SOIL CRC

Performance through collaboration

RESEARCH FINDINGS FACT SHEET

ENHANCED NUTRIENT RECOVERY FROM FOOD WASTE ANAEROBIC DIGESTATE

KEY POINTS

- Food waste fertilisers are an alternative nutrient source which can improve the soil's agronomic value and reduce reliance on synthetic fertilisers.
- Anaerobic digestion offers a sustainable way to manage food waste, reducing environmental pollution and recovering valuable nutrients. However, the liquid digestate produced via anerobic digestion is bulky and difficult to handle, while evaporating the liquid leads to nitrogen loss.
- Acidifying the liquid digestate before evaporation effectively retains ammonium, creating a higher-value product that is more cost effective to transport.
- Acidified digestate products can provide high available nitrogen, potentially reducing the use of synthetic nitrogen fertilisers such as urea, with added benefits of increased microbial function and being a source of carbon.

THE CHALLENGE

Food waste management is often inefficient. Disposing of food waste to landfill and its incineration contributes to about 20% of global greenhouse gas (GHG) emissions, as well as groundwater and surface water contamination.

Reusing food waste on agricultural land comes with many potential benefits, including:

- Reducing reliance on synthetic fertilisers
- Reducing the carbon impact of agriculture – producing nitrogen fertilisers consumes about 2% of the world's energy
- Acting as a source of carbon to improve soil health.

However, methods to treat food waste come with their own challenges (Figure 1). Traditional composting methods result in carbon dioxide and nitrous oxide emissions, and the composting process reduces the nutrient value of the end product.

During anaerobic digestion, microorganisms break down organic material in a sealed, oxygen-free tank. This produces a biogas – a mixture of methane and carbon dioxide – which can be used as a renewable energy source, and a liquid digestate.

However, the digestate is bulky, high in water, heavy, and with low nutrient value, making it costly and difficult to transport and handle. As such, it is usually recycled through the digester or disposed of in sewage rather than used on agricultural land as a fertiliser. Solidifying the digestate could ease these logistical challenges but doing so leads to a large loss in nutrients, particularly ammonium.

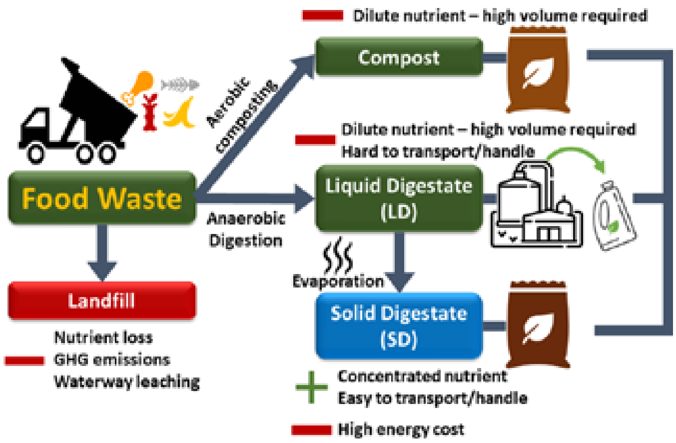

Figure 1. Food waste management options have inefficiencies and challenges. Source: James O'Connor.

THE RESEARCH

This research was part of a Soil CRC PhD project by James O'Connor from the University of Western Australia, which investigated how food waste biofertilisers affect soil chemistry, nitrogen dynamics, gaseous emissions from the soil, and crop growth and yield.

The project compared four common and emerging food waste fertilisers:

1. Compost – food organics garden organics (FOGO) compost, i.e. the Green Bin
2. Liquid digestate (LD) from anaerobic digestion
3. Solid digestate (SD) from anaerobic digestion
4. Acidified digestate (AD)*

The products were combined with and compared to urea ammonium nitrate (UAN).

*During the research, it was discovered that significant amounts of nitrogen were being lost while converting liquid digestate to solid digestate. This led to further experiments to stabilise the digestate (creating solid, acidified digestate) which was tested on soil chemistry, biology, crop growth and yield.

RESEARCH FINDINGS

Soil nitrogen content and N_2O emissions

Soils amended with liquid digestate had comparable nitrogen (N) levels to UAN amended soils but emitted 23% less nitrous oxide (N_2O). This indicates replacing UAN with liquid digestate could supply an equivalent amount of available N in the soil with lower N_2O emissions.

Compost and solid digestate treated soils had considerably lower available nitrogen levels than liquid digestate and UAN, and associated lower N_2O emissions.

Plant (ryegrass) growth

Due to higher available nitrogen, ryegrass grew better in the liquid digestate and UAN soils than the compost and solid digestate soils.

However, combining compost and solid digestate with UAN led to synergistic effects, improving soil properties (higher microbial biomass carbon, less of a reduction in soil pH) and plant growth more effectively than using UAN alone. Solid digestate + UAN gave the largest ryegrass shoot biomass, 310% higher than the control.

Soil microbial dynamics

All food waste derived fertilisers boosted beneficial plant growth promoting bacteria, indicating enhanced plant growth potential. All soils treated with food waste fertiliser had a higher abundance of *Burkholderia*, a nitrogen fixer, and potentially more nitrogen-fixing capabilities. However, the digested amended soils also had more denitrification genes, indicating the potential for more nitrogen loss via volatilisation compared to conventional mineral nitrogen fertiliser.

Microbial biomass carbon (MBC) reflects soil microbial activity, with higher MBC levels indicating higher microbial activity and healthier soils. Over 56 days, solid digestate + UAN was the only treatment with a significantly higher level of MBC than the control. It also had significantly higher MBC than all other treatments except solid digestate.

The lack of significant differences in MBC between treatments and the control are likely due to the high total carbon in the control soil (7.04%, see Table 1). In soils with lower carbon, we would expect the food waste fertilisers to provide a source of carbon and nitrogen to promote microbial biomass biosynthesis and accumulation.

Improving nutrient retention in solid digestate

Evaporating liquid digestate to solid digestate reduces storage and handling problems at digestion plants, however, this causes nitrogen loss via ammonium volatilisation (ammonium in liquid to ammonia gas), decreasing the available nitrogen content and viability of the product as a fertiliser.

Acidifying the liquid digestate before evaporation prevents this ammonium loss. The liquid digestate was acidified with three acids - sulphuric, nitric, and phosphoric acid, producing ammonium sulphate, ammonium nitrate and ammonium dihydrogen phosphate salts, respectively.

Advanced analyses (Fourier Transform Infrared Spectroscopy, X-ray crystallography, scanning electron microscopy and energy dispersive X-ray spectroscopy) confirmed the presence of these ammonium salts, i.e. they were not being lost during evaporation, and further characterised the products.

Table 1 compares the selected properties of the various acidified digestates. Note the higher ammonium-N and N recovery from evaporation in the acidified digestates compared to the untreated solid digestate. Ammonium was completely retained in all acidified digestates, whilst there was 99.7% reduction in ammonium content and 63.8% reduction in total nitrogen in solid digestate.

Table 1. Selected properties of the various amendments.

AMENDMENTS	SELECTED PROPERTIES (%)				
	Total C	Total N	Ammonium-N	Available P	N recovery from evaporation
Soil	7.04	0.36	0.00	0.00	-
Urea ammonium nitrate	-	32.00	7.70	-	-
Liquid digestate	0.90	0.35	0.29	-	-
Solid digestate	35.30	5.01	0.03	0.04	35.21
Acidified solid digestates					
Ammonium sulphate solid digestate	21.73	9.97	3.41	0.18	114.66
Ammonium nitrate solid digestate	21.50	17.07	4.17	0.13	205.81
Ammonium phosphate solid digestate	17.42	8.45	4.68	8.77	128.03

Impact of acidified digestate on soil properties and crop productivity

Acidified digestate treated soils had:

- significantly higher shoot and root biomass than the control. Results were highest in the ammonium phosphate digestate treatments due to the high bioavailable phosphorus
- higher macro and micronutrient accumulation in the plant growth
- more proteobacteria, indicating a greater capacity for nitrogen fixation, nutrient cycling, and promoting plant growth.

UAN did not improve plant growth over the control, likely due to the acidic nature of the soil (Figure 2).

For wheat, the acidified digestate products, liquid digestate and UAN had a bigger impact on crop growth and yield. Raw liquid digestate, acidified digestate products and UAN had significantly higher yields (all >2.93 t/ha) than control (0.09 t/ha) and untreated solid digestate (1.05 t/ha). The highest grain yield was on the ammonium phosphate digestate treatment (3.78 t/ha). Control and untreated solid digestate had the highest grain protein content (12.67% and 11.57%, respectively), a function of the dilution effect where protein decreases as yield increases.

The poor performance of the untreated solid digestate compared to the acidified solid digestate lends further weight to the acidifying technique as a method to improve the nutrient content and make a more valuable product, comparable to UAN.

Figure 2. From left to right: Control, UAN, liquid digestate (LD), solid digestate (SD), ammonium sulphate solid digestate (ASSD), ammonium nitrate solid digestate (ANSD), ammonium phosphate solid digestate (APSD). Scale in cm. Source: James O'Connor.

SIGNIFICANCE OF THE FINDINGS

The novel fertilisers developed from acidified digestate retain ammonium during the evaporation process and have substantial benefits over raw liquid digestate and untreated solid digestate. Acidified digestate products are solid, dewatered, and nutrient-enriched, addressing the logistical challenges currently faced by anaerobic digestion facilities. They enhance the sustainability and efficiency of food waste management by producing a stable product that is safe to store on-site and reduces transportation costs.

The food waste management industry can significantly benefit from adopting this acidification process.

Enhancing the value of biofertilisers will drive investment in sustainable practices like anaerobic digestion, effectively reducing the amount of food waste sent to landfills.

RESEARCH PUBLICATIONS

- O'Connor, J., Hoang, S.A., Bradney, L., Dutta, S., Xiong, X., Tsang, D.C.W., Ramadass, K., Vinu, A., Kirkham, M.B. & Bolan, N.S. (2021). A review on the valorisation of food waste as a nutrient source and soil amendment. Environmental Pollution, 272, 115985. **https://doi.org/10.1016/j.envpol.2020.115985**
- O'Connor, J., Mickan, B., Siddique, K.H.M., Rinklebe, J., Kirkham, M.B. & Bolan, N.S. (2022). Physical, chemical, and microbial contaminants in food waste management for soil application: A review. Environmental Pollution, 300, 118860. **https://doi.org/10.1016/j.envpol.2022.118860**
- O'Connor, J., Mickan, B.S., Rinklebe, J., Song, H., Siddique, K.H.M., Wang, H., Kirkham, M.B. & Bolan, N.S. (2022). Environmental implications, potential value, and future of food-waste anaerobic digestate management: A review. Journal of Environmental Management, 318, 115519. **https://doi.org/10.1016/j.jenvman.2022.115519**
- O'Connor, J., Mickan, B.S., Gurung, S.K., Bühlmann, C.H., Jenkins, S.N., Siddique, K.H.M., Leopold, M. & Bolan, N.S. (2024). Value of food waste-derived fertilisers on soil chemistry, microbial function and crop productivity Applied Soil Ecology, 198, 105380. **https://doi.org/10.1016/j.apsoil.2024.105380**
- O'Connor, J., Mickan, B.S., Gurung, S.K., Siddique, K.H.M., Leopold, M. & Bolan, N.S. (2023). Enhancing nutrient recovery from food waste anaerobic digestate. Bioresource Technology. 390, 129869. **https://doi.org/10.1016/j.biortech.2023.129869**
- O'Connor, J., Mickan, B.S., Yusiharni.E., Singh.G., Gurung, S.K., Siddique, K.H.M., Leopold, M., & Bolan, N.S. (2024). Characterisation and agronomic evaluation of acidified food waste digestate products. Journal of Environmental Management, 355, 120565. **https://doi.org/10.1016/j.jenvman.2024.120565**
- O'Connor, J., Mickan, B. S., Gurung, S. K., Siddique, K. H. M., Leopold, M., Bühlmann, C. H., & Bolan, N. S. (2024). Transforming waste to wealth: Impact of food waste-derived soil amendments and synthetic nitrogen fertilizer on soil dynamics. Soil Use and Management, 40, e13093. **https://doi.org/10.1111/sum.13093**

NEXT STEPS

This is an important study evaluating enhanced solid digestate on soil fertility and crop productivity. While it highlights the potential of these novel fertilisers to agriculture, there is much to learn regarding economics, cost effectiveness of acidification and evaporation, transport and handling, use in different agricultural contexts and environmental conditions, and further assessment of GHG emissions and carbon footprint impacts.

Research team

Lead researcher:

- James O'Connor, University of Western Australia (PhD candidate)

Supervisors:

- Professor Nanthi Bolan, University of Western Australia, Soil CRC
- Professor Kadambot Siddique, University of Western Australia
- Associate Professor Matthias Leopold, University of Western Australia
- Dr Bede Mickan, University of Western Australia, Richgro

The CRC for High Performance Soils (Soil CRC) brings together scientists, industry and farmers to find practical solutions for Australia's underperforming soils. Our aim is to enable farmers to increase their productivity and profitability by providing them with knowledge and tools to improve the performance of their soils. The Soil CRC is the largest collaborative soil research effort in Australia's history, with funding until 2027. We have attracted more than $167 million in cash and in-kind resources over 10 years from our 39 participants and the Australian Government.