Compost and Digestate: Dispelling the Confusion

US Composting Council®

Introduction

With the increase in attention to capturing organic materials vs. landfilling, compost and anaerobic digestate (AD) are often confused. The US Composting Council has developed this white paper to help advocates, policymakers, and others understand their characteristics.

Table 1: Summarizes the differences between both products without further processing.

	Compost	Digestate
Soil organic carbon	High	Low
Available N	Low	High
Slow release N	High	Low
Soil structure benefits	High	Low
Water retention capacity	High	Low
Sanitized	Yes	No

Basic Definitions

Compost and digestate are very distinct products resulting from aerobic and anaerobic processes, respectively. While both are made from wasted organic material and have nutritional value for crop production, their differences significantly impact soil and environmental health. Compost and digestate are distinguished by:

- production processes
- physical and chemical properties
- application techniques
- emissions liability
- contributions to soil organic carbon
- long-term soil benefits
- role in plant growth.

Processes

Microorganisms drive the decomposition of organic matter in both composting and AD. Aerobic organisms in composting break down simple compounds first and in the final phase stabilize carbon and other nutrients by binding them together to create humic compounds. Composting is common as an outdoor and batch process that accepts various biomass feedstocks because it decomposes lignin, a highly fibrous plant material. AD is an in-vessel process where anaerobic organisms break down complex compounds first, then simple compounds, and finally create methane and carbon dioxide. AD does not decompose lignin. Both processes have associated and variable greenhouse gas emissions (GHG) depending on feedstock and management practices.

Compost and Digestate: Dispelling the Confusion

US Composting Council®

Definitions

Compost is a well-vetted term largely because it has been marketed commercially for nearly 50 years, whereas digestate is a newcomer to the commercial marketplace and has not come under the decades of scrutiny and market demand for criteria from which compost has benefitted. Over the years, the definition of compost has been refined by research institutions, academics, and most recently by the Association of American Plant Food Control Officials (AAPFCO). For commercial composting, USCC recommends AAPFCO's definition: *"Compost is the product manufactured through the controlled aerobic, biological decomposition of biodegradable materials. The product has undergone mesophilic and thermophilic temperatures, which significantly reduces the viability of pathogens and weed seeds and stabilizes the carbon such that it is beneficial to plant growth. Compost is typically used as a soil amendment, but may also contribute plant nutrients."* (AAPFCO, Official 2018).

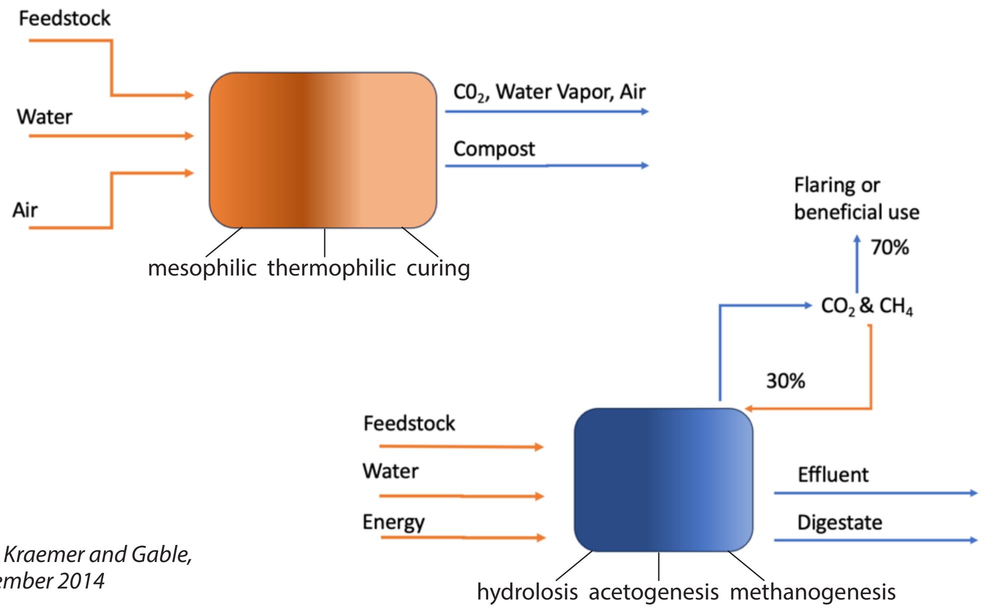
Digestate lacks a uniform, criteria-driven definition because until recently it was not considered commercially valuable, as the process typically does not create 'finished' products. Historically it has been defined as waste undistinguished from the waste produced by water resource recovery facilities (WRRFs), on-farm manure and crop residue, and biogas facilities. Four terms reference the byproducts of these facilities: digestate, biosolids, sludge, and residual solids. These terms are often used interchangeably.

- Biosolids and sludge refer to the byproducts of water resource recovery processes irrespective of the inclusion of anaerobic digestion (AD).
- Digestate and residual solids refer to the byproduct of AD regardless of facility type.

AAFPCO provides a straightforward definition along with requirements for labeling. *Anaerobic Digestate is the liquid or solid material processed through anaerobic digestion. Labeling digestate material shall be designated by prefixing the name of the feedstock from which it is produced, i.e. cow manure digestate, biosolid digestate, etc.* (AAPFCO, Official 2011)

In this white paper, digestate is defined as the residual material left over after the AD process. It consists of the solids and liquids that were not decomposed or converted to biogas. After digestion, solids are typically separated from liquids. Digestate can vary widely in composition depending on the feedstock used for digestion and the specific conditions of the digestion process. There are both higher and lower moisture content technologies.

Inputs & Outputs for Composting and Anaerobic Digestion



Adapted from Kraemer and Gable, Biocycle, November 2014

Compost and Digestate: Dispelling the Confusion

US Composting Council®

Nutritional Value

As municipalities nationwide select practices to reduce GHG emissions, they are finding that food waste recovery is a high-value input for composting and AD. Adding food waste to these processes offers diversion from landfills, quicker processing time, and higher total N values in the resulting products. Due to the converse amounts of organic N and available N, these materials have distinct effects on plant growth.

Taylor et al. (2010) found that 81% of N is readily available in food waste based digestate. This means that it is highly soluble and easily metabolized by plants within a week of application. Readily available N that is not metabolized by plants poses a risk to sensitive water bodies. Most research notes that good management of the application of digestate is critical to prevent the translocation of available nutrients.

Compost provides a small amount of readily available N and more organic N that becomes available to plants over weeks, months, and years. The application of compost can stimulate growth at critical stages, continues to provide N slowly released over time, and does not pose risk to water bodies.

Table 2: 2021 Average food waste with yard waste compost analysis provided by USCC.
Food waste based digestate figures from Taylor (2010).

Feedstock (kg/m3)	Digestate	Compost
Total N	7.40	6.24
Readily Available N	5.99	0.17
Organic N	1.41	6.07

Ammonium is the predominant form of readily available N found in digestate. This means that it is highly soluble and easily metabolized by plants. Digestate can provide an immediate flush of nutrition at strategic plant growth stages, but it does not provide a reservoir of soil organic carbon, long-term nutrition, or other soil benefits attributed to compost. These benefits are detailed in Compost and Its Benefits, a fact sheet published by the US Composting Council and found at compostingcouncil.org/compostbenefits.

Unlike digestate, compost contains more stable forms of carbon. The gold standard of these are humic substances formed during curing. Humic substances (fulvic acid, humic acid, and humin) contain nitrogen, phosphorous, potassium, and micronutrients. These critical micronutrients are bound together as the result of chemical and microbiologic activity. These remain in soil over long periods and have considerable soil improvement and carbon sequestration value releasing nutrition over time relative to crop demand and soil condition. The research examined by Gilbert et al. (2020) has not found that humic substances are created during the digestion process.

Uses

The most common current application of anaerobic digestate is to spread it on cropland for fertilization. This is achieved by pumping it in liquid format or drying it and applying it with a spreader. Other uses are fuel, nutrient extraction, and construction composites.

If digestate is composted the composted digestate can then cite beneficial characteristics credited to compost. For example,

- Compost is used as a soil amendment and nutrition provider in fruit and crop production. This application provides ecosystem services such as soil aggregation, moisture retention, and nutrition for plants
- Erosion control in compost socks and bioswales. It is sold wholesale and retail as an additive to potting soils, bagged for home gardens, and used for value-added products such as compost tea and extract.

Compost adds value in specialty crops.

Compost and Digestate: Dispelling the Confusion

Emissions comparison

Digestion and composting produce varying emissions at different stages and are highly dependent on management practices and feedstocks. During composting, a batch process, CO_2 is emitted at the beginning and can equal a large fraction (10-50%) of the initial carbon. However, once stabilized, emissions are relatively small.

During AD, methane and CO_2 are emitted but are usually contained and combusted for energy production or flared. However, since digestion in the United States is generally a continuous process, a fraction of the digestate is not completely digested and still actively generates methane and CO_2. Storage and land application of digestate can, therefore, result in high GHG emissions, especially methane.

In contrast, emissions from stored or land-applied compost are typically negligible. According to Dr. Frederick C. Michel, when digestate is stored in open anaerobic lagoons, "If just 5% of the methane potential is emitted to the atmosphere during storage, the GHG reduction benefit of any renewable energy produced is lost". Research by Grigatti et al. (2019) simulating land application in pot tests comparing compost and digestate (from the same food waste feedstock) has shown that digestate has four times the CO_2 emissions of compost after soil incorporation. The US EPA Waste Reduction Model (WARM) calculates avoided emissions from food waste digestion at (584.39) and food waste composting at (1,521.35) $MTCO_2e$ per 15,000 tons of feedstock respectively. The differential per 15,000 tons of food waste feedstock favoring compost is 937 metric tons of CO_2 equivalents.

WARM does not include emissions during storage or land application of digestate which likely further reduces the actual benefit. WARM assumes wet digestion and that the resulting digestate generates no additional methane or CO_2. It also assumes that 100% of the biogas is converted to renewable energy, which is not always the case. The EPA National Risk Management Research Laboratory (2014) did a case study of six WRRFs accepting food waste and found that two (33%) flared all or a portion of their biogas. Shen et al. (2015) found that only 10% of WRRFs utilize 100% of the biogas generated. The other 90% flare between 30 and 70% decreasing their beneficial impact.

Pathogens, Metals, and ARGs

Pathogens, weed seeds, and antimicrobial resistance genes (ARGs) may be contained in either AD or composting feedstock. The viability of these is dependent upon process heat or post-heat treatment. The definition of composting prescribes a thermophilic process, so it is effectively free of pathogens, weed seeds, and ARGs. Depending on design and feedstock demands, the AD process may be thermophilic or mesophilic, however it is almost always mesophilic. Thermophilic AD produces an unrestricted use material that meets the US EPA Process to Further Reduce Pathogens threshold. Digestate from mesophilic AD may

Digestate (Sludge) Drying Bed. Photo Courtesy of Judd and Judd Ltd.

undergo post-processing heat treatment to be classified as a Class A Biosolid. Without thermophilic treatment, digestate is a restricted use product because it contains levels of pathogens unsuitable for human contact.

Metals found in manures from large-scale animal farming and sewage sludge pose complications for composting and AD. According to Montusiewicz (2020), metals concentrate in the digestate from sewage sludge, preventing it from being used for agricultural or reclamation applications. Metals will increase concentration by percent of volume during the composting process as the total volume of the material diminishes from start to finish. Most compost facilities do not handle raw sewage sludge, but they may take digestate from WRRF AD systems and manure-based on-farm systems. Due to the formation of humic substances during composting, metals may be bound and unavailable to plants in finished compost.

Comparative Benefits of Compost and Digestate

The International Solid Waste Association recently published Benefits of Digestate and Compost for Soil (Gilbert et al., 2020), a distillation of research on these organic amendments, to recommend the highest beneficial use of each. Table 3 below, found in their report, suggests that compost is a soil improver containing all the attributes that promote soil health with the capacity to sequester carbon and provide nutrition, while digestate is the better choice for fertilization primarily due to its high N value.

Table 3: Benefits of Organic Amendments

- Compost can be classified as an organic soil improver, as it contributes towards a soil's organic matter content.
- Digestates can be classified as an organic fertilizer, as their main function is to supply plant nutrients.
- Greater amounts of carbon remain in the soil when organic wastes are composted, rather than applied directly.
- Organic matter in compost is further transformed through soil microbes into more stable forms of carbon in soil.
- Compost has the potential to sequester carbon in soil:
  - Studies have shown that over a period of 4-12 years between 11%-45% of the organic carbon applied to soil as compost remained as soil organic carbon.
  - Soil organic carbon increases of between 50-70 kg dry solids applied as compost are possible.
  - Every tonne of soil organic carbon holds the equivalent of about 3.67 tonnes of atmospheric carbon dioxide.
  - 1 tonne (fresh mass) of green waste derived-compost applied to soil over one hectare (10,000 square meters) results in a net CO_2-eq saving of 143 kg per year due to the increases in soil organic matter alone.
  - The main benefits to soiled are realized in the first 20 years until a new organic matter equilibrium is reached.
- Repeated compost application increases soil aggregate stability and soil pores, reduces compaction and increases water holding capacity.
- Applying compost to soil has been shown to increase soil microbial biomass and microbial activity, and build up a pool of plant nutrients.
- The long-term benefits to soil of anaerobic digestate are less clear cut than those of compost, and it is thought that it has a negligible effect on soil organic matter in the long term.
- Increases in soil microbial activity have been measured following digestate application.
- The significant benefit of applying digestate to soil is due to its high-nutrient content.

Conclusion

Compost and digestate provide significantly different benefits to soil and crops. They are derived from organic waste and valued for their nutrient contribution, but their similarity ends here. Composting digestate increases its carbon storage value without significantly reducing N & P fertilization capacity (Grigatti, 2020) and reduces the risk of pathogens and antimicrobial resistance genes (Roopnarian et al., 2023).

Composting digestate solves its inherent risks while retaining high values of available nutrients. Once composted it is no longer digestate, but compost.

References

Gilbert, J., Ricci-Jürgensen, M., Ramola, A., (2020, pg 19) *Benefits of Compost and Anaerobic Digestate When Applied to Soil*, International Solid Waste Association.

Grigatti, M., Barbanti, L., Hassan, M. U., & Ciavatta, C. (2020). Fertilizing potential and CO_2 emissions following the utilization of fresh and composted food-waste anaerobic digestates. *Science of the Total Environment, 698*, 134198. https://doi.org/10.1016/j.scitotenv.2019.134198 (Abstract).

Kraemer, T., & Gamble, S. (2014, November). Integrating anaerobic digestion with composting. *BioCycle.* https://www.biocycle.net/integrating-anaerobic-digestion-with-composting/

Taylor, M.J., Rolletti, A.J., Tompkins, D., Chambers, B.J. (2010, pg 3) Digestate Quality and Fertilizer Value, *15th Annual European Biosolids and Organic Resources Conference*, https://conferences.aquaenviro.co.uk/wp-content/uploads/sites/7/2018/08/65-Matthew-Taylor-1.pdf.

Michel, Frederick C. (2013, October 21 - 23) *Compatibility of Composting and Anaerobic Digestion*, Biocycle Conference, Columbus, OH, United States.

Montusiewicz, A., Szaja, A., Musielewicz, I., Cydzik-Kwiatkowska, A., & Lebiocka, M. (2020, pg 2). Effect of bioaugmentation on digestate metal concentrations in anaerobic digestion of sewage sludge. *PloS One, 15*(7), e0235508. https://doi.org/10.1371/journal.pone.0235508

Roopnarain, A., Akindolire, M. A., Rama, H., & Ndaba, B. (2023, section 2.5). Casting light on the Micro-Organisms in Digestate: diversity and untapped potential. *Fermentation, 9*(2), 160. https://doi.org/10.3390/fermentation902016.

The National Risk Management Research Laboratory (2014), *Food Waste to Energy: How Six Water Resource Recovery Facilities are Boosting Biogas Production and the Bottom Line,* (EPA 600/R-14/240) US Environmental Protection Agency, Office of Research and Development. https://www.epa.gov/sites/default/files/2016-07/documents/food_waste_to_energy_-_final.pdf

United States Composting Council, *Compost and Its Benefits* [Fact Sheet]. https://www.compostingcouncil.org/page/CompostBenefits

US Environmental Protection Agency Waste Reduction Model (WARM) version 16, March 18th, 2024, https://www.epa.gov/warm/versions-waste-reduction-model.

US Environmental Protection Agency, January 17, 2024, *What are Processes to Further Reduce Pathogens (PFRPs) and Processes to Significantly Reduce Pathogens (PSRPs)?* https://www.epa.gov/biosolids/basic-information-pathogen-equivalency-committee#whatare

Shen, Y., Linville, J. L., Urgun-Demirtas, M., Mintz, M. M., & Snyder, S. W. (2015). An overview of biogas production and utilization at full-scale wastewater treatment plants (WWTPs) in the United States: Challenges and opportunities towards energy-neutral WWTPs. *Renewable & Sustainable Energy Reviews, 50*, 346–362.