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Alternative uses for pig manure

Key external stakeholders:
Pig farmers, pig advisers and consultants, policy makers, the scientific community

Practical implications for stakeholders:
Despite restrictions and difficulties relating to the land spreading of pig manure, it is likely to be the most cost effective method of pig manure disposal in Ireland for the foreseeable future. While our cost analyses showed that the alternative technologies investigated in this project are not currently cost effective in Ireland, they may have potential in particular scenarios. For example, anaerobic digestion would be cost effective on large pig units (+2000 sows integrated) or if the renewable energy feed in tariff for energy sold to the grid was to increase in the future.

Main results:

This project demonstrated the technological feasibility and effectiveness of several alternative technologies for using and treating pig manure in Ireland. These include: anaerobic digestion of pig manure and grass silage, composting of the separated solid fraction of pig manure, use of the solid component of manure as a feedstock in pyrolysis and treatment of the liquid fraction of pig manure through integrated constructed wetlands (ICW) and woodchip biofilters. However, cost analyses of all technologies examined found all to be uneconomic, with conventional land spreading of pig manure for its fertilizer value found to be the most economic use for pig manure currently

Opportunity / Benefit:

The economic analysis performed on all of the technologies employed in this study allows examination of their economic feasibility now and in future scenarios. The results show land-spreading of pig manure for its fertilizer value to be the most economic use for pig manure currently, thus preventing farmers from making unwise financial decisions. Nonetheless, information on the effectiveness of and design guidelines for each technology examined are now available for adoption by stakeholders should economic conditions change in the future.

Collaborating Institutions:

NUI Galway, AFBI, WIT, UL.

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1. Project background:

The Nitrates Directive Action plan introduced by S.I. No.378 (2006) and updated by S.I. No. 610 (2010), prompted this research into non landspread options for pig manure. The spiraling cost of fossil fuel also means that the potential of pig manure as a renewable energy source should be examined

2. Questions addressed by the project:

- Is anaerobic digestion of pig manure feasible?
- Can the separated solid fraction of pig manure be used for composting or as a biofuel?
- Are ICW and woodchip biofilters suitable for treating the separated liquid fraction of pig manure ?
- What is the energy balance of the technologies studied?
- Do the manure treatment strategies examined stack up economically?

3. The experimental studies:

- **Anaerobic Digestion:** A total of nine experiments were carried out as part of the investigation into AD of pig manure. The researchers designed and constructed three identical continuously stirred single stage reactors (3l capacity), as well as six additional identical leaching bed reactors (2l capacity) to study the AD of pig manure with and without grass silage and maize silage. Two additional reactors were set up to investigate hydrolysis and acidogenesis of the mixture of pig manure and biomass. After these laboratory studies, a pilot scale digester was commissioned and installed at Moorepark to validate the main findings of the small scale units. Greenhouse gas (GHG) emissions were also measured during the storage of pig manure.
- **Composting of Manure Solids:** The separated solid fraction of pig manure was composted using different bulking agents (straw, sawdust, shredded green waste and woodchips) at different ratios. The composting process was monitored through physical, chemical and microbiological analyses.
- **Use of Solid Manure as a Fuel:** A small scale pyrolysis reactor in UL was used to study the suitability of producing energy from pig manure. The use of all three end products of pyrolysis (biochar, bio-oil and gases) to generate energy was evaluated. Experiments were carried out on the separated solid fraction of pig manure before and after composting. The biochar produced by the pyrolysis process was also analyzed for its value As a soil addendum.
- **Integrated Constructed Wetlands (ICW):** Sixteen meso-scaled ICW systems, each comprising 4 cells, were constructed at Teagasc Moorepark in order to assess treatment of the separated diluted liquid fraction of pig manure. Different application rates and flow rates were investigated and microbiological analyses were conducted to investigate the removal of pathogenic micro-organisms.
- **Woodchip biofilters:** Laboratory scale woodchip biofilters were designed, constructed and used to assess the suitability of using this technology to remove nutrients and pathogenic micro-organisms from the separated liquid fraction of pig manure. Twelve aerobic woodchip biofilters of 0.6 m depth were constructed to treat separated raw pig manure liquid (SR) and separated anaerobically digested pig manure liquid (SAD) at two hydraulic loading rates. Following on from this, six pilot-scale biofilters consisting of 1 m aerobic woodchip and 0.5 m saturated woodchip layers were constructed at Moorepark to verify results from the laboratory and to demonstrate effects of scale, variations in temperature and rainfall when used to treat the SR and SAD.
- **Energy Balance:** An energy balance was performed on some of the technologies studied in the

project. The energy balance was based on a case study of a 500 sow integrated pig unit producing 10,500 m^3 of liquid manure/year with a dry matter (DM) of 4.3%.

- **Economics:** A cost-benefit analysis of the technologies investigated was performed based on the same criteria used for the energy balance study.

4. Main results:

- **Anaerobic Digestion:** Using the laboratory-scale continuously stirred single stage reactors, it was found that grass silage could be co-digested with pig manure at a volatile solids ratio of 1.5 (manure/silage) in the feedstock and this was found to be feasible without reducing the specific methane yield. When the reactors were operated under an organic loading rate of up to 3 kg volatile solids/m^3/day and a grass silage volatile solids ratio of up to 40%, the system was found to be stable. However, the post methane production potential increased to 183-197 ml CH_4/g volatile solids and the volumetric post-methane production potentials increased to 9.96 ml CH_4/ml digestate. In subsequent pilot-scale experiments the specific methane yield increased from 154 ml CH_4/g volatile solids added with mono-digestion of manure to 251 ml CH_4/g volatile solids added with anaerobic co-digestion of manure and grass silage. Volatile solids removal rates increased from 41.4% (manure alone) to 53.9% (manure + silage). The results show that co-digestion of pig manure and grass silage is preferable to mono-digestion of manure alone.
- **Composting of Manure Solids:** Results demonstrated that addition of a carbon-rich bulking agent is required when composting the separated solids of pig manure. Of the bulking agents investigated sawdust produced the best quality compost. When composting the separated solids of pig manure with sawdust, stable compost can be produced using a Carbon to Nitrogen ratio as low as 16. This corresponds to a separated manure solids to sawdust ratio of 4:1 (fresh weight). In addition, microbiological analyses showed that pig manure-derived compost meets microbiological criteria for marketable processed manure products, as set out in EU regulations, as *E. coli* and *Enterococcus* were below limits and it was *Salmonella*-free.
- **Use of Solid Manure as a Fuel:** The small scale pyrolysis reactor studies showed that the proportion of biochar, bio-liquid and gas produced, and the physical and chemical characteristics of these products were influenced by both sawdust addition and feedstock composting. Increasing the sawdust content in the wood/manure mixture decreased the biochar yield and increased the bio-liquid yield. The biochar showed increased heating values, but reduced nutrient concentrations with increasing sawdust addition. The heating value of the gases produced also increased, while that of the bio-liquid was decreased with sawdust addition. Composting of the feedstock before pyrolysis increased the biochar and bio-liquid yield, but decreased the gas yield. The biochar showed reduced heating values, while the bio-liquid heating values were increased with composting. The biochar produced by the pyrolysis process was also analyzed as a soil addendum in laboratory columns. The addition of biochar to the soil increased N_2O emissions when pig manure was also added and CO_2 emissions also increased. The GHG emissions in this study were examined over a one month period following manure application. Longer term studies would be necessary to give a true picture of the overall effect of biochar addition on soil GHG emissions.
- **Integrated Constructed Wetlands:** The meso-scaled ICW study demonstrated the potential of this technology to treat the separated liquid fraction of pig manure. However due to the system's high sensitivity to ammonium, the separated liquid fraction of pig manure had to be greatly diluted before entering the ICW. This may render this technology unviable for pig farmers due to the high land area required to construct such systems. Flow through the cells reduced mean counts of coliform, yeasts and moulds and spore-forming bacteria across all treatments but there were no effects on *Enterococcus* or *E. coli* counts. As *Salmonella* was undetectable in the influent material, its removal could not be investigated. As a result, microbial removal was also investigated in large-scale on-farm ICW systems treating agricultural wastewater. Overall, reductions in enteric indicator bacteria counts were found across nine ICW systems treating dairy and piggery wastewater, with *E. coli* and *Enterococcus* non-detectable in the final effluent. Furthermore, *Salmonella*, when present in the influent material, was absent in the ICW effluent.
- **Woodchip biofilters:** The SR pilot-scale woodchip biofilters were successful in removing 49% DM, 71% CODt, 87% 5-day biochemical oxygen demand (BOD5), 89% TN and 91% total phosphorous (TP). Reductions of 54% DM, 80% CODt, 93% BOD5, 86% TN and 79% TP were achieved in the SAD pilot scale woodchip biofilters. The results confirm the occurrence of nitrification in the aerobic woodchip layers and denitrification in the submerged layers as previously found in the laboratory scale tests. When different chemical treatments were investigated for polishing of the pilot-scale biofilter effluent aluminium sulphate was found to be better than lime. It removed 71% turbidity, 63% CODt and 50% TP from the SR woodchip biofilter effluent, and 84% turbidity, 76% CODt and 99.6% TP from the

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SAD biofilter effluent. The measurement of GHG (CH_4, N_2O and CO_2) emissions from the pilot-scale woodchip biofilters using a chamber based flux measurement indicated that the average GHG equivalent emissions from the woodchip biofilters were 264 kg CO_2e/ha/day and 217 kg CO_2e/ha/day from the SR and SAD woodchip biofilters, respectively. Microbiological analyses showed that *E. coli* and *Enterococcus,* although detectable in the biofilter influent were almost always below the limit of detection in the effluent and *E. coli* counts also appeared to be reduced. Furthermore, *Salmonella*, although detected in the influent on some occasions, was never found in the biofilter effluent.

- **Energy Balance:** Anaerobic digestion was shown to be a net energy producer, with 277 MJ energy generated per t of input manure. For the separation process after AD a total of 4 MJ/ t input manure is necessary. The composting process is also an energy consumer with 16.5 MJ/ t manure input (plus the energy necessary for separation). The pyrolysis of pig manure was considered under different conditions: with and without the addition of different amounts of sawdust as well as before and after composting. The highest energy yield (496 MJ/ t manure input) was achieved when non-composted manure + sawdust at a 3:2 ratio was used as a feedstock and all three pyrolysis products were used as fuel source. The only energy input necessary for the ICW and the woodchip biofilter treatments is the energy necessary to separate the manure beforehand (4 MJ/ t input manure), as the material will be gravity-fed to the systems.
- **Economics:** The AD of pig manure and grass silage (1:1; volatile solids basis) is unviable under the current tariffs, with costs at €4.8/m^3 manure. The solid-liquid separation of the digestate would cost an additional €12.4/m^3 manure. Subsequent treatment of the separated solid fraction by composting would add €2.1/m^3 manure. The use of ICW to treat the separated liquid fraction would add €4.5/m^3 manure to the treatment costs, while the use of woodchip filters would add €2.8/m^3 manure. The costs presented showed that the technologies analyzed are currently not cost effective. Transport and spreading of raw manure, at €4.9/m^3 manure (15 km maximum distance from farm) is the most cost effective option. For distances of up to 14km from the customer's farm the tractor and vacuum tanker scenario is the most cost effective option (€4.7/m^3). For longer distances it becomes more cost effective to use a truck, with the cost of transporting and spreading manure within a distance of 50 km to the customer's farm calculated at €7.7/m^3 manure.

5. Opportunity/Benefit:

The economic analysis performed on all of the technologies employed in this study allows examination of their economic feasibility now and in future scenarios. The results show land-spreading of pig manure for its fertilizer value to be the most economic use for pig manure currently, thus preventing farmers from making unwise financial decisions. Nonetheless, information on the effectiveness of and design guidelines for each technology examined are now available for adoption by stakeholders should economic conditions change in the future

6. Dissemination:

A total of 17referred journal papers and 49 conference papers/abstracts were generated. An open day 'Research Results on Alternative Uses for Pig Manure' was held in Moorepark on the 8th June 2011 to update stakeholders on the main results of the project.

Main publications:

1. Nolan T., Troy S., Gilkinson S., Frost P., Xie S., Zhan X., Harrington C., Healy M. G., and Lawlor, P. G. (2012). Economic analyses of pig manure treatment options in Ireland. Bioresource Technology. 105, 15-23.
2. Troy, S.M., Nolan, T., Kwapinski, W., Leahy, J.J., Healy, M.G. and. Lawlor, P.G. (2012) Effect of sawdust addition on composting of separated raw and anaerobically digested pig manure. Journal of Environmental Management, 111, 70-77
3. Xie S., Lawlor P., Frost P., Hu Z. and Zhan X. (2011). 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 102, 5728-5733.

Popular publications:

Proceedings of Pig Development Department research dissemination day, 'Research results on alternative uses for pig manure'. Wednesday 8th June, 2011. 82pp.
http://www.teagasc.ie/publications/2011/1021/Moorepark_AlternativeUsesForPigManure.pdf

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