply or composted. The nitrogen-rich liquid fraction can be applied locally to grassland which has a lower requirement for P.

It is important to note that the separation of manure will result in three products to be handled and stored (raw pig manure, separated solids and separated liquid). Most pig units will have existing equipment to handle the raw manure and the liquid fraction but few units will have the equipment necessary to handle the solid fraction.

Manure separation is most commonly performed by mechanical means. The most commonly used mechanical separators are screen separators (stationary, vibrating and rotating), presses (roller, screw or belt) and centrifuges. Screen separators work by ‘sieving’ the liquid manure through a screen. Presses work on the principle of mechanical pressure where the liquid is squeezed out and the solids remain on a screen or perforated belt. Centrifuges use centrifugal force to separate particles of different density. Decanter centrifuges are the most effective separators, especially regarding phosphorus removal.

Decanter centrifuges are capable of producing a fresh solids material with 28-30% dry matter. One tonne of this material will contain about 12.5 kg of nitrogen, 6.6 kg of phosphorus and 2.0 kg of potassium. One tonne of the liquid fraction (~1.3% dry mater) will contain about 2.6 kg of nitrogen, 0.04 kg of phosphorus and 1.8 kg of potassium.

Composting Separated Solids of Pig Manure

Aerobic decomposition during composting of pig manure stabilises the organic matter into a humus-like end product. The high temperatures reached during composting destroy pathogens and weed seeds found in manure. Composting also stabilises the organic nitrogen fraction of the manure, converting it from unstable ammonium to stable inorganic forms. In addition, water content and odour are greatly reduced making the product easier to transport, store and use.

There are different methods of composting manure. Windrow composting involves piling the material to be composted in long rows. Aeration is achieved by turning and mixing the compost regularly using a tractor loader or customised machine. Static composting is another method which doesn’t require turning. For this method, pipes fitted below the composting piles are used to blow air up through the pile as required. This system is often fully automated, with the air requirements controlled by the temperatures within the composting piles.

For successful composting, the initial carbon to nitrogen ratio should be between 20 and 30, and the water content must remain between 40% and 60% throughout the composting process. Separated pig manure has a water content of approximately 70% and a carbon to nitrogen ratio of 10-12. In our compost study in Moorepark we found that the addition of a carbon-rich bulking agent was necessary when composting the separated solids of pig manure. In addition to optimise the carbon to nitrogen ratio, the addition of a carbon rich bulking agent also helps to reduce the moisture content of the mixture to levels suitable for composting.

Of the bulking agents investigated (woodchip, sawdust, shredded green waste, chopped straw and woodchip + sawdust), sawdust produced the best quality compost. When composting separated solids of pig manure and sawdust, stable compost can be produced with an initial carbon to nitrogen ratio as low as 16:1. This corresponds to a separated manure solids to sawdust ratio of 4:1 (fresh weight).

Pyrolysis of Separated Solids of Pig Manure

Pyrolysis is a process whereby a biomass feedstock, such as woodchip or livestock manure, is heated to very high temperatures in an oxygen-free atmosphere. The products of this process are biochar, bio-oil and gases. Many modern systems use the gas and oil produced during pyrolysis to provide the energy requirement of the pyrolysis unit.

The two main potential uses for the biochar are as a fertiliser or a fuel. Biochar can be used as a feedstock for coal combustion and gasification plants. It can also be applied to the soil as a soil addendum to improve fertility or to sequester carbon in the soil, earning income in the future through carbon credits. Biochar may also increase the efficiency of fertilisers. Due to its high absorptive capacity, biochar may reduce nutrient leaching and maintain the improvements due to the application of mineral fertiliser over a longer period of time than that achieved by the fertiliser alone.

Biochar produced through the pyrolysis of manures can benefit recipient farmers. It can be used to reduce nitrogen leaching from soils. Furthermore, the phosphorus and potassium content of the manure are almost completely recovered in the biochar, leading to higher concentrations in the biochar than in the original manure. When compared with biochar from wood wastes, the higher nitrogen, phosphorus and potassium concentrations in biochar from manure means that it has a higher value as a fertiliser.

The problem with producing biochar from pig manure lies with the energy required to remove the water from the manure. Manure separation and drying are required to remove the water before pyrolysis can take place. In order to make pyrolysis from pig manure a cost effective process it is necessary to add low moisture carbon rich bulking agents (e.g. sawdust) to the manure before pyrolysis. Such bulking agents will reduce the water content of the feedstock while also increasing the heating values of the oil and gas produced.

Treatment of Piggery Wastewaters Using Constructed Wetlands

Integrated constructed wetlands (ICW) consist of a series of shallow ponds that are densely planted with aquatic plants. These ponds receive influent from a farmyard, silo, settling pond or other source of contaminated waters. This influent flows sequentially through the ponds, with a high retention time (50-100 days). Through natural processes, microbial communities, plant uptake and evapotranspiration, the excess nutrients in the wastewater are removed, broken down and stored in the wetland itself. Designed correctly, there is little discharge from the constructed wetland except in events of heavy rain. The discharge from the wetland is of a standard set out by County Council discharge limits so as to have no negative effects on the receiving water body.

Research on constructed wetlands has flourished in the last 20 years and some of the greatest advances in performance have been developed in Ireland. Recently a guidance manual on the use of ICW in Ireland was published by the Department of Environment, Heritage and Local Government. This was written principally for municipal and farmyard waste but the technology also has other applications. Constructed wetlands, offer a low-cost alternative for the treatment of wastewaters.

Integrated Constructed Wetlands have a greater land requirement than more conventional treatment systems. Based on our meso-scale results, an average pig unit of 500 sows integrated would require a land area of ~10ha to treat the separated liquid fraction of the pig manure it generates. However, in a full scale ICW, some other features need to be considered (soil liners, scale etc). These other features and recycling of water could potentially increase the ammonia tolerance of the system. These might potentially halve the land area required to ~5ha, however, this would have to be proven.

Constructed wetlands, however, provide far more than just wastewater treatment. ICWs have been effectively demonstrated to enhance local biodiversity and environment. They require little energy input after construction and are generally self-maintaining. On a farm, they require the examination of pipes for blockages, mowing of embankments and observation of plant growth. The aquatic plants used, once fully established, are self-propagating and rarely require additional planting.

Treatment of Piggery Wastewaters Using Woodchip Biofilters

Woodchip biofilters are a simple, efficient, low maintenance treatment system that can be easily adapted by the Irish pig farmer. Woodchip biofilters consist of aerobic and anoxic zones necessary for the removal of solids and various nutrients.

This study investigates the use of native woodchips as a biofilter media for the treatment of (i) the separated liquid fraction of raw pig manure and (ii) the separated liquid fraction of digestate after anaerobic digestion of pig manure.

Successful treatment of the separated liquid fractions of piggery wastewaters using woodchip biofilters would reduce:

- The volume of manure to be landspread. The solid fraction of the pig manure can be retained and used as a nutrient rich fertiliser or as a substrate for creating compost or fuel.
- Nutrients released into the environment in compliance with a number of directives (SI.610.2010)
- Odour
- Handling costs

The use of woodchips as a biofilter media has a number of advantages:

- Woodchips are readily available and available at a relatively low capital cost
- Woodchips act as a physical surface and supply biodegradable carbon both of which are necessary for the growth of beneficial micro-organism
- Woodchips reduce soluble and particulate nutrients through physical, chemical and biological processes, thereby reducing nutrients in the filtered liquid
- The used woodchips and captured nutrients can be spread on land as a soil conditioner or used as a substrate for a composting or as a solid fuel

Treatment Strategies for Pathogen Removal from the Solid and Liquid Fractions of Pig Manure and Agricultural Wastewater

Considerable quantities of manure and wastewater are generated on farms, with land-spreading the usual disposal option. Due to environmental restrictions, in particular those imposed by the Nitrates Directive, the pig industry needs to investigate alternative manure and wastewater management strategies. One treatment option for the solid fraction of separated pig manure is composting. For the liquid fraction and other wastewater, treatment in integrated constructed wetlands (ICW's) may offer a viable alternative to landspreading.

However, pathogenic (disease-causing) bacteria, such as *Salmonella*, may be carried over from manure to both the solid and liquid fractions and may also be present in agricultural wastewater. Therefore, we investigated survival of *Salmonella* and faecal indicator micro-organisms during composting of the separated solid fraction of pig manure and in ICW's treating wastewater from dairy and pig farms, including the liquid fraction of anaerobically digested pig manure. Reductions in faecal indicator bacteria were observed across nine ICW systems treating farm wastewater and in composted pig manure solids, with *E. coli* and *Enterococcus* non-detectable in the final compost and in the ICW effluent.

The pig manure-derived compost complies with EU regulations as it was *Salmonella*-free and indicator organisms were below limits, although a reduction in spore-forming bacteria was not achieved. However, *Bacillus licheniformis* was the dominant aerobic spore-former recovered and should pose no risk to end-users, although the discovery of *Clostridium perfringens*, which can cause wound infections, may be a concern.

Results also demonstrate that on-farm ICW's are effective in eliminating *Salmonella* and faecal indicator organisms from agricultural wastewater. Although there are currently no microbiological standards for discharge waters, findings suggest that the treated wastewater would be suitable for release to waterways. However, repeated sampling is required. Composting and ICW's can therefore be considered as alternative treatment options for manure and wastewater, respectively that could help overcome land-spreading restrictions.

Cost Analyses of the Manure Treatment Options Investigated

Cost analyses were performed for anaerobic digestion of pig manure and grass silage, solid-liquid separation of the digested material, composting of the solid fraction and treatment of the liquid fraction by means of integrated constructed wetlands (ICW) and woodchip filters. Costs were calculated based on a case study of a 500 sow integrated pig farm unit producing 16m^3 liquid pig manure per sow per year (8000 m^3 in total per year), at 4.5% dry matter.

From the calculations for anaerobic digestion, a 500 sow integrated unit digesting grass silage and pig manure at a 1 to 20 ratio (fresh basis) would lose €60,019 per year. However, it is important to remember that, in the case of an anaerobic digestion plant, economies of scale will apply. For example, a 2000 sow unit with an investment cost of ~ €958,579 would have a payback time of 32.6 years. Furthermore, if the price paid for the electricity was to increase from €0.15/kWh to €0.22/kWh the payback time would be 138 years for the 500 sow unit but around 12 years for the 2000 sow unit.

Calculations for the solid and liquid separation of the anaerobically digested pig manure (+ grass silage) by decanter centrifuge without grants available, gave a total cost of €10.87 per m^3 of manure. In the case of compost, to break even a 500 sow integrated pig farm would need to sell compost at €0.71/litre.

For the treatment of the liquid fraction of separated pig manure from a 500 sow integrated unit, an ICW would require a land area around the unit of between 5 and 10ha. Woodchip filters, although a lower cost technology, have the limitation that their effluent cannot be directly discharged into a water body because of high levels of P and N. One solution to this that could increase the efficiency of both technologies, while reducing costs, would be to pretreat the liquid fraction in the woodchip filters to reduce levels of ammonium - nitrogen and solids in the liquid before passing it through the ICW. This would reduce the volume of extraneous water required to dilute the liquid before discharge to the ICW and consequently reduce the land area required for the ICW.

List of Publications to Date

Anaerobic Digestion

Xie S., Lawlor P., Frost P., Hu Z. and Zhan X. **Effect of pig manure to grass silage ratio on methane production in batch anaerobic co-digestion of concentrated pig manure and grass silage** Bioresource Technology, Volume 102, issue 10, May 2011, pages 5728-5733.

Xie S., Lawlor P., Frost P., Wu G. and Zhan X. **Evaluation of biogas production from anaerobic digestion of pig manure, with co-digestion of grass/maize silage** In Proceedings of the 14th European Biosolids & Organic Resources Conference, November 2009, Horan N.J. (ed), Aqua Enviro, Leeds, UK, page 27.

Xie S., Lawlor P., Frost P., Gilkinson S., Lynch B, Hu Z., Rodgers M. and Zhan X. **Effect of the manure to silage ratio on the methane production potential in co-digestion of pig manure and maize silage** In Proceedings Agricultural Research Forum, Tullamore, Co. Offaly, 12th & 13th March 2009, page 5.

Xie S., Lawlor P., Frost P., Wu G. and Zhan X. **Evaluation of biogas production from anaerobic co-digestion of pig manure and grass silage** In Proceedings of the NCBES Research Award in Life Sciences and Bioengineering, 28th, March, 2011. National University of Ireland, Galway, page 15.

Xie S., Lawlor P., Frost P., Wu G. and Zhan X. **Effect of organic loading rates on anaerobic co-digestion of solid fraction of pig manure and grass silage** In proceedings 21st Irish Environmental Researchers' Colloquium, Environ 2011, April 6th-8th, 2011, University College Cork, Ireland, page 117.

Xie S., Lawlor P., Frost P., Wu G. and Zhan X. **Effect of thermochemical pre treatment of grass silage for methane production** In Proceedings Agricultural Research Forum, Tullamore, Co. Offaly, 14th & 15th March 2011, page 127.

Xie S., Lawlor P., Frost P., Wu G. and Zhan X. **Biogas production from anaerobic co-digestion of pig manure with grass or maize silage** Poster presentation In AD in Ireland, 22nd October, 2009; Tullamore, Ireland.

Solid Fraction – Compost and Pyrolysis

Nolan T. ,Troy S., Healy M., Kwapinski W., Leahy J. and Lawlor P. **Characterization of compost produced from separated pig manure and a variety of bulking agents at low initial C/N ratios** Bioresource Technology, In Press, Available online 24 April 2011 (doi. 10.1016/j.biortech.2011.04.066).

Nolan T., Troy S., Lynch B. and Lawlor P. **Composting the solid fraction of separated pig manure with sawdust, chopped straw or shredded green waste.** In Proceedings British Society of Animal Science/Agricultural Research Forum Conference; Food, Feed, Energy and Fibre from Land – A Vision for 2010, April 12th-14th, 2010, Belfast, Ireland, page 282.

Troy S., Nolan T., Lawlor P., Lynch B. and Healy M. **Assessment of the Suitability of Co-Mixed and Composted Separated Solids of Pig Manure for Use as a Solid Fuel** In Digest of Abstracts College of engineering and informatics research day, NUI Galway, 15th April, 2010 - Environmental research section, paper ID 98.

Troy S., Nolan T., Leahy J., Kwapinski W., Lawlor P. and Healy M. **Assessment of the Suitability of Co-Mixed and Composted Separated Solids of Pig Manure for Use as a Solid Fuel** In Digest of Abstracts Engineering and informatics research day, NUI Galway – University of Limerick Alliance, Galway, 8th April, 2011 - Environmental research section.

Nolan T., Troy S., Healy M. and Lawlor P. **Characterization of compost produced from separated pig manure and a variety of bulking agents at low initial C/N ratios** In Proceedings Agricultural Research Forum, Tullamore, Co. Offaly, 14th & 15th March 2011, page 32.

Troy S., Nolan T., Healy M. and Lawlor P. **Effect of manure to sawdust ratio on the composting of separated solids from anaerobically digested pig manure** In Proceedings Agricultural Research Forum, Tullamore, Co. Offaly, 14th & 15th March 2011, page 132.

Troy S., Nolan T., Lawlor P., Leahy J., Healy M. and Kwapinski W. **Influence of the addition of different carbon rich bulking agents and composting on the characteristics of pig manure char** In proceedings 21st Irish Environmental Researchers' Colloquium, Environ 2011, April 6th-8th, 2011, University College Cork, Ireland, page 88.

Kwapinski W., Troy S., Wnetrzak R., A. Piterina, Healy M, Nolan T., Lawlor P, Leahy J. and Hayes M. **Pyrolysis of waste organic substances and products applications** In Proceedings Managing Livestock Manure for Sustainable Agriculture, November 24th-25th 2010, Wageningen, The Netherlands.

Nolan T., Troy S., Healy M. and Lawlor P. **Effect of increasing sawdust to separated pig manure solid ratio on the quality of compost produced** In proceedings 21th Irish Environmental Researchers' Colloquium, Environ 2011, April 6th-8th, 2011, University College Cork, Ireland, page 176.

Liquid Fraction – Integrated Constructed Wetlands

Harrington C. and Scholz M. **Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems** Bioresource Technology, Volume 101, Issue 20, October 2010, pages 7713-7723

Harrington C., Scholz M, Culleton N. and Lawlor P. **Meso scale systems used for the examination of different Integrated Constructed Wetland operations** In proceedings 2nd Irish International conference on constructed wetlands for wastewater treatment and environmental pollution. 1-2 October 2010, University College Dublin, pages 251-259.

Harrington C., Scholz M., Harrington R. and Culleton N. **The use of constructed wetlands for the treatment of swine wastewaters: a review** International Wetland Association, 4-8 October 2010, Venice, Italy, pages 1313-1319.

Harrington C., Scholz M., Lawlor P., Harrington R. and Culleton N. **Use of integrated constructed wetlands for the treatment of separated liquid fraction of anaerobically digested pig manure** International Wetland Association, 4-8 October 2010, Venice, Italy, pages 435-442.

Harrington C., Scholz M., Culleton N. and Harrington R. **Novel Integrated Constructed Wetlands for the Treatment of Anaerobically Digested Swine Wastewater** In Book of abstracts 3rd Wetland Pollutant Dynamics and control, Wetpol 2009, 20-24 September 2009, Barcelona, Spain, pages 359-360.

Harrington C., Scholz M., Culleton N. and Lawlor P. **The use of Integrated Constructed Wetlands for the treatment of separated swine wastewaters** In Proceedings Society of Wetland Scientists European Chapter Annual Meeting, May 26th – 28th, 2010, Tramore, Co Waterford, Ireland, pages 84-85.

Harrington C., Scholz M., Lynch B., Lawlor P. and Culleton N. **The use of Integrated Constructed Wetlands for the treatment of swine wastewaters** In Proceedings British Society of Animal Science/Agricultural Research Forum Conference; Food, Feed, Energy and Fibre from Land – A Vision for 2010, April 12th-14th, 2010, Belfast, Ireland, page 283.

Liquid Fraction - Woodchip Filters

Carney K., Rodgers M., Zhan X. and Lawlor P. **Treatment of piggery wastewaters using woodchip biofilters** In Book of Abstracts, Joint ECI-MRI

Research Day, June 17th 2010, P26.

Carney K., Rodgers M., Zhan X. and Lawlor P. **Treatment of piggery wastewaters using woodchip biofilters** In Digest of Abstracts College of engineering and informatics research day, NUI Galway, 15th April, 2010 – Civil research section, paper ID 19

Carney K., Rodgers M., Zhan X. and Lawlor P. **Treatment of piggery anaerobic digestate liquid using woodchip biofilters** In Proceedings Agricultural Research Forum , Tullamore, Co. Offaly, 14th & 15th March 2011, page 129

Carney K., Rodgers M., Zhan X. and Lawlor P. **Treatment of piggery wastewaters using aerobic woodchip biofilters** In proceedings 21th Irish Environmental Researchers' Colloquium, Environ 2011, April 6th-8th, 2011, University College Cork, Ireland, page 64.

Microbial Safety

McCarthy G., Lawlor P., Gutierrez M. and Gardiner G. . **Removal of Salmonella and indicator micro-organisms in integrated constructed wetlands treating agricultural wastewater** Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering (In press, DOI: 10.1080/10934529.2011.571627)

McCarthy G., Lawlor P., Gutierrez M. and Gardiner G. **Removal of Salmonella and indicator micro-organisms in integrated constructed wetlands treating agricultural wastewater** In proceedings 2nd Irish International conference on constructed wetlands for wastewater treatment and environmental pollution. 1-2 October 2010, University College Dublin, pages 315-322.

McCarthy G., Lawlor P., Harrington C. and Gardiner G. **Efficacy of integrated constructed wetlands for the removal of pathogens from livestock wastewater** In Proceedings Society of Wetland Scientists European Chapter Annual Meeting, May 26th – 28th, 2010, Tramore, Co Waterford, Ireland, pages 83-84.

McCarthy G., Lawlor P., Gutierrez M. and Gardiner G. **Treatment of agricultural wastewater in integrated constructed wetlands for removal of Salmonella and enteric indicator bacteria** In Proceedings Agricultural Research Forum , Tullamore, Co. Offaly, 14th & 15th March 2011, page 5

McCarthy G., Lawlor P., Gutierrez M. and Gardiner G. **Removal of Salmonella and indicator micro-organisms in integrated constructed wetlands treating agricultural wastewater** In Book of abstracts, Waterford Institute of Technology Research Day, 13th May, 2011, Waterford, Ireland.

McCarthy G., Lawlor P., Nolan T., Gutierrez M. and Gardiner G. **Biosafety assessment of pig manure during composting with straw, sawdust and greenwaste bulking agents** In Proceedings British Society of Animal Science/ Agricultural Research Forum Conference; Food, Feed, Energy and Fibre from Land – A Vision for 2010, April 12th-14th, 2010, Belfast, Ireland, page 46.

McCarthy G., Lawlor P., Troy S., Nolan T. and Gardiner G. **Composting to improve biosafety of pig manure with a view to developing a manure-derived solid biofuel** In Book of abstracts Waterford Institute of Technology Research Day, 17th May, 2010, Waterford, Ireland, page 72.

Notes