

Canadian Digestate Management Guide

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Canadian Biogas
Association
canadienne de biogaz

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Disclaimer

While this technical guide is written to provide detailed information, it should not be construed as legal advice. Readers should note that considerations for digestate management vary based on many factors. Information presented in this document should be evaluated and interpreted by the reader at his or her own risk.

Readers are strongly encouraged to seek out technical experts in the biogas industry or certified crop advisors to address their own applications.

The authors, editors, and subject matter contributors of this document will not be liable for any claims or losses of any kind arising from the use of, or reliance upon, this information.

Part 1 – Introduction to the Guide

Biogas and renewable natural gas (RNG) have continued to grow in Canada as a solution to treat organic waste, reduce greenhouse gas (GHG) emissions, produce clean energy, and return nutrients and organic matter to the soil. Biogas plants have two main outputs – biogas and digestate. Biogas or RNG is often the focus of biogas plant operations as it can be monetized and sold to different markets. However, digestate is also a valuable output as an organic fertilizer or soil amendment. Digestate provides many soil benefits over manure and mineral fertilizers. Digestate producers and managers take care to employ best management practices when handling and applying digestate to farmland. This Guide summarizes best management practices appropriate in a Canadian context, developed with input directly from stakeholders and subject matter experts.

This Guide will inform readers about:

- How digestate is produced
- Key digestate characteristics
- Best management practices for using digestate
- Nutrient stewardship principles for digestate

It is the intention of this Guide to provide practical and useful information for maximizing the benefits of the safe use of digestate products. It is recommended that digestate producers and users consult with a certified crop advisor or other competent practitioner to ensure that conditions specific to each intended digestate use is duly considered.

This is the first version of the Guide and reflects gaps in the current knowledge base. It is the expectation of the CBA that the Guide will be updated from time to time as new information becomes available.

Overview of Digestate Use in Canada

Digestate is the organic fertilizer and organic soil amendment products produced by biogas plants from the anaerobic digestion of plant and animal origin feedstock materials. As of 2020, over 1.2 million tonnes of digest is being produced annually by biogas plants across the country.

There are a number of pathways for using digestate.

- Direct land application of digestate is the most economical approach due in part to most Canadian biogas facilities being co-located on farms or near agricultural areas. Digestate producers and applicators take care to balance the application of nutrients with the nutrient uptake of crops. This type of application typically does not require significant digestate treatment and can be accomplished using common manure management equipment.
- One other avenue for the management of digestate is to consider it an intermediate product only, and to then ship the digestate for further processing at a downstream facility. For instance, de-watered digestate can be trucked to a licensed aerobic composting facility, for additional processing to allow the material to be turned into a final compost product. The blended material, the co-composted output, product is then marketed under local regulatory regimes for compost.

Part 2 – From Feedstock to Organic Fertilizer – How is Digestate Produced

Why Producing and Using Digestate Matters

Digestate describes a range of organic fertilizers, sometimes referred to as 'biofertilizers', and organic soil amendment products produced by biogas plants.

Digestate originates from a variety of organic feedstock materials of plant or animal origin that were originally produced for food, fuel, or fibre. Biogas plants use the biological process of anaerobic digestion to convert feedstock into biogas, a source of renewable low-carbon energy and digestate, which contains useful amounts of plant nutrients and organic matter. Feedstock selection and processing operations at the biogas plant can determine the amount of nutrients and organic matter in the digestate, thereby enabling the production of distinct organic fertilizer and organic soil amendment products.



As an organic fertilizer product, digestate has fertilizer characteristics similar to animal manure, in particular swine manure, but with more readily available crop nutrients and reduced odour. When used in accordance with the *Best Management Practices* described later in this Guide, nutrients in digestate can be utilized to supply crop nutrients, thereby reducing reliance on fertilizer from non-renewable sources.

In the form of an organic soil amendment product, digestate has characteristics similar to compost, i.e., supplying soil with organic matter and a suite of slow-release macro and micro-nutrients. The *Best Management Practices* describe how to effectively improve soil health and fertility by incorporating digestate as an organic soil amendment into normal crop rotation.

Digestate from industrial biogas plants is often registered with Agriculture and Agri-Food Canada (AAFC) through the Canadian Food Inspection Agency (CFIA), permitting it to be sold and used as an organic fertilizer product. Digestate can also be used to produce other valuable products such as compost and biochar.

Below are five reasons why producing and using digestate matters:



1. Digestate is effective and safe to use.

- Quality control applied at feedstock selection and digestate production ensure that the digestate product is safe for use.
- *Best Management Practices* describe how to effectively utilize digestate as an organic fertilizer and organic soil amendment.



2. Digestate is renewable.

- Feedstocks for digestate production are renewable sources of plant and animal materials.
- Reliance on mineral fertilizers produced from non-renewable sources is reduced by using digestate.



3. Digestate is sustainable.

- Using digestate completes the natural cycle by returning nutrients and organic matter to productive soils, see *Figure 1*.



4. Digestate can lower greenhouse gas emissions.

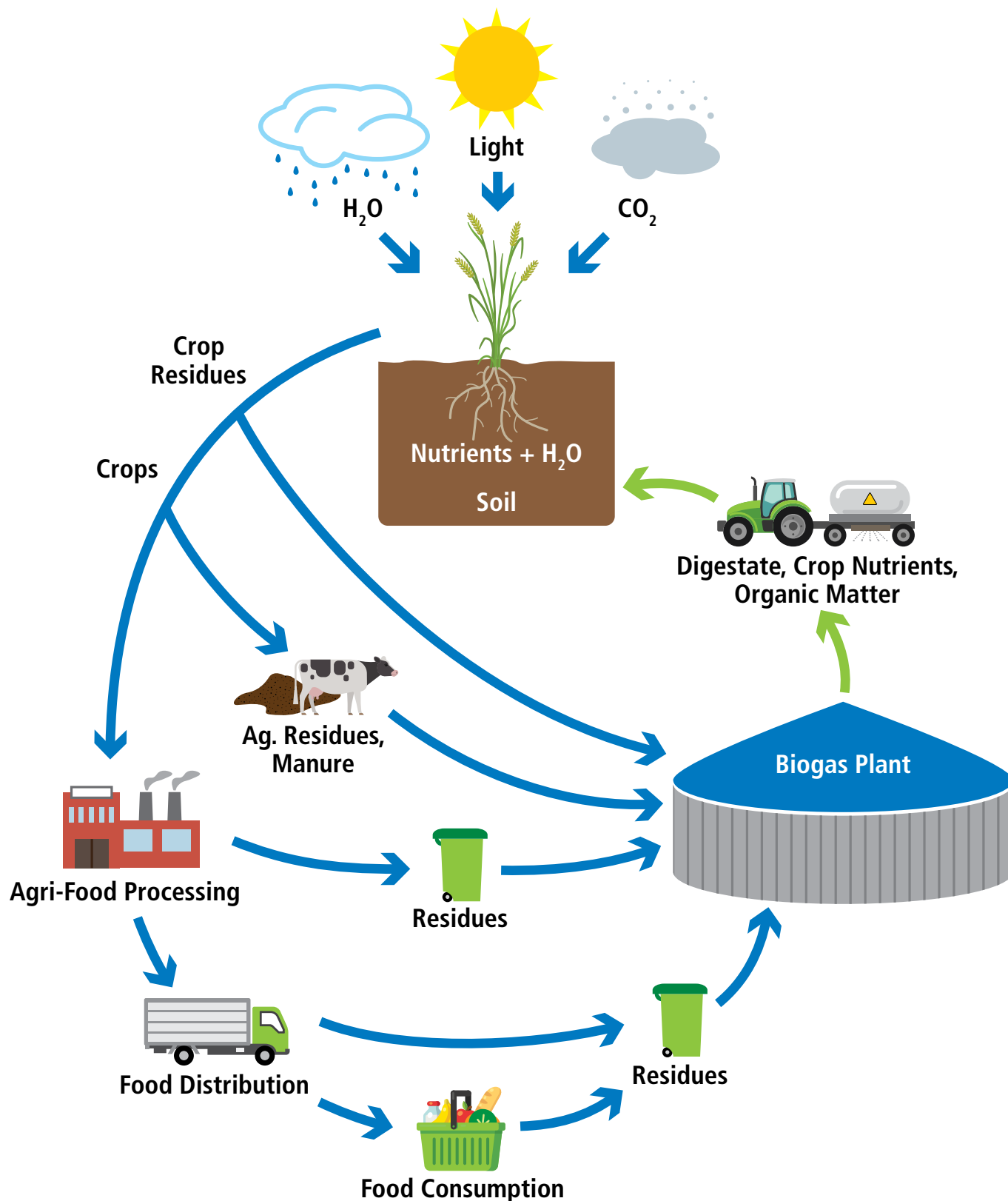
- Reducing reliance on mineral fertilizers can reduce the GHG emissions associated with their production and transportation.
- Feedstocks for digestate production can include organic materials which otherwise would have gone to landfill disposal. In the landfill, these materials generate methane, which is emitted to the atmosphere.
- Digestate production from animal manure allows for capture of greenhouse gas emissions which otherwise would have been emitted to the atmosphere.
- Digestate use can sequester atmospheric carbon in soil as stable soil organic matter.



5. Digestate builds local self-reliance.

- Digestate is produced locally at biogas plants obtaining feedstock materials from nearby businesses and communities and at on-farm biogas plants using manure and other agricultural materials, and in some cases locally-sourced off-farm materials, as feedstocks. The economic benefits of producing and using digestate are retained within the local community.
- Reduces local farmers' exposure to global supply chains and market conditions for essential crop nutrients.

Figure 1. Plant Nutrient Cycle



What Feedstocks are Used to Produce Digestate?

Biogas plant operators understand the fundamental role feedstock selection plays in successful operations and the production of quality and safe digestate products. Biogas plants select feedstocks based on many factors:

- tipping fee pricing or feedstock cost;
- availability;
- compliance with operating permits (industrial plants) or enabling legislation (on-farm plants);
- laboratory analysis of representative samples;
- the capability of the plant to receive and process the feedstock safely and effectively;
- potential to generate biogas;
- nutrient profile;
- feedstock quality and risk (i.e., presence of toxic compounds or contaminants, depackaging and other process requirements, etc.); and
- ability to produce digestate meeting end user and regulatory quality and safety requirements.

Lists of materials suitable and not suitable for biogas plant feedstocks may be included in provincial regulations or set out in operating permits issued to individual biogas plants. For example, in Ontario, the regulation of on-farm biogas plants includes a list of materials not permitted as feedstocks.

Canadian biogas plants have demonstrated that a wide variety of materials are suitable to produce biogas and digestate. Examples of feedstock materials successfully processed at Canadian biogas plants are listed in *Table 1*.



Table 1. Feedstocks Processed at Canadian Biogas Plants

Category	Examples
Animal Manures	• Liquid and solid manures from livestock operations (beef, dairy, hog, poultry, etc.)
Energy Crops	• Miscanthus • Switchgrass • Corn (Maize)
Agricultural Crops & Residues	• Silage from farm operations (corn, grain, grass, etc.) • Corn stover (also called maize straw in Europe) • Wheat straw
Agri-Food Processing Residues	• Food processing residues (oils seeds, grains, fruit & vegetables, corn, beet, potato, dairy products, alcohol, etc.) • Paunch manure from meat packing plants • Spoiled or returned food and beverage products • Excess yeast or other residuals from brewing or similar agri-food manufacturing processes
Animal & Pet Feed Processing Residues	• Off-spec and stale-dated products • Organic solid residues and sludge from on-site wastewater treatment operations at processing facilities
Fats, oils and grease	• Fats, Oil and Greases (FOG) from slaughterhouses, meat packing plants, canneries, restaurants, food processors, cafeterias, grocery stores, and grease trap cleanouts
Separated at Source Residential and Commercial Food Waste	• Green Bin material from residential source-separated organics collection programs • Non-wood containing garden & horticultural residues from greenhouses, garden centers, flower shops, municipalities, households • Separated kitchen & market residues from food processors, bakeries, pizza parlours, restaurants, cafeterias, grocery stores, hospitals, universities, households
Other Organic Wastes	• Sludges from non-sanitary wastewater treatment or industrial process water treatment

The wide variety of suitable biogas plant feedstocks is reflected in the characteristics of the feedstock most significant for biogas and digestate production, specifically the amounts of crop nutrients and the amounts and types of organic matter, which are discussed below. Suitable feedstocks can also contain contaminant materials in low amounts, which must be managed by the biogas plant operator to ensure the safety of the digestate products.

Plant and animal origin materials contain primary, secondary and micro-nutrients (also called 'trace elements'), as shown in *Table 2*.

Table 2. Nutrients Present in Plant and Animal Material Feedstocks

Primary Nutrients	Nitrogen (N), Phosphorus (P), Potassium (K)
Secondary Nutrients	Calcium (Ca), Chloride (Cl), Magnesium (Mg), Sodium (Na), Sulphur (S), Iron (Fe)
Micro-nutrients / Trace Elements	Boron (B), Cobalt (Co), Copper (Cu), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Selenium (Se), Zinc (Zn)

Feedstocks of different types, and even feedstocks of similar types but from different origins, can contain very different types and amounts of plant nutrients. Feedstock nutrients are almost entirely conserved in the digestate, although in some cases in different chemical forms. Therefore, higher nutrient feedstocks will produce higher nutrient content digestate products. *Table 3* shows how typical feedstocks can contain very different amounts of crop nutrients.

Different feedstocks contain different amounts and types of organic matter. Chemically simple organic compounds such as carbohydrates (sugar, starch), fats, and proteins will be largely decomposed and converted into biogas. More complicated compounds like hemi-cellulose and cellulose are typically only partially decomposed. Lignin, which is a major component of woody plant materials, is not decomposed by anaerobic digestion. *Table 4* shows how typical feedstocks can contain very different amounts of degradable and less degradable organic matter.



Table 3. Nutrient Content of Some Biogas Plant Feedstocks

Parameter	Units ⁽¹⁾	Agricultural Sources			Agri-Food and Animal and Pet Food Processing Residues		Source Separated Food Waste (post physical contaminant removal)	
		Pig Slurry ⁽²⁾	Cattle Slurry ⁽²⁾	Corn Silage ⁽³⁾	Chicken Processing Dissolved Air Flotation Sludge ⁽³⁾	Off-Spec. Pet Food ⁽³⁾	Model European Food Waste ⁽⁴⁾	Commercial Food Waste ⁽⁵⁾
Total Solids / Dry Matter	% FW	4 – 7	7 – 10	42.7	31.4	92	24	30.9
Volatile Solids / Organic Matter	% FW	-	-	33.7	24.8	72	22	26.4
Total N	% FW	0.3 – 0.5	0.4 – 0.5	0.41	2.79	3.7	0.74	0.98
NH ₄ -N ⁽⁶⁾	% Total N	70 – 75	50 – 60	2.4	8.6	0.6	-	10
NO ₃ -N ⁽⁶⁾	% Total N	-	-	negligible	negligible	negligible	-	1.2
Total P	% FW	0.01	0.01	0.12	0.47	1.12	0.1	0.16
Total K	% FW	0.2 – 0.3	0.4 – 0.6	0.32	0.04	0.87	0.03	0.31
Total Ca	% FW	-	-	0.09	0.92	1.75	-	0.67
Total Mg	% FW	-	-	0.05	0.12	0.12	-	0.04
Total S	% FW	-	-	0.03	0.28	0.45	0.07	0.25

Notes

1. Reported results converted to consistent units. FW = fresh weight, i.e., weight measurement of the material in the form which it is typically handled.
2. EIP-AGRI 2017. Mini-paper -Towards increasing the mineral fertilizer replacement value of bio-based fertilisers. EIP-AGRI Focus Group Nutrient Recycling.
3. OMAFRA 2010 Feedstock and Digestate characteristics dataset
4. Banks, C.J., Heaven, S., Zhang, Y., Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37.
5. Zhang, R, et al. 2006. Characterization of food waste as feedstock for anaerobic digestion. Bioresource Technology, Volume 98, Issue 4, 2007, Pages 929-935.
6. NH₄-N and NO₃-N refer to Total Ammoniacal (TAN) and nitrate forms of nitrogen respectively as described later in this Guide.

Table 4. Organic Matter Content, Composition and Degradability of Some Biogas Plant Feedstocks

Parameter	Units ⁽¹⁾	Agricultural Sources				Food Processing Residues			Source Separated Food Waste (post physical contaminant removal)
		Cover Crop ⁽²⁾	Cattle manure ⁽²⁾	Dairy Manure ⁽³⁾	Switchgrass ⁽³⁾	Pasta ⁽³⁾	Cabbage ⁽³⁾	Fat, Oil, Grease ⁽³⁾	Model European Food Waste ⁽⁴⁾
Total Solids / Dry Matter	% FW	10 - 18	12.2	12.4	93	42.3	7.9	26.7	24
Volatile Solids / Organic Matter	% FW	8.4 - 16.2	9.9	10.2	90.5	40.8	7.2	23	22
Carbohydrates (starch and sugar)	% VS	41.5 - 75.9	66.5	20	0	80.1	44.6	0	48
Lipids				16.1	0	3.4	1.4	100	15
Proteins				5.7	0.7	16.5	17.8	0	21
Hemi-Cellulose				9.6	42.2	0	0	0	7
Cellulose				32.6	48.8	0	36.2	0	6
Lignin		3.8 – 18.2	7.3	13.8	8.3	0	0	0	3
Biochemical Methane Potential (BMP)	L _{STP} kgVS ⁻¹	257 - 288	272.5	242.7	122.2	326.1	256.5	402.3	450
Chemical Oxygen Demand (COD)	g _{O2} kgVS ⁻¹	1280 - 1296	1395	128.9	706.7	934.3	90.9	600.1	-
Biodegradability ⁽⁵⁾	%	0.63	0.56	0.55	0.24	0.68	0.58	0.44	-

Notes

1. Reported results converted to consistent units. FW = fresh weight. VS = Volatile Solids.
2. Franco, R, et al. 2019. An improved procedure to assess the organic biodegradability and the biomethane potential of organic wastes for anaerobic digestion. Waste Management and Research, SAGE Publications, 2019, 37 (7), pp.746-754. For cover crop, data are range of two mixtures. For cattle manure, data are average values.
3. Labatut, R, et al. 2010. Biochemical methane potential and biodegradability of complex organic substrates.
4. Banks, C.J., Heaven, S., Zhang, Y., Baier, U. 2018. Food waste digestion: Anaerobic Digestion of Food Waste for a Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37.
5. Biodegradability calculated as the ratio of COD converted (at a theoretical rate of 1 g COD converted per 350 mL CH₄ generated) to total COD. See Buswell, AM, Mueller, HF, 1952. Mechanism of methane fermentation. *Ind. Eng. Chem.* 1952, 44, 3, 550–552, Publication Date: March 1, 1952.

Special Feedstock Considerations

Certain feedstock materials may be particularly significant to biogas plant operators because they are identified in regulation as having specific handling and processing requirements or may pose greater processing challenges. Feedstocks requiring special consideration include the following:

- **Raw meat:** Operating permissions for on-farm biogas plants can impose specific feedstock material restrictions. Facilities that can receive raw meat, including wastewater sludges from raw meat processing facilities, require pasteurization or other treatment processes to be allowed to receive those materials.
- **Human waste:** Feedstocks containing human waste may be prohibited without specific treatment to address potential pathogens.
- **Specified Risk Materials¹:** Unless a permit is obtained from Agriculture and Agri-Food Canada, biogas plants cannot receive SRM materials, and SRM in any form cannot be used in fertilizers or supplements.
- **Prohibited Materials²:** The *Fertilizers Act and Regulations* require that fertilizers and supplements containing Prohibited Materials must be appropriately labelled, recorded, and controlled. Labels for fertilizers and supplements containing any prohibited materials must include precautionary statements, in both English and French, indicating that:
 - feeding the product to cattle, bison, sheep, goat, elk, deer or other ruminants is illegal and subject to fines or other punishments under the *Health of Animals Act*;
 - the product is not to be used on pasture land or other grazing areas for ruminants;
 - the product is not to be ingested; and
 - a person should wash their hands after using the product.



1 From *Health of Animals Act/Regulation 2021*. Specified Risk Materials (SRM) means the skull, brain, trigeminal ganglia, eyes, palatine tonsils, spinal cord and dorsal root ganglia (DRG) of cattle aged 30 months or older, as well as the distal ileum of cattle of all ages. These materials are designated as SRM because, in Bovine Spongiform Encephalopathy (BSE) infected cattle, these tissues contain the BSE agent and may transmit the disease. The OTM skull, excluding the mandible and horns, is designated as SRM as well because of the high probability of it becoming contaminated at the time of stunning and during manipulation of the other tissues if their separate removal was permitted.

2 From *Health of Animals Act/Regulation 2021*. Prohibited Material means anything that is, or that contains any:

- protein that originated from a mammal, other than a porcine or equine; milk or products of milk;
- gelatin derived exclusively from hides or skins or products of gelatin derived exclusively from hides or skins;
- blood or products of blood; or
- rendered fats, derived from ruminants, that contain no more than 0.15% insoluble impurities or their products.

Prohibited material that has been treated in a manner approved by the Minister to inactivate the agents that cause transmissible spongiform encephalopathies is no longer prohibited material.

How Do Biogas Plants Convert Feedstock into Renewable Organic Fertilizer?

Biogas plants are highly engineered facilities for optimizing the process of anaerobic digestion to convert plant and animal material-based feedstocks into biogas and digestate. Biogas is subsequently converted into various forms of renewable, low-carbon energy. The digestate is a renewable organic fertilizer and soil amendment. Biogas plants have a long history of successful operation in many countries, including Canada. Development of new biogas plants is underway across the country and will help Canada improve national waste management practices and make progress towards their net-zero commitments by producing clean energy and reducing GHG emissions, such as methane.

Biogas plants across the country are all different, each expressing a solution to unique opportunities and challenges of feedstock supply, renewable energy markets and digestate product marketing opportunities. The design of a biogas plant is created by selecting from the many different and proven anaerobic digestion and ancillary technologies available, the combination that satisfies the specific requirements of each owner. Digestate users don't require expert knowledge of biogas plants but may benefit from an understanding of the different types of technologies and operations involved and can refer to the [Canadian Anaerobic Digestion Guideline](#) for more information.

In Canadian provinces, as in many other jurisdictions, different regulatory requirements are applied to biogas plants depending on whether they are associated with farm operations. Requirements for constructing and operating a biogas plant are administered at the provincial level, in terms of the requirements of relevant environmental legislation, and at the municipal level in terms of the applicable requirements of land use planning and permissions. Within this regulatory framework, it is common that biogas plants located on farms are considered to be part of the farm operations while other biogas plants are regulated as waste treatment facilities. Since this distinction extends to the use of digestate, it is useful to consider two types of biogas plants, industrial and agricultural, based on the application of regulatory requirements, as follows:

- Typically, industrial biogas plants, are:
 - located in areas designated for industrial or employment uses;
 - privately owned and operated as commercial ventures or publicly-owned and operated to serve the needs of the local community;
 - designed to receive and process feedstocks from a combination of industrial, commercial, or residential sources;
 - regulated as waste treatment facilities by operating permits issued by a provincial regulatory agency, usually an environmental regulatory agency; and
 - responsible for digestate transportation, storage, and land application.

For industrial biogas plants, there is an option to secure registration and certification of the digestate as a fertilizer from the Canadian Food Inspection Agency. The requirements for registration are set out in the Canadian *Fertilizers Act and Regulations*. In some jurisdictions, digestate for which fertilizer registration has been secured is deemed to be a product and can be sold and used similar to other commercially available fertilizer and soil amendment products. However, as a fertilizer, its use may be subject to nutrient management regulations. Industrial biogas plants may, depending on local market opportunities, subject digestate to further transformations to produce other products meeting specific quality requirements, such as through aerobic composting to produce compost products. Digestate transformation technologies are described in *Appendix B* to this Guide.

Figure 2. Industrial Biogas Plant: Toronto's Dufferin Organics Processing Facility



- Agricultural biogas plants are typically:
 - located on a farm with a large livestock operation;
 - owned and operated by the farm operator to meet own needs and in many cases also as a supplemental commercial venture;
 - designed to receive and process manure, energy crops, and other agricultural materials;
 - may receive permitted types and quantities of off-farm feedstock material;
 - regulated under provincial legislation;
 - applying digestate on owner's farm or at nearby farms; and
 - the farm operator is typically responsible for digestate storage, transportation, and application.

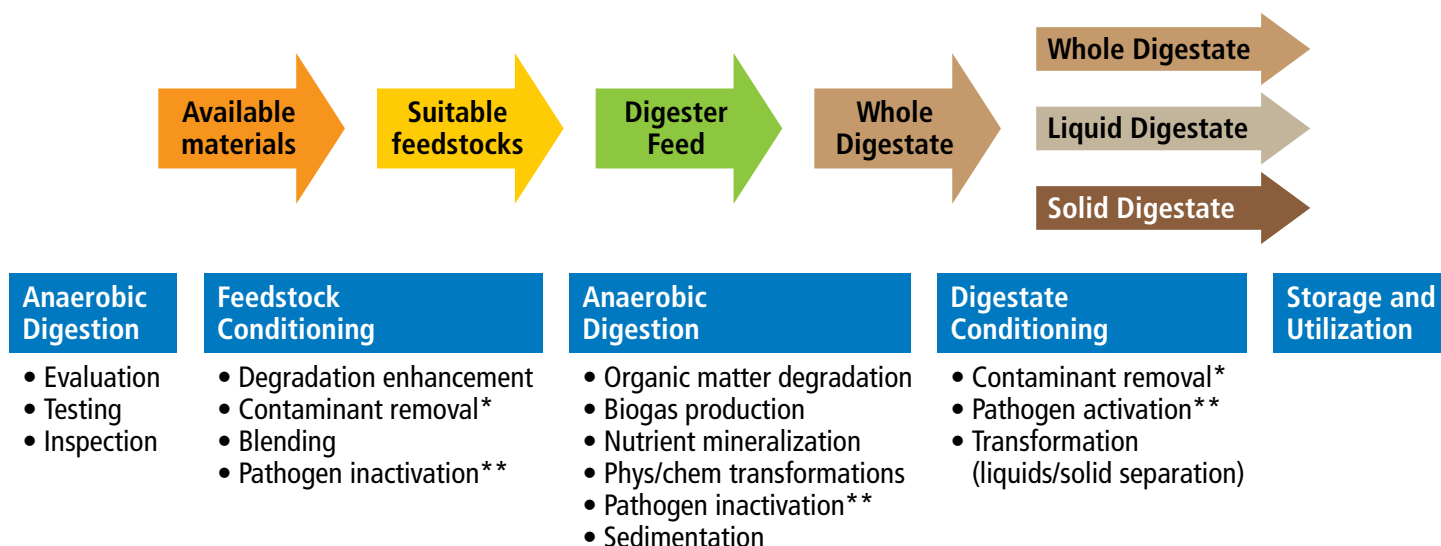
Figure 3. On-Farm Biogas Plant



These are not rigid categories since biogas plants located on farms could, subject to securing necessary permits, operate as industrial biogas plants.

All biogas plants regardless of their status as industrial or agricultural, or the specific types of technologies used, will use the same basic steps shown in *Figure 4* and described in the following sections to convert feedstocks into digestate fertilizer or soil amendment products.

Figure 4. Steps to Convert Feedstocks into Digestate Fertilizer or Soil Amendment Products



Notes:

*Contaminant removal, if required, can occur at either or both of feedstock and digestate conditioning steps.

**Pathogen inactivation occurs at the latest step at which the time and temperature requirements of pasteurization are achieved.

Feedstock Acceptance

Feedstock acceptance ensures that only suitable feedstocks are accepted at the biogas plant.

Typical activities may include:

- evaluating feedstock sources, types of materials, and conditions by which they are generated;
- test each feedstock by having representative samples analysed by an accredited laboratory; and
- procedures to periodically inspect feedstock on arrival and reject unsuitable loads based on criteria for feedstock acceptance such as concentration of inhibiting compounds, contamination, or moisture content.

Feedstock Conditioning

Feedstock conditioning produces a clean, homogeneous, and consistent feed for the anaerobic digestion process to optimize the production of biogas and digestate. Typical activities may include:

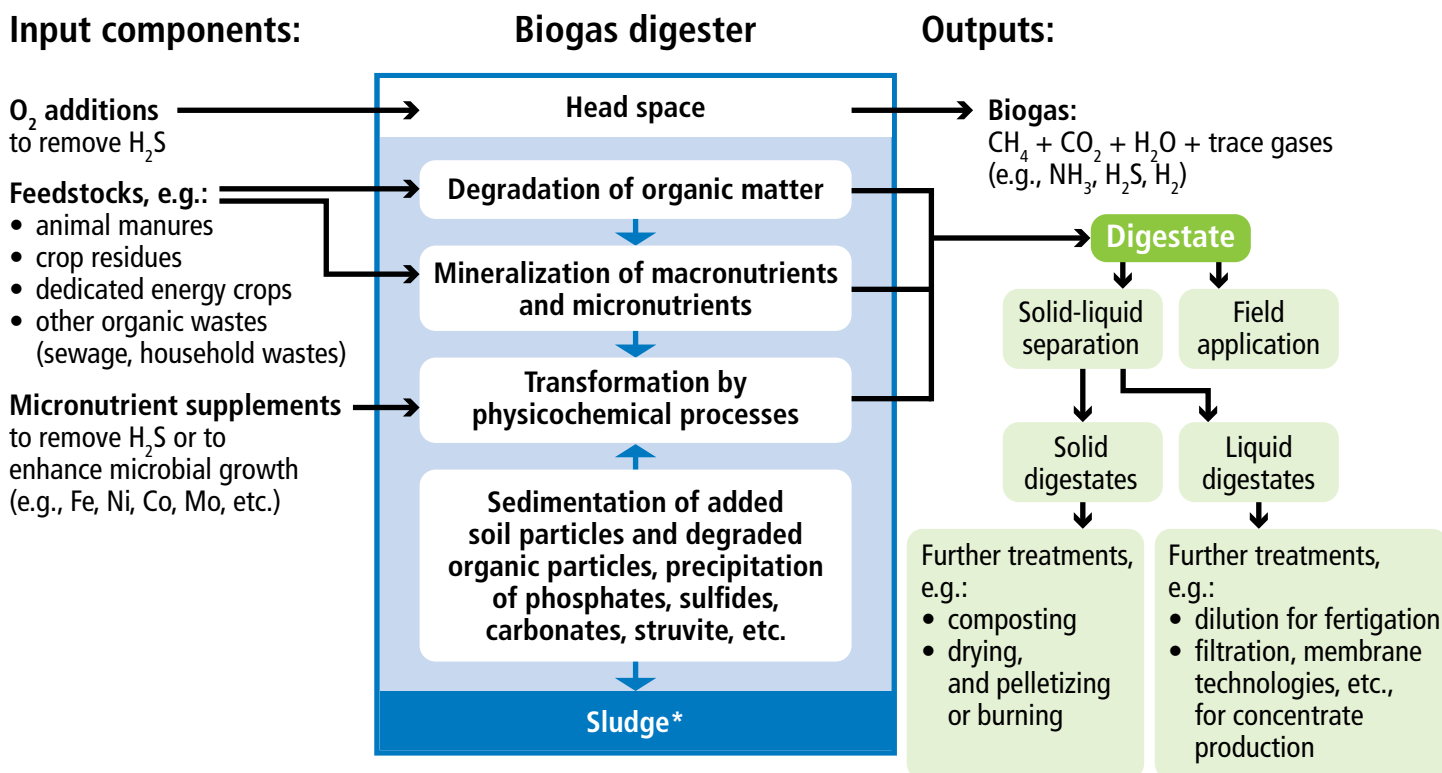
- Degradation enhancement which typically includes size reduction involving shredding, grinding, extrusion pressing, and hydropulping, and which may also include chemical, thermal, or biological treatments to 'dissolve' normally insoluble materials. The overall effect is to cause an increase in the rate and degree of organic matter degradation and biogas production during anaerobic digestion.
- Removal of physical contaminants, also referred to as foreign-materials, such as plastics, glass, ceramics, metals and grit, and non-processible materials such as bones and shells. Typical removal operations include depackaging of food wastes, filtering, screening, and density separation by allowing contaminants to float or sink. Physical contaminant removal operations can occur at either or both of the feedstock or digestate conditioning steps. While physical contamination is impossible to completely eliminate, it can be mitigated with best management practices. Effective physical contaminant removal to produce a clean digestate product is critical for biogas plants receiving feedstocks from residential, commercial, and industrial sources.
- Blending of different feedstocks to maintain a consistent, homogeneous feed to ensure stable performance of the anaerobic digestion process in terms of biogas production and digestate characteristics.
- Pathogen elimination, if required to satisfy product quality requirements. Industrial biogas plants, and on-farm biogas plants receiving off-farm feedstock materials, typically require a pathogen elimination process. Pasteurization, which eliminates pathogens by maintaining temperatures of 50°C for 20 hours or 70°C for one hour, is a widely used approach which can be used to treat feedstocks during preprocessing or to treat digestate after digestion.



Anaerobic Digestion

Once the feedstock is prepared to be fed into the digester, the feedstock is supplied to the anaerobic digestion step where microorganisms decompose degradable organic matter producing biogas and digestate. The biological pathway for converting degradable organic material into biogas is well covered in the [Canadian Anaerobic Digestion Guideline](#) and elsewhere and so is not covered here. The process changes that occur during anaerobic digestion which produce the characteristics most significant for the use of digestate as organic fertilizer or organic soil amendment products are shown in *Figure 5*, described below and summarized in *Table 5*.

Figure 5. Process and Matter Flow of Anaerobic Digestion³



*Sludge remains for a longer period in the digester until separate removal

³ From Möller K, Müller T. 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. *Engineering in Life Sciences* vol. 12(3), 2012

Degradation of Organic Matter

The process of anaerobic digestion is defined by the biological degradation of organic matter. The magnitude of organic matter degradation determines the quantity of biogas production and drives transformations of physical and chemical characteristics that define the properties of the resulting organic fertilizer or organic soil amendment digestate products. Organic matter degradation during anaerobic digestion is a function of the feedstock characteristics and the design and operation of the biogas plant.

Feedstocks can differ significantly in the total content of organic matter and in the extent to which the organic matter can be degraded by anaerobic digestion, referred to as biodegradability. Quantitative estimates of the potential biodegradability of specific feedstocks can be calculated from the ratio of the Biochemicalmethane Potential (BMP) to Chemical Oxygen Demand (COD), both of which can be determined by laboratory analysis. The biodegradability of some biogas plant feedstocks is shown in *Table 4*. Biodegradability increases with the presence of simple compounds like carbohydrates, fats, and proteins and feedstocks containing a large proportion of these compounds, such as food waste, animal slurries and cereal grains, have high biodegradation potentials. Biodegradability decreases with the presence of more complicated compounds that are slower and more resistant to biodegradation like cellulose and lignin. Feedstocks containing a large proportion of less biodegradable compounds, such as litter bed material and beef cattle manure, will have lower biodegradation potentials and will produce digestate containing a large amount of relatively stable organic matter.

The design and operation of the biogas plant will control how much of the potential biodegradation is realized. Biodegradation can be improved by intensive feedstock conditioning, higher temperature, and longer residence time during anaerobic digestion. Practical constraints cause biogas plants to achieve less than the full biodegradation potential. Measuring organic matter degradation within the anaerobic digester is a key process control parameter for biogas plant operations and is usually expressed as the percentage of volatile solids destroyed or COD removed or as the residual BMP remaining in the digestate.

The amount and types of organic matter remaining in the digestate largely determines its suitability as either an organic fertilizer or soil amendment. As a result of the anaerobic digestion process, the organic matter in digestate is largely in more chemically complex and stable forms compared to the original feedstock. Anaerobic digestion does not contribute to the humification of organic materials, however, by decomposing easily broken-down organic compounds, anaerobic digestion concentrates the more stable organic compounds in the digestate such that digestate can support the creation of stable soil organic material.

Anaerobic digestion also affects other beneficial transformations of the feedstock material. By decomposing volatile organic compounds, the potential to release odours is reduced. By decomposing sugars and small particles of organic matter, the viscosity is reduced. Both of these transformations benefit the land application process by making liquid digestates easier to pump and handle, while generating fewer odours.

Feedstock Nutrient Transformations

Feedstock nutrients are mostly conserved through the anaerobic digestion process and are retained within the digestate products. Therefore, the quantities of nutrients within the digestate depend on the nutrients supplied with the feedstock materials. The chemical forms of the nutrients, however, will have undergone transformations driven by organic matter degradation. Some nutrient loss occurs via the biogas which contains trace amounts of NH_3 and H_2S , and from complexation and precipitation reactions causing nutrients to be temporarily retained within the digester and eventually removed during digester cleaning.

Nitrogen

Nitrogen is present in feedstocks in two forms, (i) as a component of organic materials, especially proteins, referred to as organic nitrogen and (ii) mineral nitrogen which includes ammonia (NH_3) or ammonium (NH_4), referred to together as Total Ammoniacal Nitrogen (TAN), plus nitrate (NO_3) or nitrite (NO_2). Nitrogen in mineral forms are available to plants.

During anaerobic digestion, the decomposition of organic materials causes organic nitrogen to be converted to TAN. The digestate will contain approximately the same total nitrogen content as the feedstock materials, less minor volatilization and precipitation losses mentioned above. However, the proportion of available mineral nitrogen forms, TAN, will have increased by 25% to 50%.⁴ Because the anaerobic digestion process occurs in the absence of oxygen very little NO_3 or NO_2 nitrogen is produced.

Phosphorus

Phosphorus is also present in feedstock materials in organic and mineral forms. As organic materials are decomposed during anaerobic digestion, organic phosphorus is converted to mostly soluble mineral forms which are plant available. This increase in bioavailability is somewhat offset by a shift in the chemical equilibrium caused by increased pH towards formation of phosphate and the precipitation of calcium and magnesium phosphates which are less soluble. As well, mineral phosphorus tends to associate with suspended organic matter which may reduce its solubility. Overall, the digestate will contain approximately the same total amount of phosphorus as the feedstock materials and the available portion may be slightly increased or decreased compared to the feedstock materials depending on the digestate pH.

Potassium

Potassium is not a structural component of organic molecules and as a result anaerobic digestion does not significantly affect the quantity or forms of potassium. Most of the potassium remains in the plant-available form of free potassium ions.

Secondary Nutrients, Micronutrients

The digestate will contain approximately the same total quantities of secondary nutrients, minerals, micronutrients, and heavy metals present in the feedstock materials. Like nitrogen and phosphorus, the decomposition of organic materials will increase the proportion of these elements present in mineral forms. Some sulfur may be lost from the anaerobic digestion process through H_2S in the biogas. The solubility of these elements will decrease as increasing pH motivates precipitation with sulfide (S^{2-}), carbonate (CO_3^{2-}) and phosphate (PO_4^{3-}). Some precipitates may be temporarily retained within the digester where they sink or settle to the bottom.

⁴ Möller K, Müller T. 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. *Engineering in Life Sciences* vol. 12(3), 2012

Other Physical – Chemical Transformations

During anaerobic digestion, several processes act to increase the pH such that the final pH of digestates is typically in the range of 7 – 9. The pH increase is driven by the consumption of volatile fatty acids and by the production of ammonium. Also, biogas plant operators routinely add alkalinity to the anaerobic digestion process as a buffer against a pH decrease which could inhibit the activity of methane-forming bacteria.

Table 5. Summary of Anaerobic Digestion Effects on Biogas Plant Feedstock⁵

Characteristic	Effect	Resulting Change	Main Mechanisms
Total Solids / Dry Matter	Decrease	-1.5% to – 5.5% (absolute)	Organic matter degradation and conversion to biogas
Volatile Solids / Organic Matter	Decrease	-5% to -15% DM (absolute)	
Viscosity	Decrease	Variable	Degradation of small particles
Biodegradability	Decrease	Variable	Depends on AD design and process conditions
pH	Increase	+ 0.5 to + 2 unit	VFA destruction, TAN release
Fibre Content	Increase, as % DM	Variable	Depends on feedstock composition. Cellulose poorly biodegradable, Lignin non-biodegradable
Nutrient Availability	Overall increase for N, P, K	Variable	Depends on organic N and P mineralization
TAN	Increase	+ 25% to + 55%	Mineralization of organic N (proteins, amino acids)
Total N	Increase or decrease	Usually little to no change	Concentration increase from OM degradation; decrease from precipitation or NH ₃ loss
Total P, K, Ca, Mg, S	Mostly conserved	Usually little to no change	Concentration increase from OM degradation; decrease from precipitation or H ₂ S loss
C:N ratio	Decrease	-3 to -5 units	C mineralization
Odour	Decrease	Significant	VFA degradation

⁵ Adapted from Guilyan, F, et al. 2020. Valorization of digestates from urban or centralized biogas plants.

Digestate Transformation

Many biogas plant operators perform additional processing steps to transform digestate in response to opportunities or challenges specific to the local digestate market, for example when:

- digestate storage capacity is limited;
- digestate fibre is separated and used as bedding;
- digestate must be transported over long distances;
- there are restrictions on nitrogen or phosphorus application rates that limit application of the whole digestate; and
- there are opportunities to supply specific agricultural, garden, landscaping, and soil products.

A wide variety of digestate transformation processes are in use at biogas plants. The decision on the best process is site specific and depends on the individual plant concept, market conditions, and regional availability for land application. Furthermore, the individual processes are evaluated according to end goal, technology, energy, and equipment requirements, which can vary greatly from manufacturer to manufacturer and sometimes also differ from the information provided.

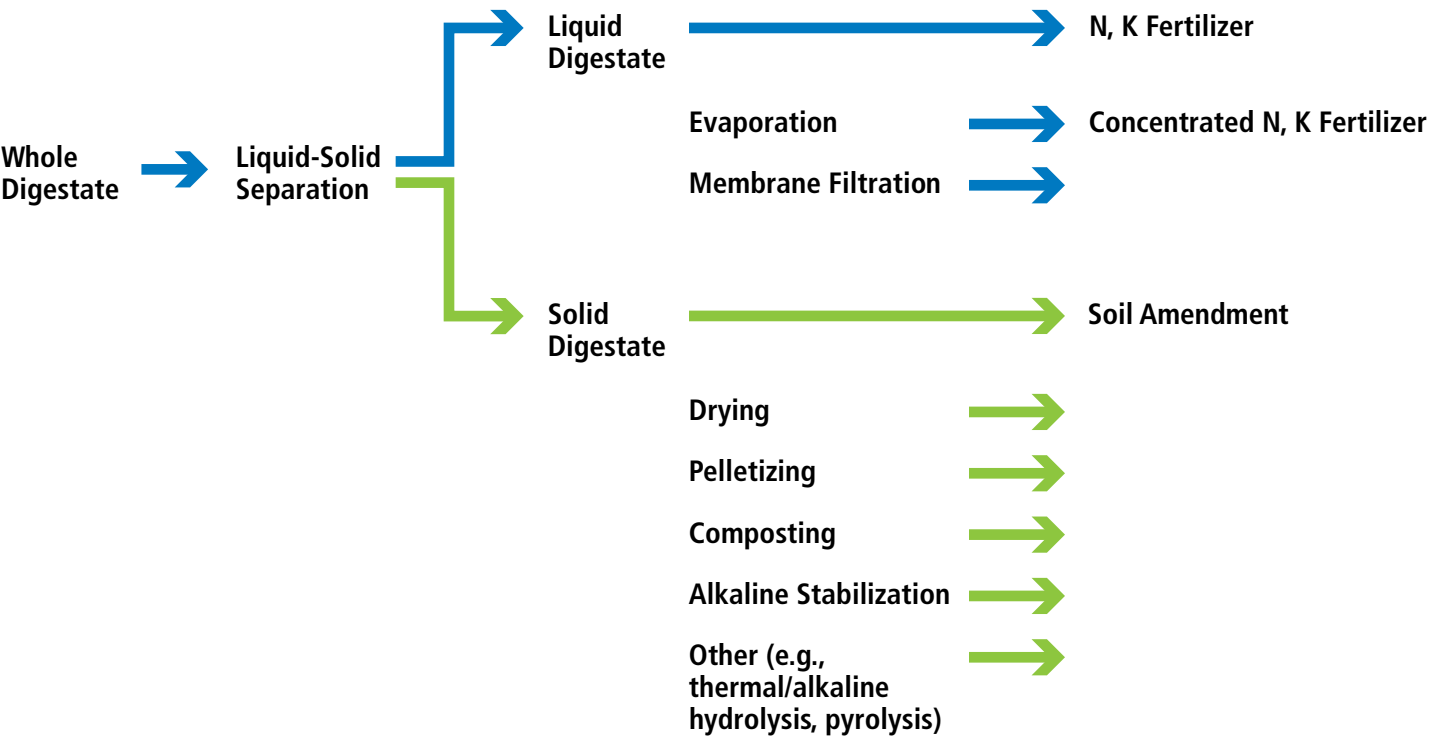
The first transformation step is usually liquid – solid separation, also called dewatering, which creates a pumpable liquid (liquid digestate), and a stackable, solid (solid digestate) with a dry matter content typically ranging between 20-40%. There is no reduction in volume; only the volumetric need for storage tanks for liquid digestate is reduced by around 10-20% by separating the solid fraction, depending on the quantity of organic material remaining and the efficiency of the separation technology.

The liquid-solid separation products have different characteristics and are suitable for different uses. The solid digestate is enriched with phosphorus and organic matter and can be used to build up soil phosphorus while avoiding nitrogen application limits. The solid digestate also acts as an organic soil amendment by contributing to the maintenance of soil organic matter. On-farm biogas plants digesting high fibre content feedstock, such as straw animal bedding, can recover much of the fibre in solid digestate which itself can be used for bedding.

The liquid fraction with a dry matter content of 1-8% has high flowability and is suitable for injection or band application (trailing hose/ trailing shoe), and if surface applied, can easily drip off the plant and enter the soil. Due to the enrichment of TAN, this fraction can be used as a fast-acting fertilizer supplying nitrogen and potassium to growing crops while avoiding phosphorus application limits.

Both solid and liquid digestate can be subjected to additional transformation steps as shown in *Figure 6*. The technologies most commonly applied in these transformation processes are described in *Appendix B*.

Figure 6. Digestate Transformation Processes and Outputs



Part 3 – Digestate Characteristics

Introduction to Digestate Characteristics

This Guide describes the characteristics of digestate derived from suitable feedstock materials produced as whole digestate and the solid and liquid digestate products resulting from transformation the whole digestate by mechanical liquid-solid separation. The digestate transformation technologies described in *Appendix B* offer the possibility of producing digestate with characteristics to suit specific needs.

In the characteristics of each digestate product are reflected the unique combination of feedstock blend and process design and operation of the biogas plant at which it was produced. The effective use of digestate in agriculture relies on knowledge of the key characteristics of the specific product to be used including organic matter and nutrient content, carbon to nitrogen (C:N) ratio, salinity, and pH, as these can vary significantly between digestate products and from 'typical' reported values. Key digestate characteristics are described in this and the following section of this Guide.

Quantitative information on digestate characteristics is obtained from the analysis by an accredited laboratory of samples representative of the digestate at the time of application. The analytical laboratory should be able to test for the full list of parameters in the tables in *Appendix C*. Analytical laboratories providing accredited testing services for manure, biosolids or compost will also be capable of providing digestate testing services. The Canadian Association for Laboratory Accreditation⁶ maintains a list of accredited laboratories and the testing services they can provide.

Where the sale or use of digestate products is enabled by or subject to federal⁷ or provincial⁸ regulations, those regulations will specify the minimum list of test parameters and sampling frequency required for compliance. Sampling techniques for other organic fertilizer or organic soil amendments such as manure⁹, non-agricultural materials¹⁰ or compost¹¹ can be employed to collect representative samples of whole, liquid or solid digestate products for analysis.

Reported ranges for the analytical test parameters that describe the key agricultural characteristics of whole, liquid, and solid digestate products are summarized in *Table 9* and *Table 10*. The summary data represents full-scale operating biogas plants processing a broad spectrum of feedstock materials (manures, agricultural and energy crops, commercial and industrial food waste and source-separated residential organics) obtained from published resources and from the OMAFRA digestate dataset and personal communication with Canadian biogas plant operators. Despite efforts to obtain inclusive data, actual test results for some digestate products may lie outside of the reported range. Reported ranges for the same test parameters for liquid swine manure and aerobic compost are included in *Table 9* and *Table 10* for comparison purposes.

⁶ See www.cala.ca

⁷ See Canadian *Fertilizers Act and Regulations*. <https://inspection.canada.ca/plant-health/fertilizers/eng/1299165827648/1299165914316>

⁸ For example see Ontario Regulation 267/03 General under the *Nutrient Management Act, 2002*. <https://www.ontario.ca/laws/regulation/030267>

⁹ For example see OMAFRA Best Management Practices: Manure Management. <http://www.omafra.gov.on.ca/english/environment/bmp/manure.htm>

¹⁰ For example see *2012 Sampling and Analysis Protocol for Ontario Regulation 267/03 Made under the Nutrient Management Act, 2002*. <http://omafra.gov.on.ca/english/nm/regs/sampro/samprotc-12.htm>

¹¹ See Bureau de Normalisation du Quebec (BNQ) Standard CAN/BNQ 0413-200 Organic Soil Improvers – Composts <https://www.bnq.qc.ca/fr/normalisation/environnement/composts.html>

Key Digestate Characteristics

Characteristic: Organic Matter

The benefit of soil organic matter is well understood as improving the physical, biological and fertility properties of soil. Sequestering carbon by increasing soil organic matter content is considered to have significant potential to partially offset increasing atmospheric carbon dioxide emissions and mitigate global climate change.

The amount and composition of organic material in a digestate product will reflect the amounts of simple readily degradable and complex less degradable compounds in the feedstock blend and the extent to which the biogas plant was able to decompose these materials and convert them to biogas and microbial biomass. Digestate organic matter will be in dissolved forms, such as volatile fatty acids, and suspended (i.e., non-dissolved) forms such as fibres comprised of undigested cellulose and lignin compounds. Digestate transformation by liquid-solid separation will concentrate suspended organic matter in the solid digestate product.

Laboratory test methods indicate the quantity of organic matter present in digestate by determining the weight of material with water removed, reported as Dry Matter or Total Solids, and the proportion of the Dry Matter which is lost when ignited at high temperature, primarily through conversion of carbon and hydrogen to CO₂ and H₂O, reported as Organic Matter or Volatile Solids. Organic carbon can be measured directly by the laboratory or can be estimated as a percentage of Organic Matter or Volatile Solids. For organic fertilizer or soil amendment materials, Organic Carbon is frequently estimated as 55% of the Organic Matter content¹².

Applying digestate organic matter to soil supplies:

- energy and nutrients to support soil microbial activity;
- slow-release primary, secondary and trace crop nutrients; and
- complex organic materials to create stable soil organic matter.

The soil benefit of applying digestate organic matter depends on the quantity applied and the rate and extent to which soil biological processes decompose the organic materials and convert the organic forms of carbon and nutrients into mineral forms, a process referred to as 'mineralization'. Mineralization of digestate organic matter in soil depends on soil characteristics, climatic (temperature, precipitation) and field conditions, and on the composition of the organic matter.

In contrast to fresh plant residues or animal manure, the organic materials present in compost or digestate decompose relatively slowly when added to soil and have a greater potential to contribute to the formation of stable soil organic matter because they have already undergone a significant amount of decomposition during biological treatment causing the remaining organic material to contain a higher proportion of more stable organic compounds.

Effective organic carbon (EOC) or effective organic matter (EOM), which measure the proportion of applied organic carbon or organic matter respectively that remains in soil one year following application, are considered useful indicators of the potential to create stable soil organic carbon. EOC seems to be strongly associated with the proportion of organic carbon in suspended forms. As shown in *Table 6*, for whole digestate products, EOC is estimated to range from approximately 50% to 70% of total organic carbon, slightly higher than undigested pig slurry, while the estimated EOM of solid digestate at approximately 70% – 75% is lower than that of compost at over 90%¹³. Humification of organic material occurs during the composting process but is not thought to occur during anaerobic digestion.

¹² <https://compost.css.cornell.edu/calc/carbon.html>

¹³ Reuland, G, et al. 2022. Assessment of the Carbon and Nitrogen Mineralisation of Digestates Elaborated from Distinct Feedstock Profiles. *Agronomy* 2022, 12, 456.

Table 6. Effective Organic Matter in Manure, Digestate, Compost
– results in mg/kg fresh weight unless noted¹⁴

Material	Dry matter (%)	Organic Matter (% DM)	HC ¹ (% OM)	EOM ² (% DM)
cattle slurry	86	65	63%	41
pig slurry	48	44	34%	15
cattle solid	247	174	64%	112
pig solid	280	192	38%	72
whole digestate	64	36	64%	23
compost	620	227	93%	211

Notes

1. Humification Coefficient: the remaining percentage of organic matter after one year of incorporation in the soil
2. Effective Organic Matter = Organic Matter x HC

As can be seen from *Table 9*, whole and liquid digestate products are low in organic matter and when applied at rates limited by the nutrient requirements of growing crops will not contribute directly to the creation of stable soil organic matter, but can contribute indirectly when used in conjunction with cover crops, as described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide.

The organic matter content of solid digestate will depend on the effectiveness of the liquid-solid separation process and can vary significantly between different digestate products, as shown in *Table 10*. For well dewatered solid digestate, the organic matter content is comparable to that of aerobic compost but, as previously described, has a slightly lower potential to promote the formation of stable soil organic matter. Also, solid digestate can contain significantly more mineral nitrogen and available phosphorus than aerobic compost which can limit its application rate. With knowledge of the organic matter and nutrient characteristics a solid digestate product can be used as described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* examples to sustain soil organic matter without over application of nutrients.

Characteristic: Crop Nutrients

Digestate contains useful amounts of primary, secondary and micro and trace nutrients that when used efficiently, as described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide, can be as effective as mineral fertilizer in satisfying the nutrient requirements of growing crops. The amount and forms of nutrients in a specific digestate product will reflect the nutrient content of the feedstock blend and the extent to which the anaerobic digestion process has converted nutrients into crop available forms. Digestate transformations can also affect the nutrient content of a digestate product through concentrations or losses, or through selective separation or partitioning of nutrients into specific digestate products.

It is important to note that the relative proportions of nutrients in a digestate product may not align exactly with crop requirements and consulting with a certified crop advisor is recommended.

Table 7 provides information on the forms of crop nutrients in digestate products.

¹⁴ Veeken, A, et al. 2017. The value of recycling organic matter to soils – Classification as organic fertilizer or organic soil improver. EIP-AGRI Focus Group- Nutrient Recycling.

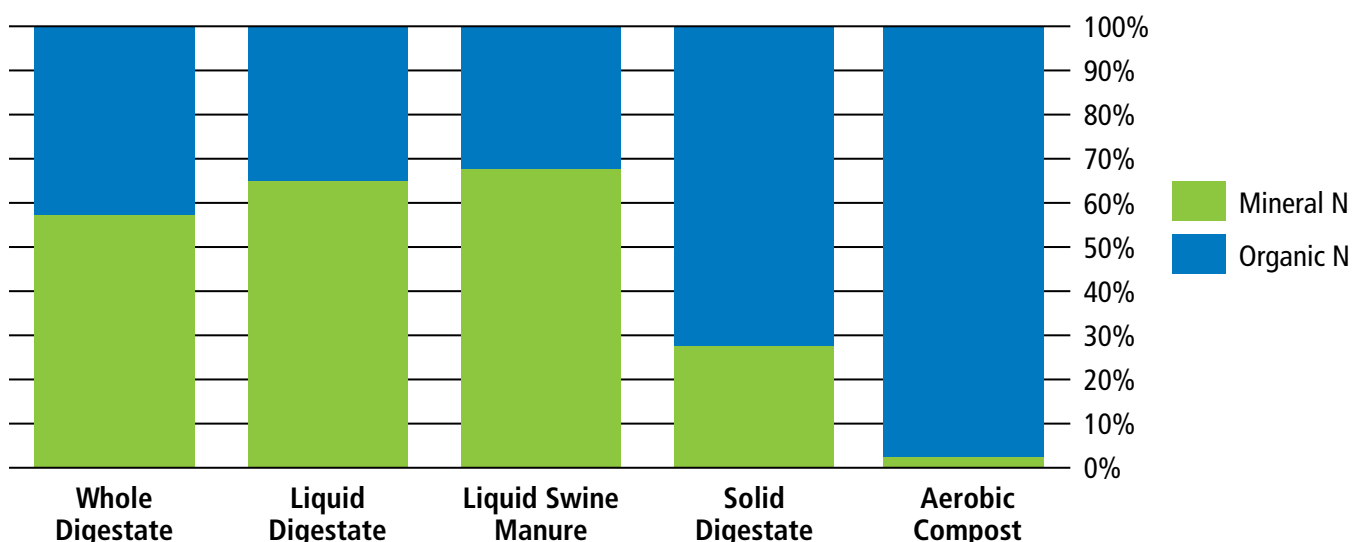
Table 7. Forms of Crop Nutrients Present in Digestate Products

Primary Nutrients	
Nitrogen	Nitrogen is present in digestate in organic and mineral forms, primarily TAN. The anaerobic digestion process does not create significant amounts of NO_3. TAN can be taken up by growing crops directly but is also a risk of nitrogen loss through ammonia volatilization. Soil microorganisms can very rapidly convert TAN into NO_3 which is a risk of nitrogen loss through leaching. Organic N is released in mineral forms as soil microorganisms decompose organic matter. Rate of release depends on the C:N ratio and organic matter stability of the digestate, and on the timing of and soil and weather conditions during application. Digestate products with high TAN / TN percentage are very well suited for use as organic fertilizers and, when used in accordance with the <i>Best Management Practices</i> described in this Guide, can approach the nitrogen use efficiency of commercial mineral fertilizers. Typical proportions of organic N and TAN in digestates and manure are shown in <i>Figure 7</i>.
Phosphorus	Phosphorus is present in digestate in organic and inorganic forms. Mineral phosphorus typically represents more than 50% and up to 90% of total phosphorus in digestate while for undigested manure the proportion of phosphorus in mineral forms can range from 30% to 60%.¹⁵ A large proportion of mineral phosphorus is soluble and organic phosphorus is readily converted in the soil to soluble mineral forms. Typically, 80% to 90% of total digestate phosphorus can be taken up by growing crops, which is similar to the crop available proportion of total phosphorus in undigested manure.¹⁶ The remaining 10% to 20% of total digestate phosphorus is present in relatively insoluble mineral forms and is not immediately available to crops.
Potassium	Almost all (estimated 90%) of the potassium is present in plant available forms.
Secondary Nutrients	As for N and P, the greater the degree of organic matter decomposition, the higher will be the proportion of the secondary nutrients present in plant-available mineral forms. For digestate at the high end of the pH range, some mineral forms may form slightly or somewhat insoluble precipitates and become temporarily unavailable to plants.
• Calcium • Magnesium • Sulfur	

¹⁵ Bachmann, S, et al. 2016. Phosphorus distribution and availability in untreated and mechanically separated biogas digestates. *Scientia Agricola*. 73. 9-17. Möller, K. 2015. Effects of anaerobic digestion on soil carbon and nitrogen turnover, N emissions, and soil biological activity. A review. *Agron. Sustain. Dev.* 35, 1021–1041 (2015). Moller, K. 2016. Assessment of alternative phosphorus fertilizers for organic farming: Compost and digestates from urban organic wastes. Möller K, Müller T. 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. *Engineering in Life Sciences* vol. 12(3), 2012.

¹⁶ Ibid.

Figure 7. Typical Proportions of Organic Nitrogen and Total Ammoniacal Nitrogen in Digestate, Manure and Aerobic Compost



Knowledge of the nutrient content of a digestate, and particularly the amounts of organic nitrogen and TAN, is necessary to apply best management practices to maximize nutrient use efficiency and minimize losses.

Analytical laboratories will typically report the nutrient content of a digestate product as summarized in *Table 8*.

Table 8. Typical Digestate Product Nutrient Content Reporting

Nutrient	Typical Nutrient Content Reporting
Nitrogen	Measurement of total nitrogen is reported as elemental nitrogen or as Total Kjeldahl Nitrogen (TKN), which measures combined organic nitrogen and TAN. TKN is a good approximation of total nitrogen because anaerobic digestion does not produce significant amounts of NO_3^-. Measurement of mineral nitrogen is reported as $\text{NH}_3/\text{NH}_4\text{-N}$ or TAN and measurement of NO_3^- is sometimes also provided. Organic nitrogen is not measured directly but can be calculated from the difference between total nitrogen and mineral nitrogen; i.e., Total nitrogen = organic nitrogen + mineral nitrogen (TAN)
Phosphorus	Total phosphorus is reported as elemental phosphorus or as phosphorus pentoxide commonly referred to as phosphate (P_2O_5). To convert between elemental phosphorus and P_2O_5: $\text{P}_2\text{O}_5 = \text{P} \times 2.29$
Potassium	Total potassium is reported as elemental potassium or potash (K_2O). To convert between elemental potassium and K_2O: $\text{K}_2\text{O} = \text{K} \times 1.20$
Sulfur	Total sulfur is reported as elemental sulfur or as sulfate (SO_4). To convert between elemental sulfur and sulfate: $\text{SO}_4 = \text{S} \times 3.0$
Calcium, Magnesium, trace and micro nutrients	These nutrients are typically reported as total amounts in elemental form.

As can be seen from *Table 6*, digestate products can differ significantly in nutrient content, with the difference between the most and least nutrient dense products being a factor of 2 or 3. Overall, the range of reported nutrient contents for whole digestate very closely overlaps that of liquid swine manure.

Digestate transformation by mechanical liquid-solid separation produces a solid digestate product with concentrated amounts of organic nitrogen, phosphorus as well as secondary nutrients, while the liquid digestate product retains usable amounts of TAN and potassium and lesser amounts of other nutrients. Overall, the range of reported nutrient contents for solid digestate very closely overlaps that of aerobic compost, with the significant exception that in solid digestate a significant portion of the nitrogen is present in mineral form while the mineral nitrogen content of aerobic compost is minimal.

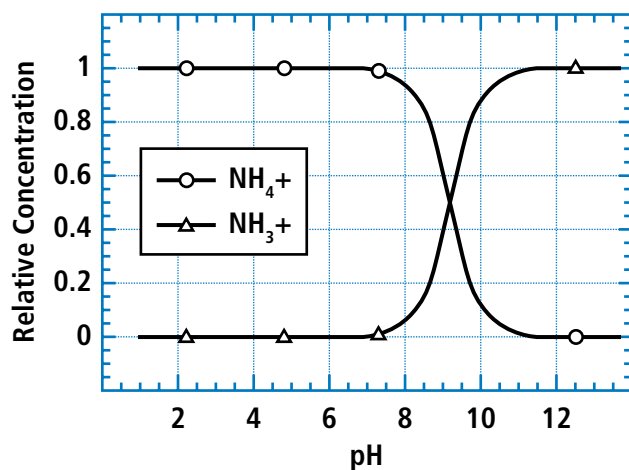
Characteristic: pH

Digestate products will typically have a neutral to slightly alkaline pH due to the up to 2 pH unit increase that occurs during anaerobic digestion.

A significant effect of pH on digestate characteristics is the form of crop nutrients, most significantly in the balance between the ammonia (NH_3) and ammonium (NH_4) forms of mineral nitrogen as shown in *Figure 8*. Ammonia is volatile and can be lost to the atmosphere while ammonium is not volatile.

At the high end of the range of reported pH values for digestate products a significant portion of the mineral nitrogen is present as volatile ammonia. Since digestate products hold most of their nitrogen in mineral form, the relatively high pH creates the potential for significant nitrogen loss if ammonia is allowed to evaporate during digestate storage or application. The *Best Management Practices* presented in this Guide provide options for minimizing ammonia loss.

Figure 8. Relative Concentrations of Ammonium and Ammoniacal Nitrogen vs pH¹⁷



¹⁷ From <https://compost.css.cornell.edu/odors/ammonia.html>

Characteristic: Carbon to Nitrogen (C:N) Ratio

The carbon to nitrogen ratio is the quotient of the weight of organic carbon to the weight of total nitrogen and is usually expressed as a single number. For example, a C:N ratio of 20 means that there are 20 g of carbon for each 1 g of nitrogen present.

The C:N ratio of an organic fertilizer or soil amendment is accepted as a useful predictor of nitrogen dynamics in the soil following application. Of specific importance for nutrient management is whether the microbial decomposition of the applied organic matter will result in temporary immobilization of mineral nitrogen, thus reducing the amount of mineral nitrogen available to crops, and how quickly mineralization will release organic nitrogen.

Of the many elements required for microbial decomposition, carbon and nitrogen are the most important. Soil microorganisms have a C:N ratio of 8 -10. Carbon provides both an energy source and the basic building blocks of microbial cells making up about 50% of the mass. Nitrogen is a crucial component of the proteins, nucleic acids, amino acids, enzymes and co-enzymes necessary for cell growth and function. At a C:N ratio of approximately 25, an organic fertilizer or soil amendment will contain enough nitrogen to support microbial decomposition of the organic matter without soil microorganisms having to take in and immobilize mineral nitrogen from the soil. Therefore, the predicted soil nitrogen dynamics based on the C:N ratio are:

C:N Ratio	Predicted soil nitrogen dynamics¹⁸
< 20	Nitrogen is in excess. Rapid mineralization and release of N occurs. The lower the C:N ratio, the more rapidly nitrogen will be mineralized.
20 – 30	Carbon and nitrogen are in 'balance.' No net immobilization is expected and organic nitrogen will be slowly mineralized.
> 30	Carbon is in excess. Temporary immobilization of mineral nitrogen is expected. The higher the C:N ratio the greater the quantity of nitrogen that will be immobilized and the longer the time period over which the nitrogen is mineralized.

The C:N ratios of whole and liquid digestate products lie within the range where rapid mineralization is predicted. Overall, digestate products with relatively low C:N ratios and high $\text{NH}_4\text{-N}/\text{Total N}$ ratio can perform similar to synthetic nitrogen fertilizers such that a high rate of nitrogen use by a growing crop can be achieved. The C:N ratio of solid digestate products can vary over a wide range. Solid digestate at the high end of the C:N range may not be suitable for supplying nitrogen to crops grown during the season of application but can serve as an nitrogen source in the subsequent growing season.

Predictions of nitrogen dynamics based on C:N ratio can be improved with knowledge of the relative degradability of the organic matter present in the digestate. Whether the organic matter can be characterized as readily degradable or more stable will help clarify the expected timeline for nitrogen immobilization or mineralization. As well, the C:N ratio assumes that all mineral nitrogen present in the organic fertilizer or soil amendment is available to decompose the organic matter, which may be inaccurate if significant amounts of mineral nitrogen are taken up by the crop or lost through volatilization or leaching. Calculation of the ratio of organic carbon to organic nitrogen, C:N_{org} , can provide an additional predictor of soil nitrogen dynamics.

¹⁸From <https://www.ontario.ca/page/carbonnitrogen-ratios-organic-amendments>

Characteristic: Salinity

In chemistry, a salt is a chemical compound consisting of positively charged cations and negatively charged anions. A common example is table salt, with positively charged sodium ions and negatively charged chloride ions.

All digestate products contain salts, some of which are associated with nutrients such as potassium, magnesium and calcium, and others that may be harmful to soil organisms and crops such as sodium and chlorides.

Laboratory analysis can measure the amounts of individual salts present in a digestate however it is common to rely on measurements of total salinity to inform the management requirements of organic fertilizers and organic soil amendments. An indicative measurement of total salinity is obtained by measuring the electrical conductivity of a sample of digestate diluted with distilled water usually at a digestate to water weight ratio of 1:5. The more salts, and other free ionic compounds such as ammonium, present the higher will be the electrical conductivity.

Electrical conductivity measurements can be reported as Electrical Conductivity and expressed in units of microSeimens per centimeter ($\mu\text{S}/\text{cm}$) and milliSeimens per centimeter (mS/cm), or reported as Total Salts and expressed in units of micromhos per centimeter ($\mu\text{mhos}/\text{cm}$) and millimhos per centimeter (mmhos/cm). These measurements are equivalent and can be converted using: $1 \text{ mmho}/\text{cm} = 1 \text{ mS}/\text{cm} = 1,000 \mu\text{mhos}/\text{cm} = 1,000 \mu\text{S}/\text{cm}$.

Application of materials with high salinity comes with the risk of salt Injury to seeds and plants (root burn or tissue burn). Also, addition of salts increases the osmotic potential of the soil solution which affects the flow of soil water. The higher the osmotic potential of the soil solution, the more difficult it is for seeds or plants to extract soil water. Particular care is required to prevent salt injury when using digestate products with measured Electrical Conductivities at the high end of the ranges shown in *Table 9* and *Table 10*, i.e., 25 mS/cm and above, and products with this characteristic may not be suitable for use with salt sensitive crops.

Factors influencing or increasing the risk for plant injury include:

Root Burn

- High application rates
- Low water volumes
- Dry soil conditions
- Same day planting into banded and/or high rate applications
- Application to areas with saline soils

Tissue Burn

- High application rates
- Low water volumes
- High ambient temperatures
- High relative humidity

Characteristic: Stability

Stability is a desirable characteristic of digestate products since it refers to a diminished potential for biological decomposition during handling and storage. A diminished potential for biological decomposition correspondingly diminishes the potential for:

- generation of biogas methane which if not captured and destroyed will contribute to atmospheric Greenhouse Gases;
- regrowth of certain pathogenic organisms; and
- generation of odours attracting pests and creating nuisances.

Ensuring that a satisfactory degree of stability has been achieved is particularly important if the digestate product will be stored during periods of warm weather.

The stability of a digestate product is determined by the performance of the anaerobic digestion operation at the biogas plant in degrading and converting organic materials into biogas. Specific laboratory tests and threshold values to determine stability have long been established for other organic fertilizer and organic soil amendment products such as compost and biosolids. For digestate, being a relatively new product, discussion of suitable stability requirements is in the early stages. It is possible, however, to use available laboratory test results and biogas plant operating data to assess the stability of specific digestate products. Approaches for assessing the stability of a digestate product include the following.

Measuring Residual Biochemical Methane Potential

Laboratory testing can measure the biochemical methane potential of the digestate product which is a direct indication of digestate product stability. However, very little data on the residual biochemical methane potential of digestate products is currently available and no threshold values have yet been adopted for use at Canadian biogas plants. The U.K. biogas industry has adopted a digestate stability standard which sets a maximum biogas generation limit of 0.45 L biogas g VS⁻¹ ¹⁹. The effectiveness of this standard and potential suitability for Canada have not been investigated.

Although not direct indications of stability, the following approaches can be used by biogas plants to ensure that processing operations are continuously producing suitably stabilized digestate.

Measuring Volatile Solids Destruction

Laboratory testing of the digestate product and the feedstock will enable a calculation of the percentage of feedstock volatile solids that have been removed by the anaerobic digestion process through conversion to biogas. Biogas plants aim to maximize production of valuable biomethane and therefore a high degree of volatile solids destruction, typically in excess of 60%, can be expected. Similarly, laboratory testing can measure the volatile solids destruction which can occur from additional digestion of the digestate product. For volatile solids destruction measurements and calculations see US EPA 2003 Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge EPA/625/R-92/013²⁰.

¹⁹ <https://wrap.org.uk/resources/guide/bsi-pas-110-producing-quality-anaerobic-digestate>

²⁰ <https://www.epa.gov/sites/default/files/2015-07/documents/epa-625-r-92-013.pdf>

Comparing Actual and Potential Biomethane Generation

Laboratory testing can measure the biochemical methane potential of the biogas plant feedstock. Actual biomethane generation can be calculated from the biogas plant's operating data. A comparison of actual to potential generation is an indication of the biochemical methane potential realized at the biogas plant and remaining in the digestate product. Biogas plants are designed to realize most of the biochemical methane potential of the feedstock and results in excess of 70% can be expected.

Further work by the Canadian biogas industry is required to determine appropriate requirements for digestate stability.

Organic Fertilizer or Organic Soil Amendment

Some digestate products are most suitable for use as organic fertilizers while others are better suited for use as organic soil amendments, with the distinction being:

- as an organic fertilizer, a digestate product will satisfy a significant proportion of the nutrient requirements of a growing crop when applied at typical rates, and
- as an organic soil amendment, a digestate product will sustain or replenish soil organic matter improving soil health and fertility without supplying excess nutrients when applied at typical rates.

Whole digestate is an organic fertilizer well suited to supply primary, secondary and micro nutrients to growing crops. Studies have shown increased crop yields following digestate application due to its high nutrient content as these are present in mineral form thus readily available for crop uptake. Whole digestate is similar to hog slurry in terms of its high proportion of available nitrogen and low dry matter content. Liquid digestates are characterized as N-K fertilizers comparable to mineral N-K fertilizers or animal urine.

Solid digestates may be characterized as organic soil amendments that also supply slow-release nitrogen and valuable amounts of phosphorus and secondary and micronutrients and is comparable to some forms of solid animal manure. Solid digestate is best suited to application on arable land in order to sustain or increase soil organic matter and to replace P losses via harvested P-rich crops such as grains.

The different digestate products provide flexibility in nutrient management; solid product can be used to supply phosphorus without over applying available nitrogen while the liquid product can supply available nitrogen and potassium without over supplying phosphorus. Ideal for spring/ in-crop application/with cover crop application.

Table 9. Key Agricultural Use Characteristics of Whole and Liquid Digestate and Liquid Swine Manure [Fresh Weight (FW) basis]

Parameter	Range ¹	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure
pH	H	pH units	8.5	8.5	9	pH units	8.5	8.5	9	pH units	8.5	8.5	9
	M				7.5				7.5				
	L		7.5	7.5	6		7.5	7.5	6		7.5	7.5	6
Total Solids / Dry Matter	H	%	10	5	10	kg m ⁻³	103.5	51.8	103.5	lb 1000 gal(l) ⁻¹	1037.3	518.7	1037.3
	M		6.5	3.5	3.6		67.3	36.2	37.3		674.3	363.1	373.4
	L		3	2	2		31.1	20.7	20.7		311.2	207.5	207.5
Volatile Solids / Organic Matter	H	%	5	2.5	7	kg m ⁻³	51.8	25.9	72.5	lb 1000 gal(l) ⁻¹	518.7	259.3	726.1
	M		3.5	1.5	4		36.2	15.5	41.4		363.1	155.6	414.9
	L		2	0.5	1		20.7	5.2	10.4		207.5	51.9	103.7
Organic Carbon ²	H	%	3.1	2.4	4	kg m ⁻³	32.1	24.8	41.4	lb 1000 gal(l) ⁻¹	321.6	249	414.9
	M		2.1	1.7	2.4		21.7	17.6	24.8		217.8	176.3	249
	L		1.1	1	0.6		11.4	10.4	6.2		114.1	103.7	62.2
Total Nitrogen	H	%	0.7	0.7	0.8	kg m ⁻³	7.2	7.2	8.3	lb 1000 gal(l) ⁻¹	72.6	72.6	83
	M		0.45	0.5	0.39		4.7	5.2	4		46.7	51.9	40.5
	L		0.2	0.3	0.2		2.1	3.1	2.1		20.7	31.1	20.7

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Parameter	Range ¹	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure
NH ₄ -N	H	%	0.5	0.35	0.6	kg m ⁻³	5.2	3.6	6.2	lb 1000 gal(l) ⁻¹	51.9	36.3	62.2
	M		0.325	0.225	0.265		3.4	2.3	2.7		33.7	23.3	27.5
	L		0.15	0.1	0.15		1.6	1	1.6		15.6	10.4	15.6
NH ₄ -N / Total N	H	% (w/w)	75	80	75	% (w/w)	75	80	75	% (w/w)	75	80	75
	M		57.5	65	68		57.5	65	68		57.5	65	68
	L		40	50	60		40	50	60		40	50	60
C : N ³	H	Ratio	7	5	6	Ratio	7	5	6	Ratio	7	5	6
	M		5	3.75	3.7		5	3.75	3.7		5	3.75	3.7
	L		3	2.5	2		3	2.5	2		3	2.5	2
C : N _{org} ⁴	H	Ratio	17	10.5		Ratio	17	10.5	0	Ratio	17	10.5	0
	M		12	9	19.2		12	9	19.2		12	9	19.2
	L		7	7.5			7	7.5	0		7	7.5	0
Electrical Conductivity	H	mS/cm	39	39	40	mS/cm	39	39	40	mS/cm	39	39	40
	M		26.5	26.5	20		26.5	26.5	20		26.5	26.5	20
	L		14	14	5		14	14	5		14	14	5
Phosphorus	H	%	0.15	0.1	2	kg m ⁻³	1.6	1	20.7	lb 1000 gal(l) ⁻¹	15.6	10.4	207.5
	M		0.085	0.055	1.2		0.9	0.6	12.4		8.8	5.7	124.5
	L		0.02	0.01	0.02		0.2	0.1	0.2		2.1	1	2.1

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Parameter	Range ¹	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure	Units	Whole Digestate	Separated Liquid Digestate	Liquid Swine Manure
Potassium	H	%	0.4	0.4	4	kg m ⁻³	4.1	4.1	41.4	lb 1000 gal(l) ⁻¹	41.5	41.5	414.9
	M		0.25	0.275	0.19		2.6	2.8	2		25.9	28.5	19.7
	L		0.1	0.15	0.1		1	1.6	1		10.4	15.6	10.4
Calcium	H	%	0.2	0.2		kg m ⁻³	2.1	2.1		lb 1000 gal(l) ⁻¹	20.7	20.7	
	M		0.15	0.15	0.13		1.6	1.6	1.3		15.6	15.6	13.5
	L		0.1	0.1			1	1			10.4	10.4	
Magnesium	H	%	0.07	0.07		kg m ⁻³	0.7	0.7		lb 1000 gal(l) ⁻¹	7.3	7.3	
	M		0.045	0.045	0.07		0.5	0.5	0.7		4.7	4.7	7.3
	L		0.02	0.02			0.2	0.2			2.1	2.1	
Sulphur	H	%	0.08	0.05		kg m ⁻³	0.8	0.5		lb 1000 gal(l) ⁻¹	8.3	5.2	
	M		0.055	0.04	0.07		0.6	0.4	0.7		5.7	4.1	7.3
	L		0.03	0.03			0.3	0.3			3.1	3.1	

Conversion

Density kg m⁻³ = 1035

Density lb 1000 gal⁻¹ = 10373.1

Notes

1. H = high, M= average or mid-range, L = low
2. If not reported, calculated as OC% = DM% / 1.8
3. If not reported, calculated as C:N = OC% / Total N%
4. If not reported, calculated as C:N_{org} = OC% / (Total N% - NH₄-N%)

Table 10. Key Agricultural Use Characteristics of Solid Digestate and Aerobic Compost [Fresh Weight (FW) basis]

Parameter	Range ¹	Units	Separated Solid Digestate	Aerobic Compost	Units	Separated Solid Digestate	Aerobic Compost	Units	Separated Solid Digestate	Aerobic Compost
pH	H	pH units	9	8.5	pH units	9	8.5	pH units	9	8.5
	L		8	6.5		8	6.5		8	6.5
Total Solids / Dry Matter	H	% FW	40	65	kg tonne ⁻¹	400	650	lb tonne ⁻¹	896	1456
	M		32.5	52.5		325	525		728	1176
	L		25	40		250	400		560	896
Volatile Solids / Organic Matter	H	% FW	30	30	kg tonne ⁻¹	300	300	lb tonne ⁻¹	672	672
	M		24	24		240	240		537.6	537.6
	L		18	18		180	180		403.2	403.2
Organic Carbon ²	H	% FW	17	17	kg tonne ⁻¹	170	170	lb tonne ⁻¹	380.8	380.8
	M		11.25	13.5		112.5	135		252	302.4
	L		5.5	10		55	100		123.2	224
Total Nitrogen	H	% FW	1.2	2	kg tonne ⁻¹	12	20	lb tonne ⁻¹	26.9	44.8
	M		0.825	1.25		8.25	12.5		18.5	28
	L		0.45	0.5		4.5	5		10.1	11.2
NH ₄ -N	H	% FW	0.4	< 0.1	kg tonne ⁻¹	4	< 0.1	lb tonne ⁻¹	9	< 0.1
	M		0.225	-		2.25	-		5	-
	L		0.05	-		0.5	-		1.1	-
NH ₄ -N / Total N	H	% (w/w)	35	< 1	% (w/w)	35	< 1	% (w/w)	35	< 1
	M		27.5	-		27.5	-		27.5	-
	L		20	-		20	-		20	-
C : N ³	H	Ratio	27	25	Ratio	27	25	Ratio	27	25
	M		18.25	17.5		18.25	17.5		18.25	17.5
	L		9.5	10		9.5	10		9.5	10
C : N _{org} ⁴	H	Ratio	35	25	Ratio	35	25	Ratio	35	25
	M		24	17.5		24	17.5		24	17.5
	L		13	10		13	10		13	10

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Parameter	Range ¹	Units	Separated Solid Digestate	Aerobic Compost	Units	Separated Solid Digestate	Aerobic Compost	Units	Separated Solid Digestate	Aerobic Compost
Electrical Conductivity	H	mS/cm	26	50	mS/cm	26	50	mS/cm	26	50
	M		25	27.5		25	27.5		25	27.5
	L		24	5		24	5		24	5
Phosphorus	H	% FW	1.2	0.5	kg tonne ⁻¹	12	5	lb tonne ⁻¹	26.9	11.2
	M		0.7	0.3		7	3		15.7	6.7
	L		0.2	0.1		2	1		4.5	2.2
Potassium	H	% FW	0.7	2	kg tonne ⁻¹	7	20	lb tonne ⁻¹	15.7	44.8
	M		0.45	1.15		4.5	11.5		10.1	25.8
	L		0.2	0.3		2	3		4.5	6.7
Calcium	H	% FW	1.1	3.5	kg tonne ⁻¹	11	35	lb tonne ⁻¹	24.6	78.4
	M		0.8	2.75		8	27.5		17.9	61.6
	L		0.5	2		5	20		11.2	44.8
Magnesium	H	% FW	0.5	0.9	kg tonne ⁻¹	5	9	lb tonne ⁻¹	11.2	20.2
	M		0.325	0.55		3.25	5.5		7.3	12.3
	L		0.15	0.2		1.5	2		3.4	4.5
Sulphur	H	% FW	0.25	0.3	kg tonne ⁻¹	2.5	3	lb tonne ⁻¹	5.6	6.7
	M		0.175	0.2		1.75	2		3.9	4.5
	L		0.1	0.1		1	1		2.2	2.2

Conversion

1 tonne = 2240 lb

Notes

1. H = high, M= average or mid-range, L = low
2. If not reported, calculated as $OC\% = DM\% / 1.8$
3. If not reported, calculated as $C:N = OC\% / \text{Total } N\%$
4. If not reported, calculated as $C:N_{org} = OC\% / (\text{Total } N\% - NH_4-N\%)$

Why Use Digestate?

Digestate Nutrient Addition and Value Calculations

Calculations of primary nutrients available to crops following applications of whole and solid digestate are presented in the examples below. The value of the available nutrients is calculated for each application using unit pricing for mineral N, P_2O_5 and K_2O fertilizer current as of the date of publication. Digestate will also supply organic matter, Ca, Mg and S, which are absent in chemical mineral N-P-K fertilizers.

Example 1 – Value of Digestate as an Organic Fertilizer

Whole digestate is applied ahead of planting corn to supply available nitrogen and other nutrients to a growing crop.

Application ¹		Digestate Analysis		Cost of Mineral Fertilizer Nutrients ²	
Digestate Type	Whole Digestate	Parameter	% FW	Nutrient	Cost (\$ kg ⁻¹) [\$ lb ⁻¹]
Rate	40 m ³ ha ⁻¹ [3560 gal acre ⁻¹]	DM	5.0	Nitrogen	2.50 [1.13 \$ lb ⁻¹]
Timing	Spring	OM	3.5	Phosphorus as P_2O_5	2.00 [0.91 \$ lb ⁻¹]
Method	Injection	Total N	0.5	Potassium as K_2O	1.20 [0.54 \$ lb ⁻¹]
Density	1035 kg m ⁻³ [10,373 lb 1000 gal ⁻¹]	TAN	0.325		
		Total P	0.1		
		Total K	0.25		

Notes

1. Imperial gallons
2. Approximate cost of nutrients as of November 2022
3. Estimation of crop available nutrients is described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide.

Nutrient Value Calculations				
Nutrient	Quantity Applied	Proportion Crop Available ³	Total Crop Available	Cost of Equivalent Mineral Fertilizer
TAN	$40 \text{ m}^3 \text{ ha}^{-1} \times 1035 \text{ kg m}^{-3} \times 0.325\% = 134.5 \text{ kg ha}^{-1}$ [120 lb acre ⁻¹]	100%	134.5 kg ha^{-1} [120 lb acre ⁻¹]	$336 \$ \text{ ha}^{-1}$ [136 \$ acre ⁻¹]
Organic Nitrogen	$40 \text{ m}^3 \text{ ha}^{-1} \times 1035 \text{ kg m}^{-3} \times (0.5\% - 0.325\%) = 72 \text{ kg ha}^{-1}$ [65 lb acre ⁻¹]	44 %	32 kg ha^{-1} [28.5 lb acre ⁻¹]	$80 \$ \text{ ha}^{-1}$ [32 \$ acre ⁻¹]
Total Nitrogen	$134.5 + 72 = 206.5 \text{ kg ha}^{-1}$ [184 lb acre ⁻¹]	81 %	166.5 kg ha^{-1} [148.5 lb acre ⁻¹]	$416 \$ \text{ ha}^{-1}$ [168 \$ acre ⁻¹]
Phosphorus	$40 \text{ m}^3 \text{ ha}^{-1} \times 1035 \text{ kg m}^{-3} \times 0.1\% \times 2.29 = 95 \text{ kg ha}^{-1}$ [85 lb acre ⁻¹] as P_2O_5	80%	76 kg ha^{-1} [68 lb acre ⁻¹]	$152 \$ \text{ ha}^{-1}$ [61.5 \$ acre ⁻¹]
Potassium	$40 \text{ m}^3 \text{ ha}^{-1} \times 1035 \text{ kg m}^{-3} \times 0.25\% \times 1.2 = 124 \text{ kg ha}^{-1}$ [111 lb acre ⁻¹] as K_2O	90%	112 kg ha^{-1} [100 lb acre ⁻¹]	$134 \$ \text{ ha}^{-1}$ [54 \$ acre ⁻¹]

Notes

1. Imperial gallons
2. Approximate cost of nutrients as of November 2022
3. Estimation of crop available nutrients is described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide.

Example 2 – Value of Digestate as an Organic Soil Amendment

Solid digestate is applied in the early fall following wheat harvest and before planting a cover crop. Digestate nitrogen and other nutrients will enhance cover crop growth and will be available to a corn crop planted the following spring.

Application ¹		Digestate Analysis		Cost of Mineral Fertilizer Nutrients	
Digestate Type	Solid Digestate	Parameter	% FW	Nutrient	Cost (\$ kg ⁻¹) [\$ lb ⁻¹]
Rate	20 tonne ha ⁻¹ [9 tonne acre ⁻¹]	DM	32	Nitrogen	2.50 [1.13 \$ lb ⁻¹]
Timing	Earl fall, ahead of planting cover crop	OM	24	Phosphorus as P ₂ O ₅	2.00 [0.91 \$ lb ⁻¹]
Method	Broadcast	OC	13	Potassium as K ₂ O	1.20 [0.54 \$ lb ⁻¹]
Incorporation	48 hours	Total N	0.825		
		Total P	0.7		
		Total K	0.45		

Amendment Value Calculations				
Organic Matter	20 tonne ha ⁻¹ x 24% = 4.8 tonne ha ⁻¹ [2 tonne acre ⁻¹]	In addition to the organic matter supplied by the digestate directly, digestate nutrients will increase cover crop biomass significantly. Solid digestate combined with a cover crop is an effective approach for sustaining or increasing soil organic matter.		
Nutrient	Quantity Applied	Proportion Crop Available ³	Total Crop Available	Cost of Equivalent Mineral Fertilizer
Total Nitrogen	20 tonne ha ⁻¹ x 0.825% = 166 kg ha ⁻¹ [148 lb acre ⁻¹]	45 %	75 kg ha ⁻¹ [67 lb acre ⁻¹]	187.5 \$ ha ⁻¹ [76 \$ acre ⁻¹]
Phosphorus	20 tonne ha ⁻¹ x 0.7% x 2.29 = 320 kg ha ⁻¹ [285 lb acre ⁻¹] as P ₂ O ₅	80%	256 kg ha ⁻¹ [228 lb acre ⁻¹]	512 \$ ha ⁻¹ [207 \$ acre ⁻¹]
Potassium	20 tonne ha ⁻¹ x 0.45% x 1.2 = 110 kg ha ⁻¹ [98 lb acre ⁻¹] as K ₂ O	90%	99 kg ha ⁻¹ [88 lb acre ⁻¹]	119 \$ ha ⁻¹ [48 \$ acre ⁻¹]

Notes

1. Imperial gallons
2. Approximate cost of nutrients as of November 2022
3. Estimation of crop available nutrients is described in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide.

Why Digestate is Safe to Use

Biogas plants operators apply their knowledge of feedstocks and good operational practices to ensure that their digestate products consistently satisfy applicable quality requirements for safe use.

Quality requirements for the safe application of materials to land and the protection of soil and ground and surface water quality typically address the following types of contamination which are described in later sections:

- Potentially toxic elements, also referred to as heavy metals
- Trace organic contaminants
- Pathogens
- Physical contaminants

As of the date of this Guide, no pan-Canadian quality standards specifically for digestate products exist. Quality requirements applicable to the safe application of digestate to agricultural land are set out in provincial policies. It is common practice for industrial biogas plants to secure fertilizer registrations for their digestate products from Agriculture and Agri-Food Canada. Securing a fertilizer registration requires that a digestate product satisfies the safety requirements set out in the *Fertilizers Act and Regulations*. Refer to *Appendix E* for an overview of relevant federal and provincial policies.

Biogas plants are not a source of contaminants, however contaminants can be present in the feedstock arriving at the site. Managing contaminants present in feedstocks to ensure the safety of digestate products is a critical focus of biogas plant operations and includes:

- **Feedstock screening:** Gaining knowledge of feedstock supply chains to understand potential contaminant sources. Can include feedstock testing and accepting only suitable clean and source-separated feedstock materials.
- **Processing operations:** Design and operate processing operations to remove or eliminate contaminants.
- **Product testing:** Regular testing to confirm compliance with applicable quality requirements.
- **Product use information:** Providing users with information necessary for the safe and effective use of the product.

The experience of Canadian biogas plants is consistent with that of plants operating in other jurisdictions in that the above steps, diligently applied, will produce digestate products that consistently satisfy applicable quality requirements for safe use. The biogas industry is aware that quality requirements will change as the awareness and understanding of, and ability to measure, specific contaminants improve over time. Through its ongoing engagement with government policy and regulatory agencies, digestate producers and users, the Canadian Biogas Association ensures that the Canadian biogas industry is informed of developing policies and is taking appropriate measures to respond to changing requirements.

Potentially Toxic Elements

Potentially toxic elements (PTE), also commonly known as heavy metals, refers to a group of elements identified in regulations for the purpose of limiting their application to, or concentration in, soil.

The commonly regulated heavy metals are: arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se), Zinc (Zn).

These elements are naturally present in the environment, in soils, and in ground and surface waters, are safe at low concentrations, and are essential in small quantities for plants and animals. Several of the regulated heavy metals (i.e., Cu, Mo, Ni, Se, Zn), are also crop micronutrients and their presence at low concentrations is beneficial. At high concentrations, however, heavy metals are toxic to plants, animals, and humans.

PTEs have been intensively studied over decades and most jurisdictions have regulations that set safe limits for their addition to soil. The *Fertilizers Regulation* sets concentration limits for PTEs to restrict their accumulation in soil from repeated fertilizer applications over a long term. Limit concentrations are conservative, based on total rather than the available amount of the element.

Digestate and other organic fertilizers and soil amendments contain measurable amounts of some PTEs because they are present in the feedstock materials. Sources of heavy metals in feedstocks include:

- accumulation in soils and crops through atmospheric deposition, contaminated irrigation water, metals present in mined mineral fertilizers and application of pesticides;
- take-up by crops and bioaccumulation at higher levels of the food chain;
- animal feed supplements can contain heavy metals, particularly copper and zinc; and
- food products can accumulate metals at all stages of the supply chain; production, packaging, transportation, storage, retail, consumption.

The amounts of PTEs present in feedstock materials has been gradually diminishing over time as the use of PTEs in products is reduced or banned.

The quantity of PTEs present in digestate products will reflect the quantity present in the feedstock blend. The concentration of PTEs in digestate will be increased with respect to the feedstock blend due to the conversion of organic matter to biogas. If digestate is transformed by liquid – solid separation PTEs will be concentrated in the solid product.

Biogas plant operators need to be knowledgeable about the source of their feedstocks and the potential for heavy metals to be added during the supply chain. Clean and source-separated feedstock materials present the lowest risk of heavy metal contamination. Extra vigilance, including more frequent feedstock testing, is appropriate where the potential for heavy metal additions exist.

Experience to date confirms that digestate produced from clean and source-separated feedstock streams will consistently result in digestate with concentrations of heavy metals below applicable regulatory limits.

Trace Organic Contaminants

Trace organic contaminants refers to many natural and manufactured chemicals or by-products of industrial processes that are characterized by their persistence and movement in the environment, their ability to bioaccumulate, and their ability to cause toxic effects in humans and animals at low concentrations. Production and use of trace organic contaminants over many decades has resulted in their presence throughout the environment. Production of many trace organic contaminants has been banned, however they will remain present in the environment for some time.

Groups of trace organic contaminant compounds commonly addressed in standards and guidelines for the protection of soil and surface and groundwater quality include:

- Halogenated organic compounds which includes polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs) and organochlorine pesticides
- Polycyclic aromatic hydrocarbons (PAHs)
- Phthalic acid esters (PAEs)
- Nonylphenol ethoxylates (NPEs)
- Per- and polyfluoroalkyl substances (PFAS)

Describing the origins and significance of trace organic contaminants is beyond the scope of this Guide. Readers seeking more information on the presence of trace organic contaminants in the environment are referred to Health Canada's Chemicals Management Plan²¹, to the Canadian Council of Ministers of the Environment's (CCME) Canadian Environmental Quality Guidelines²², or to provincial standards for soil and water quality.

As a result of the background environmental presence and continued use of trace organic contaminants, low but measurable amounts of some trace organic contaminants can be found in biogas plant feedstocks. Sources of trace organic contaminants in biogas plant feedstocks include:

- **Crops:** atmospheric deposition, use of wastewater for irrigation, urban activities, proximity to toxic waste sources, pesticide and fertilizer use;
- **Livestock:** contaminated soil and grass, proximity to chemical production areas, exposure to paints, sealants and coatings used in livestock structures, contaminated feed and water;
- **Processing and packaging:** contact with packaging materials; and
- **Consumption:** PAHs and PCBs can form at high cooking temperatures.

Anaerobic digestion has been reported to reduce some trace organic contaminants however complete elimination is not achieved. Reduction is achieved primarily through biological activity and is thought to improve over time as the microbial community becomes adapted to the presence of the specific trace organic contaminants. Processing at thermophilic temperatures is thought to achieve greater reductions compared to mesophilic temperatures. In general, it may be concluded that anaerobic digestion is a valid process for degradation of trace organic contaminants and usually the concentrations of organic pollutants are lower after the process than before, albeit not all of the compounds can be entirely degraded.

Studies of trace organic contaminants in digestate report that when produced from clean and source-separated feedstocks digestates are generally of good quality with trace organic contaminant concentrations below regulatory limits, in jurisdictions where limits exist, or below levels considered to be conservative and safe, however some exceedances of the most conservative limits are reported.

²¹ <https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan.html>

²² <https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines>

There are no pan-Canadian standards for trace organic contaminants in digestate except for the PCDD/PCDF concentration limit in the *Fertilizers Act and Regulations* and the requirement for PCDD/PCDF analysis is dependent on the ingredients (and their sources). Testing for trace organic contaminants is not a routine requirement of biogas plants processing suitable feedstock materials.

In Canada and many other jurisdictions, reliance is placed on feedstock selection to ensure that the risk of trace organic contaminants in digestate products remains acceptably low. By selecting only suitable clean and source separated feedstocks, biogas plant operators can ensure that digestate products reflect only background levels and risk of contamination during supply chains is minimized. As well, it is expected that trace organic contaminant levels in digestate and other organic fertilizer and soil amendment products will decline over time as more restrictions or prohibitions are placed on the production or use of trace organic contaminants.

Pathogens

Feedstocks will contain a diverse population of microorganisms varying in types and numbers based on the feedstock type and source. Feedstocks can accumulate microbial populations at all stages of the product lifecycle: production, processing, distribution, consumption and disposal. The microbial population will include organisms in the forms of bacteria, protozoa, viruses, helminths (parasitic worms e.g., tapeworms, nematodes), yeast and fungi, known to cause disease in humans, plants and animals.

Feedstocks that contain specific types of animal material are designated by the federal *Health of Animals Act and Regulations* as Specified Risk Materials (SRM) or Prohibited Materials. These feedstocks may contain an abnormal protein, called a prion, that is the agent responsible for transmitting Bovine Spongiform Encephalopathy (BSE), also known as mad cow disease.

Federal and provincial policies impose requirements on the production and use of products to be applied to agricultural land to reduce the risk of pathogen exposure to humans or livestock (refer to *Appendix E*). For biogas plants and other facilities producing organic fertilizer or soil amendment products, these requirements may include:

- use of processing operations known to inactivate pathogenic organisms;
- testing to ensure that numbers of pathogens or pathogen indicator organisms are below safe limits;
- waiting periods between product application and crop harvesting or grazing; and
- specific processing and permitting requirements for facilities receiving feedstocks containing SRM or Prohibited Materials.

Anaerobic digestion is a proven method of inactivating many pathogenic organisms. The degree of pathogen inactivation is dependent on the process temperature and residence time of the digestion process. At the higher temperatures of thermophilic digestion (> 50°C), greater pathogen inactivation is achieved compared to mesophilic digestion (37°C). Biogas plants that use mesophilic digestion can also include a process to pasteurize the feedstock materials or the digestate to achieve the required inactivation of most pathogen and pathogen indicator organisms. Other processes suitable for processing solid digestate are also capable of pathogen elimination including aerobic composting, alkaline hydrolysis, and alkaline stabilization.

Anaerobic digestion and pasteurization are not effective for the inactivation of the BSE prion. Biogas plants require additional processing operations approved by the Canadian Food Inspection Agency to process feedstocks containing SRM or Prohibited Materials.

The inactivation of pathogens to safe levels can be confirmed by:

- process monitoring, control and documentation at the biogas plant showing that the process time and temperature requirements of the pathogen inactivation process have been achieved; and
- by testing of digestate samples for the presence of pathogens and pathogen indicator organisms.

Digestate produced from a biogas plant that uses thermophilic digestion or that includes a pasteurization process will reliably contain numbers of pathogen and pathogen indicator organisms below the maximum acceptable levels set out in the *Fertilizers Regulations Trade Memorandum T-4-93 Safety Standards for Fertilizers and Supplements*, reproduced in Table 11, and is thereby considered safe for handling and application.

Table 11. Maximum Acceptable Level of Pathogen and Indicator Organisms in Fertilizers and Supplements

Organism	Level	Minimum detection limit
Salmonella	Not detectable	Less than 1 CFU (colony forming unit)/25 grams
Faecal Coliforms	1000 MPN (most probable number/gram solid)	Less than 2 CFU/gram

Some bacterial pathogens are known to be able to grow and reproduce in digestate and other organic fertilizers and soil amendments under certain conditions. Care must be taken by the biogas plant operator and by the digestate user to prevent contamination of the pathogen-inactivated digestate by contact with untreated materials or unclean equipment or facilities. Where contamination of the treated digestate is suspected, the waiting periods between application and crop harvesting or grazing set out in the *4Rs Principles of Nutrient Management for Digestate – Right Rate* section of this Guide should be followed to further minimize the risk of pathogen transmission.



Physical Contaminants

Feedstocks can contain physical contaminants, also referred to as foreign materials, in the form of visually identifiable items or pieces of metal, glass, ceramics, rigid or film plastic, rubber, textiles, or small manufactured items. Sources of physical contaminants in biogas plant feedstocks include:

- production processes, especially when the feedstock is a by-product of production;
- packaging materials;
- improper at-source separation, especially by generators of residential organics; and
- component of a solicited item for residential organics diversion programs.

Physical contaminants can be very low in agricultural or industrial feedstocks but can represent 10% - 20% by weight of feedstocks from commercial and residential sources.

If present in digestate and other organic fertilizers and soil amendment products, physical contaminants are a hazard for injury to humans and animals, a potential source of PTEs and TOCs and, by being visible, cause the product to appear 'contaminated' and not to be used. As well, film and other plastic physical contaminants present will break down over time to create microplastics, which are defined as plastic particles less than 5mm in the longest dimension.²³ Microplastics can enter the food chain with unknown consequences and are therefore a hazard for human and animal life.²⁴ In response, Canada has recently enacted Single-use Plastic Prohibition Regulations under the Canadian Environmental Protection Act to reduce the amount of macroplastics and microplastics that end up in the environment.

Provincial policies that regulate the application of organic fertilizer or soil amendment materials to agricultural land typically include limits on the types and amounts of physical contaminants present. For example, in Ontario the Nutrient Management Act and Regulation prohibits the application of a Non-Agricultural Source Material if:

- its content of glass, metallic objects, plastic and other foreign objects exceeds 2 per cent, calculated on a dry weight basis;
- its content of plastic exceeds 0.5 per cent, calculated on a dry weight basis; or
- it contains particles of any material that will not pass through a screen whose largest opening has an area of 2.5 square centimetres.

Biogas plants are designed with processing operations appropriate for the effective removal of the amount and forms of physical contaminants expected in the feedstock blend. Regular testing ensures that physical contaminants in digestate products remain below safe limits.

²³Weithmann, N, et al. 2018. Organic fertilizer as a vehicle for the entry of microplastic into the environment. Journal of Science Advances, 2018, Vol.4 No 4. <https://doi.org/10.1126/sciadv.aap8060>

²⁴Environment and Climate Change Canada. 2020. Science Assessment of Plastic Pollution. October 2020. Cat. No.:En14-424/2020E-PDF. <https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/science-assessment-plastic-pollution.html>

Part 4 – Best Management Practices for Using Digestate as Organic Fertilizer or Soil Amendment

Best management practices are proven, practical, and efficient approaches for maximizing the benefits of using digestate as an organic fertilizer or soil amendment while protecting human health and the environment.

The best management practices described in this section focus on the management of digestate from the time that it is produced at an industrial or on-farm biogas plant, through the transportation, handling, and storage steps of the supply chain, to the time that it is applied to agricultural fields as an fertilizer or soil amendment. Guidance for the production of digestate is provided in Section 6.2 of the [Canadian Anaerobic Digestion Guideline](#).

The approaches described in this Guide complement established best practices for managing manure and other organic fertilizers and amendments. Digestate users should be familiar with best management practices applicable to their geographic area. Provincial agriculture ministries and agricultural organizations provide extensive information on best management practices for manure and other organic fertilizers. Please refer to the Resources identified in *Appendix A – Resources and References* of this Guide.

Delivery and Receipt

When farmers and growers receive digestate from an industrial biogas plant or an on-farm biogas plant separate from their farm operation, it is recommended that they follow the practices set out in this section to ensure that the quality of the digestate received satisfies end use targets, safety requirements, and the steps for safe storage and use are understood.

General good practice for digestate users:

- Get to know suppliers and their product, visit the biogas plants to see the process.
- Speak to other farmers and growers about their experience of using the product and any long-term benefits such as improved yields and reduced consumption of fossil fertilizers. If you don't know anyone who has used the products, ask your supplier to put you in touch with other customers.
- Confirm with the supplier whether the digestate is to be supplied as a CFIA registered fertilizer product and whether additional local regulatory requirements apply to the management of the digestate. Users, supported by the digestate supplier, should familiarize themselves with applicable regulatory requirements and are referred to *Appendix A* of this Guide for more information.
- Obtain from the supplier complete, current, and accurate delivery documentation describing the product and verifying its quality. Delivery documentation is described in the following section.
- Try to be in the field when the first loads arrive to ensure that you are happy with the quality as supplied.
- If quality does not meet requirements, users can and should reject the material before it is deposited in storage or applied to land.

Digestate that is stored before application should, if possible, be kept separate from manure and from other stored organic fertilizers or amendments to avoid creating a material with unknown characteristics. Digestate users should also be aware that adding a CFIA-registered fertilizer product to other fertilizers or amendments to which regulatory requirements apply will typically result in the digestate product also becoming a regulated material.

Delivery Documentation

The biogas plant operator should provide information to the farmer and to the party responsible for managing the application identifying the product and its origin and its characteristics, and giving instructions for the safe and effective use of the product.

The delivery documentation recommendations included in this section are intended to be complementary to regulatory documentation requirements. Labelling requirements for CFIA registered fertilizer products are set out in *Trade Memorandum T-4*, under the *Fertilizers Regulations*.

Delivery documentation provided to the farmer and to the party responsible for managing the application could include:

- **Producer information:** biogas plant name, location, contact information for owner and/or lead operator.
- **Feedstock information:** main input materials by category, such as manure, agricultural waste, source separated organics, etc.
- **Product information:** name, and for CFIA registered fertilizer products includes fertilizer registration documentation and Guaranteed Analysis
- **Use instructions:** directions for storage, directions for use, precautions necessary to mitigate risk of harm to human, animal, or plant health
- **Delivery information:** quantity delivered, date of delivery, identification of the production lot, batch number, or production interval
- **Product analysis:** current, complete, and accurate quantitative analysis results which are representative of the digestate delivered and expressed in a user-friendly format clearly and consistently presented, see *Appendix D* for sample tables of how the analysis could be represented

Note that the Guaranteed Analysis set out in a CFIA fertilizer product registration, which specifies only the minimum NPK content, is not an adequate substitute for product analysis information since the nutrient content of the digestate may be significantly higher than the guaranteed minimum and may change over the period during which the digestate is supplied.

- **Quality validation:** confirmation by the producer that the digestate conforms to end use and safety quality requirements

Note that the characteristics of digestate in storage will change over time and may be significantly different during application than when first added to storage. Analysis of stored digestate at the time of application is required to provide the accurate information needed for crop nutrient management.

Also, digestate that has been treated by pasteurization or other approved process to reduce pathogens may be contaminated by contact with untreated manure or other fecal materials, e. g. from birds, rodents, etc., or vessels or equipment which have not been cleaned. If contamination has occurred, the pathogen status of the digestate at the time of testing will no longer be valid.

Storage

Canadian biogas plants typically produce digestate year-round. However, digestate can only be applied to fields at specific times outside of seasonal restrictions (i.e., no spreading when soil is frozen or snow covered) and should only be applied when crops will utilize the nutrients, when waiting periods can be achieved, and when crop damage can be limited. See the *4Rs of Nutrient Stewardship for Digestate* section of this Guide for more information on the timing of digestate application. Providing buffer capacity to store digestate for extended periods is therefore recommended.

Capacity

Digestate storage capacity requirements may be specified in regulations, government guidelines, or in a biogas plant's operating permit. Ontario's Nutrient Management Regulation²⁵ requires that on-farm biogas plants have storage capacity for a minimum of 240 days of digestate production. Greater storage capacity, up to 275 days (approximately 9 months), may be needed if opportunities for fall application are limited. Additional storage capacity will provide operational flexibility needed to adapt to uncooperative weather.

Industrial biogas plants have several options to secure sufficient storage capacity:

- permanent storage facilities located at the biogas plant;
- permanent facilities located separate from the biogas plant but not located on farms (permanent off-farm); and
- permanent or temporary storage at the farms utilizing the digestate.

Reliance on storage capacity not under the control of the industrial biogas plant operator may introduce risk necessitating additional contingency capacity. The total volume of the secured storage should provide the required capacity plus contingency. On-farm biogas plants will typically have permanent storage facilities located on the farm.



²⁵ Ontario Regulation 267/03 General under the *Nutrient Management Act, 2002*

Siting and Construction

Different types of structures can be used as permanent facilities for digestate storage including lined steel tanks, reinforced concrete tanks, lined earthen lagoons, and plastic bags usually supported within earthen berms. Storage facilities can be new, purpose-built structures, or can, subject to confirmation of suitability, be repurposed existing manure storage structures.

New and existing structures intended for digestate storage are subject to regulatory requirements to ensure proper siting and safe containment of the stored material. Requirements for storage structures are specific to their provincial and municipal jurisdictions and are not repeated in this Guide.

Siting, design, and operating requirements for digestate storage facilities at industrial biogas plants or at permanent off-farm locations, or permanent on-farm facilities receiving digestate from industrial biogas plants, are defined by applicable planning and environmental regulations and site-specific permits (refer to [Canadian Anaerobic Digestion Guideline](#)). Proponents should engage qualified persons in the facilities' planning, design and construction phases.

Regulations applicable to farm operations may provide an approval pathway for storage facilities located with an on-farm biogas plant and receiving digestate only from the on-farm biogas plant. Siting, design, and operating requirements for these facilities often are similar to requirements for livestock manure storage and are therefore not covered in this Guide. Operators of on-farm biogas plants intending to construct new or repurpose existing on-farm storage should consult with their local agriculture ministry representative to confirm requirements and suitability.

Minimizing Methane and Ammonia Emissions from Stored Digestate

At the time of writing this Guide (March 2023), Agriculture and Agri-Food Canada had released the discussion document, *'Reducing emissions arising from the application of fertilizer in Canada's agricultural sector'*²⁶ which proposes targets and describes approaches for significantly reducing absolute levels of GHG emissions from fertilizer use in agriculture. The Document states that the practice of replacing synthetic fertilizers with manures, compost, or digestate has the potential to reduce emissions by 10-20%.

Best management practices for reducing NH_3 and CH_4 emissions from storage locations support an expanded role for digestate in reducing GHG emissions from agriculture. Reducing NH_3 emissions retains valuable crop nutrients, thereby increasing the quantity of synthetic fertilizer which can be replaced, while also reducing contributions to atmospheric and surface water pollution. Since both NH_3 and CH_4 emissions contribute to atmospheric greenhouse gases, indirectly and directly respectively, their reduction should be a priority for digestate management.

Emissions of NH_3 , CH_4 and other volatile compounds such as H_2S and volatile fatty acids, result from diffusion driven by concentration gradients across the liquid – gas interface at the surface and across the depth of the stored digestate. Emissions increase with surface area, quantity of the volatile compound, temperature, and turbulent air to keep surface concentrations low. Emissions can also 'spike' while the stored material is agitated prior to application. Methane and H_2S in gas bubbles aggregating in manure and digestate lagoons can contribute to an abrupt release and present a health and safety hazard for operators.

The sections below illustrate why storage emissions are important to understand, followed by best management practices that are employed to minimize atmospheric emissions of NH_3 and CH_4 .

²⁶ <https://agriculture.canada.ca/en/about-our-department/transparency-and-corporate-reporting/public-opinion-research-and-consultations/share-ideas-fertilizer-emissions-reduction-target/discussion-document-reducing-emissions-arising-application-fertilizer-canadas-agriculture-sector>

Ammonia Emissions

Stored liquid digestate has the potential to release a significant quantity of NH_3 gas to the atmosphere over time because:

- most of the nitrogen in digestate is in the form of TAN;
- at the typical digestate pH some of the TAN is in the form of volatile NH_3 ;
- digestate, having been heated during anaerobic digestion, is warm which reduces the solubility of NH_3 , promoting volatilization; and
- whole digestate from low-fibre feedstocks and liquid digestate form little to no natural crust in storage (see the next section).

In addition to representing a loss of valuable crop nutrients, NH_3 emissions form particulates (ammonium nitrate (NH_4NO_3) and ammonium sulphate ($(\text{NH}_4)_2\text{SO}_4$)) which impair human health and cause negative environmental impacts. This is due to the re-deposition of volatilized NH_3 which contributes to the eutrophication and acidification of water bodies and the generation of the greenhouse gas N_2O via the biological nitrification of ammonium (NH_4) and subsequent denitrification of nitrate (NO_3).

NH_3 emissions from liquid manure storage have been extensively studied and reported²⁷ and baseline emission factors (for uncovered storage of untreated manure) are available²⁸. These studies are referenced to demonstrate this research exists, but the Canadian Biogas Association is not endorsing these values. The IPCC also provides default values for nitrogen loss due to volatilization on NH_3 and NO_x from manure management in their 2006 IPCC Guideline for National GHG Inventories, Agricultural Forestry and Other Land Use, Chapter 10 Emissions from Livestock and Manure Management. This includes defaults for anaerobic lagoons and pit storage.

Few studies report NH_3 emissions from digestate storage at farm scale and more investigation is required. Reported emission factors suggest that digestate can lose a significant portion of its TAN if stored for an extended period during warm weather, as illustrated in the following example.

Example: Estimation of NH_3 Emission Loss from Digestate Storage

Two digestate storage structures are each filled to capacity with 5,000 m^3 of digestate. The digestate has an initial TAN concentration of 3 g N/L for a total quantity of TAN of 15 tonne. The storage period is May 1 to August 31 for a total of 123 days. Reported emission factors for this spring-summer period range from approximately 15 to 25 g m^{-2} d^{-1} with the higher rate corresponding to low Dry Matter digestate which does not form a natural crust²⁹. Storage details and estimated emission losses are presented in *Table 12*.

²⁷ See Kupper, T, et al. 2020. Ammonia and greenhouse gas emissions from slurry storage – A review. Agriculture, Ecosystems & Environment, Volume 300, 2020.

²⁸ See EEA, 2019. EMEP/EEA Air Pollutant Emissions Inventory Guidebook 2019. Technical Guidance to Prepare National Emission Inventories. European Environment Agency

²⁹ Emission factors taken from Baldé, H, et al. 2018. Ammonia emissions from liquid manure storages are affected by anaerobic digestion and solid-liquid separation. Agricultural and Forest Meteorology, Volume 258, 2018, Pages 80-88.

Table 12. Estimated Ammonia Loss from Stored Digestate

Storage Details		NH ₃ Loss (tonne)	NH ₃ Loss (% TAN)
Circular Concrete Tank	Diameter 42 m	2.6 – 4.4	17 – 29
	Depth 3.5 m		
	Surface Area 1,429 m ²		
Rectangular Earthen Lagoon	Top Length 55.5 m	3.8 - 6.3	25 – 42
	Top Width 37 m		
	Depth 3 m		
	Side slope 1:2		
	Surface Area 2054 m ²		

Ammonia emissions from stored liquid digestate can be reduced by:

- minimizing the surface area;
- use of impermeable or permeable covers (see next section);
- reduce storage temperature by using outdoor below-grade storage structures and shadowing of storage structures;
- reducing air velocity on storage surface by providing a sufficiently high freeboard and by planting a tree shelterbelt; and
- reducing the pH to reduce the amount of TAN in the volatile NH₃ form (referred to as ‘acidification’, see next section).

Since digestate storage and application are sequential activities, the measures to reduce NH₃ emissions during storage should be followed by measures to minimize NH₃ emissions at application to ensure the storage NH₃ savings are not lost. The following sections of this Guide recommend best management practices to reduce NH₃ emissions during land application.



Methane Emissions

Anaerobic digestion is a proven approach for reducing atmospheric emissions of methane from the management of manure and other organic waste materials. Emissions from digestate will be highly variable from plant to plant. Practically, this is often addressed with a secondary storage tank prior to discharge into a lagoon or digestate tank to capture emissions still contained within the digestate. There are less volatile solids remaining in digestate compared to undigested materials. Therefore, the potential to generate CH_4 while in storage, where anaerobic digestion occurs naturally, is reduced.

However, CH_4 emissions from digestate storage can still represent the greatest proportion of the direct GHG emissions from biogas plant operations with studies reporting CH_4 emissions from open storage of digestate, without measures to reduce emissions, as frequently being up to 10% of total biomethane production and higher rates in the range of 20% are reported³⁰. Therefore, reducing atmospheric CH_4 emissions from digestate storage has the potential to increase the overall environmental benefit of biogas plants and to reduce the carbon intensity assigned to biogas which could result in an increased value as a renewable, low-carbon fuel.

Methane emissions from stored liquid digestate can be reduced by:

- minimizing the surface area of the storage facility;
- minimizing the quantity of volatile solids in the digestate which can be achieved by:
 - maximizing volatile solids destruction during anaerobic digestion, e.g., by feedstock pre-treatment, by increasing retention time within the digester or by operating at a higher temperature, i.e., thermophilic vs mesophilic;
 - conditioning the digestate by liquid-solid separation, however there might be increased potential for NH_3 emissions since the separated liquid likely will not form a natural crust (see Storage Covers below);
- reduce storage temperature by using outdoor below-grade storage structures and shadowing of storage structures;
- use of permeable covers to mitigate direct release of emissions (see next sections);
- use of impermeable covers (see next sections) to contain and collect biogas with subsequent treatment to destroy methane;
- reducing pH of stored digestate to inhibit further anaerobic digestion (referred to as 'acidification', see next sections).

Digestate storage emits other greenhouse gases such as N_2O and CO_2 , however, they are not targets of these best management practices. The conditions of digestate storage are not typically favourable to N_2O production and therefore the contribution of N_2O to total greenhouse gas emissions is low, despite having a higher 100-year Global Warming Potential than CH_4 (298 for N_2O vs 34 for CH_4 , over a 100-year period³¹), and typically reported as < 5% of CH_4 on an equivalent CO_2 basis. As well, CO_2 emissions are typically ignored since they are considered to make no net contribution to atmospheric greenhouse gas concentration.

³⁰ Bakkaloglu, S, et al. 2022. Methane emissions along biomethane and biogas supply chains are underestimated. One Earth, Volume 5, Issue 6, Pages 724-736

³¹ IPCC 2007. Assessment Report 4 Climate Change 2007: Impacts, Adaptation, and Vulnerability. <https://www.ipcc.ch/report/ar4/wg2/>

Minimize Surface Area

Minimizing the surface area of the digestate storage structure(s) required to provide the necessary storage capacity can be achieved by:

- use of vertical walled storage structures, e.g., concrete tanks, instead of earthen lagoons which require sloped sides for stability; and
- using the greatest storage depth practicable considering agitation, emptying and cleanout and other operational requirements.

Storage Covers

Use of suitable, properly constructed, and well-maintained covers can significantly reduce atmospheric emissions from stored liquid digestate compared to uncovered storage. Emissions reduction relies on several mechanisms³²:

- the covering layer reduces the diffusion of gases from the liquid phase by forming a physical barrier or by creating a substrate that can biologically or chemically bind the gases;
- the covering layer can limit the turbulent transport in the liquid layer by reducing wind exposure and heat loss from the surface layer;
- the covering layer can limit the transport of gases in bubbles, as the surface layer can break or stop the bubbles, so that the gases are “forced” to be transported by diffusion through the boundary layer.

The effectiveness of these mechanisms can depend on the type of storage cover. Cover options for liquid digestate storage are as for liquid manure and are typically categorized as impermeable or permeable. Cover options and their suitability and effectiveness in reducing emissions of CH_4 and NH_3 are described below and in *Table 13*.

Impermeable Covers

Impermeable covers create a complete barrier to the transfer of gas and liquids. Impermeable cover options include rigid covers, such as steel or reinforced concrete roofs, and flexible covers which are typically a film layer of high-density polyethylene (HDPE) or polyvinyl chloride (PVC) in supported, inflated or floating configurations. Impermeable covers can be either completely gas tight or allow a small leakage area around the perimeter of the holding tank.

The use of floating covers on lagoons can present operational challenges related to the need to agitate accumulated digestate in advance of application. The operational challenges will be unique to the type of cover installed. This issue will need to be addressed in the plan to manage any such installation.

In Canada, floating lagoon covers are used across the country in anaerobic wastewater treatment applications. Managing rain and snow on the top of a floating cover is an important aspect of the cover design.

Gases released from the stored digestate, including biogas, are contained within the cover and need to be collected and managed. NH_3 emissions are significantly reduced using impermeable covers. Collecting the biogas creates an opportunity to significantly reduce CH_4 emissions by destroying the collected biogas either biologically or by combustion.

Impermeable covers divert precipitation allowing for digestate storage volume savings and can usually remain in place to reduce emissions during agitation.

³² VanderZaag, A, et al. 2008. Floating covers to reduce gas emissions from liquid manure storages: a review. *Applied Engineering in Agriculture*. 24(5): 657-671.

Permeable Covers

Permeable covers may be a natural floating layer, formed by gas bubbles giving buoyancy to dry matter in the digestate, or may be a constructed porous layer of particulate, blown straw, woven, or other constructed material (e.g., straw covers, floating hex covers, geotextile cover, floating cover, circus style tent, clay balls such as lightweight expanded clay aggregate (LECA), etc.). Permeable covers resist mass transfer from liquid to air and in some cases can also act as a biofilter by supporting the growth of microorganisms that convert undesirable gases to more innocuous forms. Options for constructed permeable covers are the use of natural or synthetic media alone, or in combination.

Permeable covers have a highly variable effectiveness for reducing NH_3 , CH_4 , and odour emissions. The effect is highly dependent on type of cover used. Little data exists in literature or industry to comment definitively.

Depending on the selection of media, permeable covers can be relatively inexpensive to construct however they may need to be wholly or partially replaced after each agitation. Other disadvantages of permeable covers are that they allow precipitation to enter and may allow NH_3 and odour emissions during agitation.



Table 13. The Suitability and Emission Reduction Effectiveness of Cover Options for Liquid Digestate Storage³³

Cover Option		Typical Construction	Suitability	Reported Storage Emissions Reduction ¹	
				CH ₄	NH ₃
Impermeable	Rigid	Concrete or steel roof	Suitable for tanks and silos	None, unless biogas methane destroyed	80
	Flexible	Supported, e.g., tent structure	Suitable for tanks and silos		80
		Inflated, e.g., pressurized air dome	Suitable for tanks and silos		60 – 80
		Floating, e.g., two film layers with polystyrene floats	Suitable for all storage structure types. May need system to collect and remove precipitation.		60
Permeable	Constructed	Typical materials include chopped straw or cornstalk, woodchips, lightweight expanded clay aggregates (LECA), expanded volcanic glass aggregates (perlite). Biochar has also been identified as a potential cover material.	Suitable for all storage structure types but may be difficult to construct on large lagoons. Materials with limited buoyancy (straw, cornstalk) may not be suitable for digestate that does not form a natural crust due to sinking and may be susceptible to wind and rain damage. Effectiveness depends on material and thickness. Thicknesses of 10 – 30 cm for straw, cornstalk, woodchips and 5 – 15 cm for expanded clay are reported. Covers made of organic materials will degrade and lose their effectiveness after 6 to 8 months and will need to be replaced. Addition of organic matter to digestate may increase CH ₄ emissions.	None. Potentially increased if organic material added as a cover.	40 – 80
	Synthetic	Geotextile, floating geometrical plastic bodies	May not be suitable for digestate that forms a natural crust	None	

Notes

- Based on liquid manure storage. Estimated reductions are relative to emissions from uncovered storage.

³³ Adopted from: Lupis, S, et al. 2012. Best management practices for reducing ammonia emissions: Lagoon covers. Colorado State University Extension Fact Sheet No. 1.631B; United Nations Economic Commission for Europe. 2015. (UNECE 2015) Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions (2015); University of Minnesota Extension (2018) Covers for Manure Storage; Santonja, G, et al. 2017. Best Available Techniques (BAT) reference document for the intensive rearing of poultry or pigs : Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control), European Commission, Joint Research Centre, Publications Office, 2017.

Figure 9: Example of Impermeable Flexible Supported Cover³⁴

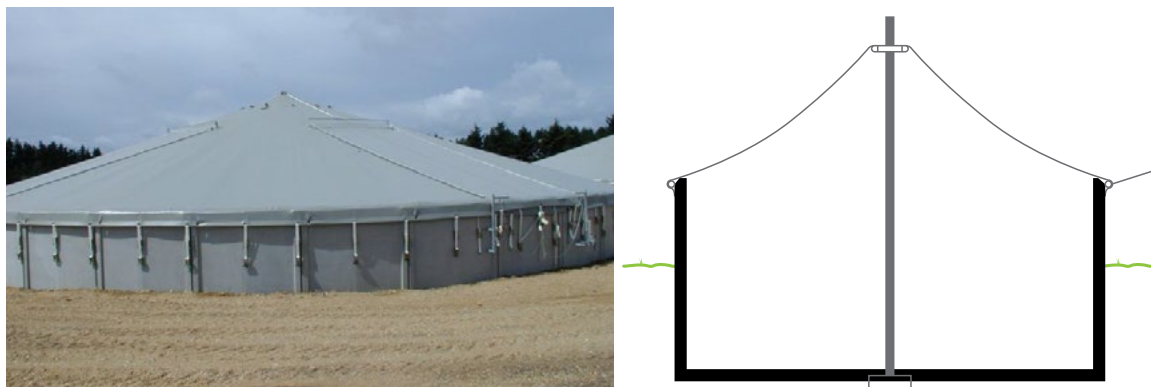


Figure 10: Example of Impermeable Rigid Cover³⁵

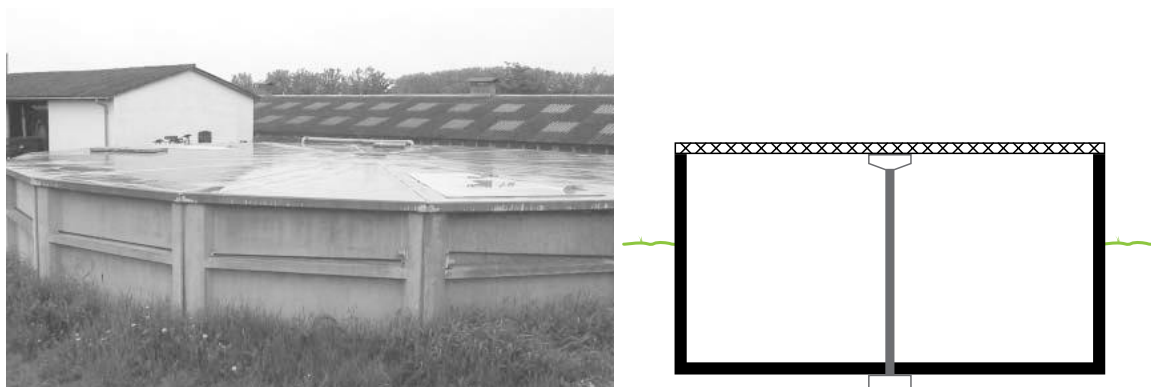
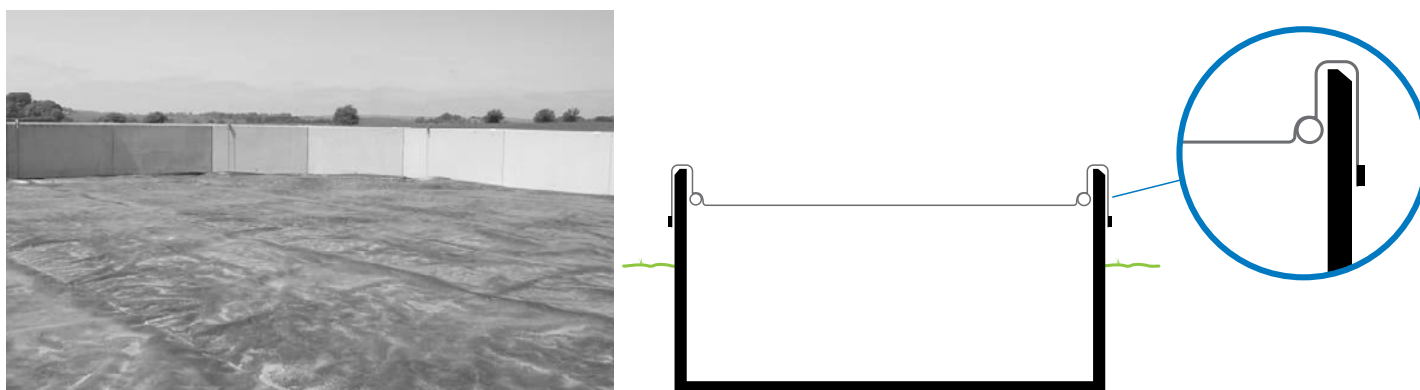


Figure 11: Example of Flexible Impermeable Floating Cover³⁶



³⁴ Images from Danish EPA. 2014. Report on the effect of cover of storage facilities for manure.

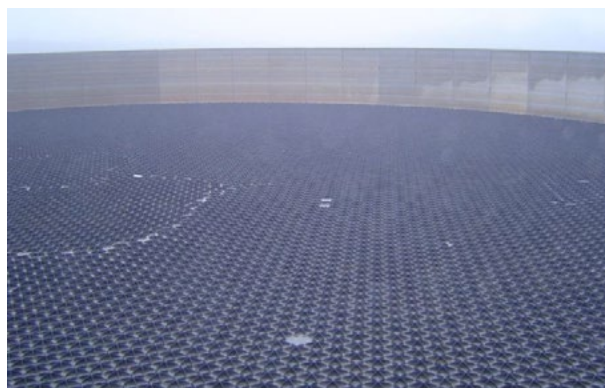
³⁵ Ibid.

³⁶ Ibid.

Figure 12:
Example of Permeable Constructed Cover³⁷



Figure 13:
Example of Permeable Synthetic Floating Cover



Acidification

Several Scandinavian and European countries have adopted acidification as a best management practice for reducing NH_3 emissions from manure management. In these jurisdictions, acidification is considered to be equivalent to or more effective than storage covers and as effective as injection for NH_3 emission reduction. Acidification can also significantly reduce CH_4 emissions which is difficult to achieve by other means, for example using impermeable covers. Experience with acidification of digestate is limited, however reports indicate that similar emissions reductions can be achieved albeit at significantly greater cost compared to manure.

Acidification of manure or digestate is yet to be adopted in North America due to the cost and the absence of supportive policies or incentives, however it may be reasonable to expect these barriers to be reduced over time. As well, more research and demonstration will be required to develop techniques appropriate for local conditions. This Guide does not present acidification as an existing best management practice but rather as a promising opportunity to increase the overall benefit and value of digestate as a renewable organic fertilizer.

As applied to manure or digestate, reducing NH_3 emissions by acidification involves treating the material with additives to lower pH to a target point at which very little TAN is present as volatile NH_3 . Lowering the pH also inhibits the biological pathways of anaerobic digestion (acidogenesis, acetogenesis, methanogenesis) slowing the production of biogas CH_4 .

Sulphuric acid (H_2SO_4) is the most extensively investigated and used additive for the reasons of cost, effectiveness, relative ease of use and the nutrient benefit of the added sulphate (SO_4). Other amendments, including inorganic acids such as nitric (HNO_3) and hydrochloric (HCl) acids, organic acids such as acetic and lactic acids, chemicals such as alum, ferric and aluminum chloride and natural compounds such as saccharose and glucose, have also been investigated. Important considerations for additive selection include price and availability, requirements for safe handling and use and impact on other digestate quality characteristics.

³⁷ Ibid.

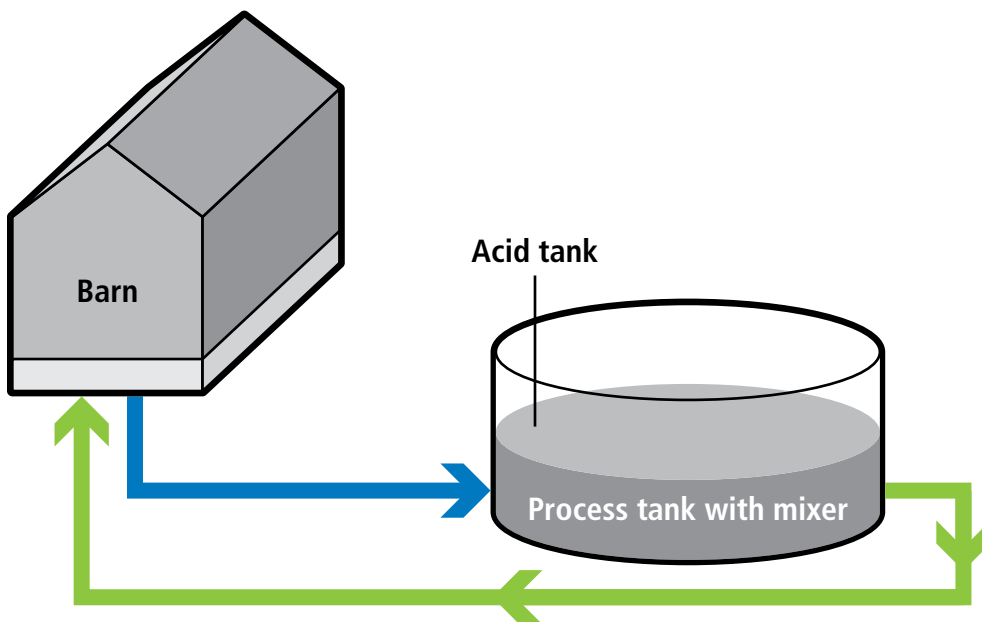
Acidification Techniques

Three techniques have been developed for effective acidification: in-house, in-storage and field application.

In-house

This technique involves the acidification of liquid manure as it is removed from the barn and before it is sent to storage. While this technique does not involve digestate directly, it is mentioned here because acidification may affect the biogas production potential of the manure. Acidification with H_2SO_4 has been reported to reduce biogas production likely due to inhibition of the anaerobic digestion process resulting from the addition of sulphate. Co-digestion of acidified and non-acidified manure however, has been reported to increase biogas production. Other additives may also impact the biogas production potential of the treated manure.

Figure 14: In-House Acidification³⁸

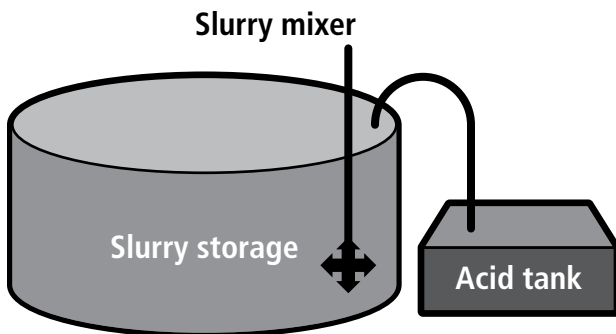


In-storage

The technique of in-storage acidification adds the additive to the storage tank or lagoon until the desired pH endpoint is achieved. Reducing the pH will have the immediate and short-term effect of increasing emissions of H_2S , CO_2 and VFAs as added H^+ moves existing sulphide, carbonate and VFAs into volatile forms. H_2S is dangerous and precautions to minimize human exposure are required. CO_2 and other gases trapped at the surface of the digestate may cause foaming and therefore vigorous mixing is required to control foaming and to ensure homogenization of the treated digestate.

³⁸Figure from Kavanagh, I, et al. 2019. Mitigation of ammonia and greenhouse gas emissions from stored cattle slurry using acidifiers and chemical amendments. Journal of Cleaner Production, Volume 237, 2019.

Figure 15: In-Storage Acidification³⁹



The quantity of additive needed depends on the target pH, the strength of the additive and on the digestate quantity, pH and capacity to buffer pH changes which is created by a complex system of NH_4 , carbonates, phosphates and volatile fatty acids. Due to the chemical complexity of digestate, laboratory titration methods are required to estimate the correct additive dosage and some trial and error is required to confirm the correct dosage during treatment.

While in storage, the pH of the treated digestate will gradually increase due to the effects of pH buffering and ongoing chemical (e.g., hydrolysis of organic compounds including hemicellulose, cellulose and volatile fatty acids, dissolution of carbonates) and microbial (e.g., conversion of organic N to TAN) processes. The rate at which the pH increases, and therefore the period during which the lower pH is effectively reducing emissions, has been found to depend on the additive used (with strong inorganic acids, e.g., H_2SO_4 and HNO_3 , have a longer lasting effect than organic acids, e.g., lactic or acetic) and is reduced by higher dry matter contents and temperatures above 15°C .

In-storage acidification in the spring to a pH endpoint of < 5.5 is reported to effectively reduce NH_3 and CH_4 emissions for a significant portion of the spring and summer. Effective NH_3 and CH_4 emissions reductions compared to untreated digestate of up to 80% and 90% respectively, over periods ranging from 90 to up to 120 days, are reported. Additive dosages required to achieve this pH endpoint are reported ranging from approximately 6 to 14 kg of 95% H_2SO_4 per tonne of treated digestate.

Acidification in this manner is not reported to negatively affect natural crust formation and is an effective alternative to storage covers. Re-acidification may be required if time, or the addition of more digestate to storage, has resulted in a significant pH increase over the treatment endpoint. Maintaining reduced pH level over the winter is not required as NH_3 and CH_4 emissions are significantly reduced by cold temperatures.

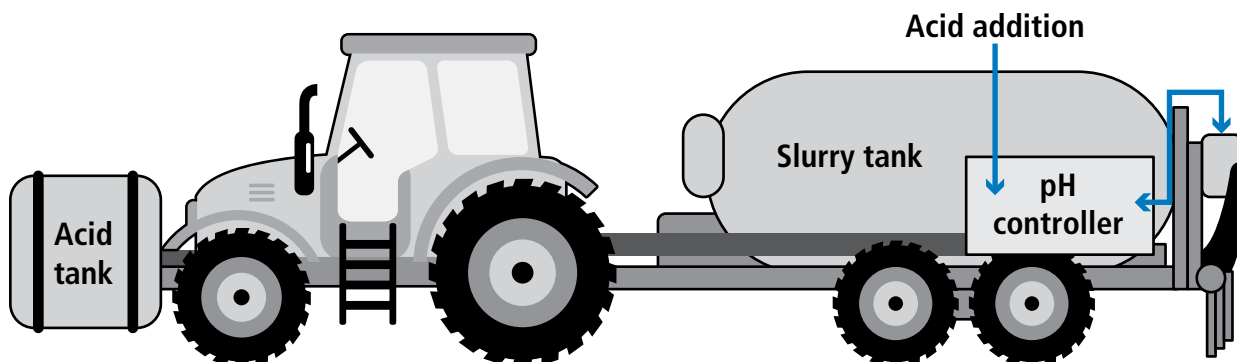
In-storage acidification can also be employed to reduce NH_3 emissions by up to 70% following field application compared to untreated digestate. A target pH of < 6.5 is recommended at the time of application which can either result from a previous treatment, as described above, or be achieved by acidification to a pH endpoint of < 6.5 within 30 days of application.

Field Application

The additive is added in the field as the digestate is being applied, usually via a static mixer at the output of the tanker. The reported pH endpoint and emissions reduction are similar to that of in-storage acidification prior to application. Additive dosages required to achieve this pH endpoint are reported ranging from approximately 3 to 11 kg of 95% H_2SO_4 per tonne of treated digestate.

³⁹ Ibid.

Figure 16: Acidification During Field Application⁴⁰



Effects of acidification on other characteristics of digestate important for its use as an organic fertilizer or soil amendment are summarized below.

Increased nutrient content	More retained TAN compared to untreated digestate. Additional nutrients supplied with additive e.g., sulphate from H_2SO_4 addition. Acidification has overall benefit of making nutrient management of Digestate as organic fertilizer more predictable since NH_3 losses are significantly reduced.
Increased mineral fertilizer equivalent value	In addition to retained TAN, reducing the pH may cause dissolution of some precipitates, e.g., struvite, which could increase the fertilizer equivalence value by making some nutrients, e.g., phosphorus, more available.
Increased organic material content and degradability	The lower pH accelerates the hydrolysis of organic material into soluble forms however the biological conversion of organic material to biogas is slowed.
Pathogens	Acidification is not reported to consistently achieve significant reductions of pathogens or pathogen indicators.
Leaching	Nutrients and PTEs which become more soluble through acidification are at greater risk of leaching.
Effect on Application Timing and Method	Since nutrients can be move available in acidified digestate, its more important to schedule application at times of high crop nutrient demand. Acidification be used as an NH_3 emission reduction alternative when injection is not practicable or when the efficiency of surface application is required but immediate incorporation is not possible. Acidified slurry is appropriate to be used in fields with growing plants where tillage is not possible.
Effect on Soil	The lower pH of acidified digestate does not affect soil pH more significantly than other fertilization practices. Acidified digestate has pH similar to manure or rainwater which have pH values in the range of 5.5.- 5.7. The soil impacts of the acidification additive need to be considered. For example, if H_2SO_4 is used the application of sulfur in excess of crop requirements needs to be managed to avoid reducing soil pH, particularly in low pH or low buffer capacity soils.
Effect on Yield	It is reported that the use of acidified slurry resulted in similar or higher yields compared to untreated slurry but the yield difference was not statistically significant. No damages to the crops are noted and the growth of plants as well as the yield and quality formation was reported as normal.

⁴⁰ Ibid.

Storage of Solid Digestate

At present, there are few options for reducing NH_3 emissions from stored solid digestate. Clear best-practice guidelines nevertheless apply. Management guidelines for limiting NH_3 emissions are as follows:

- storing under a roof or covering with a plastic sheet preferably on a concrete base, the use of plastic sheeting has been shown to reduce NH_3 emissions substantially without significantly increasing CH_4 or N_2O emissions.
- make the surface area of the stack as small as possible (e.g., by constructing walls to increase the height); and
- keep solid digestate as dry as possible.



Part 5 – 4R Principles of Nutrient Stewardship for Digestate

Best management practices for applying digestate to agricultural fields should be based on the 4Rs of Nutrient Stewardship approach:

- Right Rate,
- Right Time,
- Right Place, and
- Right Method.

The 4Rs are most impactful when applied as a whole and not as separable parts and must consider the specific conditions of each field intended to receive digestate application. As well, the 4Rs approach should consider whether the characteristics of the digestate are suitable for use as an organic fertilizer or an organic soil amendment.

Digestate utilization is maximized when:

- There are opportunities to apply at various times in the seasons to various crops in a diverse crop rotation
- Applied as close to crop needs as possible
 - Injected or incorporated as quickly as possible or applied into a standing crop canopy
 - Weather conditions co-operate



Digestate that will supply nutrients for growing crops when applied, as indicated by a high proportion of nutrients in plant-available forms and low C:N ratio (less than 10), is suitable for use as an organic fertilizer. As an organic fertilizer, digestate will supply NPK in forms comparable in availability to mineral NPK fertilizers, and will also supply secondary and trace nutrients, not normally present in mineral NPK fertilizers such as trace concentrations of heavy metals.

Solid and liquid digestates are typically used as organic fertilizers and can be applied pre-planting and during the growing season as a side-dress application, or post-harvest ahead of seeding a winter cereal crop or cover crop. Solid digestate with similar characteristics can also be used as an organic fertilizer. However, some solid digestate is more suitable for use as an organic soil conditioner. The 4Rs approach ensures that digestate nutrients are used efficiently and losses are minimized such that a high degree of equivalence with N-P-K supplied by mineral fertilizers, referred to as *Mineral Fertilizer Equivalence*, can be achieved.

In general, long-term application of mineral NPK fertilizers without any organic matter input will lead to a reduction of soil organic matter and diminished soil quality. Digestate can be an effective tool to replenish soil organic matter indirectly, as a fertilizer for crops or cover crops, or directly as an organic soil amendment.

Digestate with a high C:N ratio (greater than 20) and organic matter content will release nutrients and replenish soil organic matter over time and is more suitable for use as organic soil conditioner to improve soil structure, fertility and biological health and diversity. Solid digestate, particularly if produced from high fibre feedstocks, is typically used as an organic soil conditioner. Similar to manure, it would typically be applied prior to planting in the spring or after harvest and before planting of a cereal or cover crop. The 4Rs approach ensures that digestate organic matter and slow-release nutrients can be incorporated into a crop rotation to achieve significant soil benefits without over fertilization.

Adopting a 4Rs approach will ensure that the user maximizes the economic, crop productivity and soil health benefits of digestate while protecting health and the environment.

Benefits of 4Rs management of digestate use:

- reduces mineral fertilizer requirements;
- maintains or improves crop yield and quality and in good growing conditions can significantly increase crop biomass (roots and top growth);
- replenishes soil organic matter improving structure, fertility and biological health and diversity; and
- protects health and the environment by minimizing impacts to the air, ground and surface water.

Application of the 4Rs principles as described in this section is intended to inform and complement but not supersede or replace requirements set out in established policies, or the advice of certified crop advisors or other competent persons with respect to specific applications of digestate products.

Right Rate

What is Right Rate for Applying Digestate as an Organic Fertilizer?

Right rate is matching the quantity of digestate nutrients applied to crop needs, whether using digestate alone or in combination with other nutrient sources, and using digestate nutrients efficiently. Crop nutrient needs vary over the growing season and depend on soil fertility. Using digestate nutrients efficiently means maximizing the proportion of the applied available nutrients taken up by crops in the current growing season and also over a multi-year crop rotation cycle and minimizing loss of nutrients to the environment through evaporation and GHG emissions, leaching and runoff. Nutrient loss leads to under fertilization or increased need for mineral fertilizer and to environmental problems including increased atmospheric greenhouse gases and ground and surface water pollution.

Practical steps in aid of determining the Right Rate for a specific application of digestate as an organic fertilizer or soil amendment are described below.

Step 1: Plan to incorporate digestate for crop nutrients or soil benefits

Planning to incorporate digestate as a nutrient source or as a soil amendment in a multi-year crop rotation is the best approach for achieving efficient use of digestate nutrients and should consider:

- The characteristics of the available digestate products and their suitability as organic fertilizers or organic soil amendments.
- Matching the supply of available TAN to the needs of a growing crop. For side-dress applications, crop needs can be informed by a Pre-sidedress Nitrate Test (PSNT). For fall applied digestate, supplied TAN could be taken up by the needs of a growing cover crop.
- Matching the supply of P and K to crop removal over the crop rotation cycle. Use regular soil tests to monitor soil fertility.
- Where digestate organic fertilizer and soil amendment products are available, consider split applications e.g., fall soil conditioner followed by side-dress fertilizer application the following growing season.
- Complementing digestate nutrients with other nutrient sources if possible. When applying digestate organic fertilizer to supply nitrogen to a growing crop e.g., corn or wheat, apply digestate to supply no more than $\frac{1}{2}$ to $\frac{3}{4}$ of the crop nitrogen requirement and supplement the remaining portion with mineral fertilizer (i.e., starter, side-dress, etc.)
- Allow for nutrients supplied by previous applications of digestate or other organic fertilizer or soil amendments.
- Keeping records of digestate use, similar to fertilizer and manure use will help document benefits and fine-tune management.

Step 2: Use current and accurate information on digestate nutrient concentrations at the time of application

The nutrient content of digestate is affected by many factors such as feedstock changes and biogas plant operations and storage conditions, and can change over time. Accurate information on the digestate nutrient concentration at the time of application is important for determining the Right Rate. Sources of nutrient concentration information include:

- For digestate received from an industrial biogas plant for immediate application, this information can be provided by the producer with the delivery documentation.
- Sample and analyze digestate when storage may have changed the nutrient concentration, for example from ammonia loss or added water from precipitation, and when digestate is blended with other organic fertilizers, for example with different digestate, biosolids or manure. For low solids, i.e., < 3 % DM, digestate, nitrogen and potassium concentrations can be estimated from vertical profile samples taken at 1/4 - 1/3 and 2/3 - 3/4 depth. For > 3% DM digestate, and for phosphorus measurement, agitation of the stored digestate is required. Digestate analysis should provide the Agricultural Use Information shown in *Appendix D*.

Several devices are commercially available which will provide quick, on-farm estimates of total N, $\text{NH}_4\text{-N}$ and total P concentrations of various types of manure. A variety of measurement methods are used including density, conductivity, colourimetry (colour change) and measurement of the volume of gas produced by the conversion of $\text{NH}_4\text{-N}$ to N_2 gas. The devices are calibrated for specific manure types and report results in kg m^{-3} or lb 1000 gal^{-1} . Independent evaluations report good results for some methods and typically more accurate results for low solids than high solids manure types. The use of quick test methods for digestate is not established and the estimation accuracy has not been evaluated. Digestate users intending to use quick test methods should satisfy themselves as to the calibration of the devices and accuracy of the resulting estimates.

Step 3: Use available options for Right Time and Right Method to Maximize Nutrient Use Efficiency

Attention to the Right Time and Right Method of application are particularly important for digestate because of its relatively high concentration of available nutrients, particularly NH_3 , and potential for nutrient loss compared to manure or other organic fertilizers.

When options are available, decisions regarding the Right Time and Right Method of a digestate application should focus on maximizing nutrient use efficiency by maximizing the potential for crop uptake and minimizing nutrient losses, especially nitrogen loss, as illustrated in Figure 17.

Right Time and Right Method recommendations for maximizing nutrient use efficiency are summarized in Table 14.

Figure 17. Pathways of Nitrogen Loss

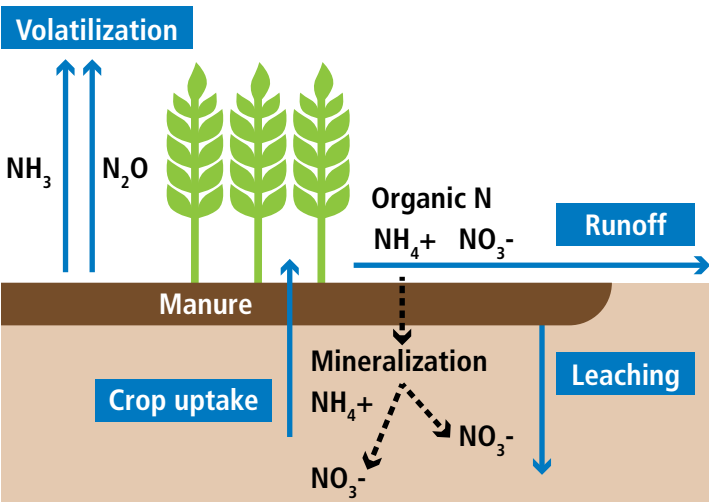


Table 14. Right Time and Right Method Recommendations for Maximizing Nutrient Use Efficiency

	Recommendations	
Maximize Digestate Nutrient Use Efficiency by	Right Timing (refer to <i>Right Time</i> section for more information)	Right Method (refer to <i>Right Method</i> section for more information)
Maximizing Crop Uptake	Apply when growing crops require nutrients. Refer to the <i>Digestate Application Calendar</i>	Injection between crop rows or banded in the crop row (strip till) a few days ahead of planting.
Minimizing Volatilization Loss	Avoid application during periods of high temperatures or high winds. Ammonia losses are generally smaller from low dry matter liquid materials with uniform application at relatively low rates, because they more rapidly infiltrate into the soil. Higher dry matter liquid materials remain on the soil/crop surface for longer, leading to greater losses. Losses are also higher when they are applied to dry soils under warm weather conditions.	Use injection or band application methods where possible, or incorporate surface applied digestate within 24 hours.
Minimizing Leaching / Runoff Loss	Avoid application ahead of anticipated rainfall	Maintain setbacks from surface water features, wells, etc. Do not exceed the maximum loading rate for liquid digestate application.

Step 4: Use best available information to estimate the proportion of applied digestate nutrients available to the crop considering the timing and method of application

The quantity of digestate nutrients available to a crop will be less than the total quantity applied due to losses and nutrient retention within the soil. Since direct measurements of crop available nutrients resulting from a digestate application are impractical, it is necessary to make estimates based on the actual quantities of nutrients applied and best available information on the proportions of the applied nutrients which will be available considering the crop and timing and method of application.

Where no better information is available, Formula 1 and Formula 3 and *Table 20* can be used to estimate the quantity of applied digestate nutrients which will be available to a crop in the year of application, for spring or summer applied digestate, or in the subsequent growing season for late summer or fall applied digestate. It should be noted that current estimates are based on experience with manure and work to develop specific estimates for digestate products is required. For digestate products with high pH, NH₃ volatilization losses may be greater, particularly if the digestate is broadcast applied without immediate incorporation.

Specific digestate applications may result in nutrient availabilities different from the estimates provided in this Guide. Familiarity with a digestate product supported by collected soil and crop data should enable the digestate user to develop more accurate estimates specific to their situation. Some scenarios are described in the following pages.

Estimating Crop Available Nitrogen from Spring/Summer Applied Digestate

The amount of nitrogen available to a crop following a spring or summer application of digestate is estimated in the same manner as for spring or summer applied manure, and can be calculated using Formula 1 below:

$$\begin{aligned}
 \text{Formula 1: } & \text{Amount of Crop Available Nitrogen (kg/ha) [lb/acre]} = \text{Quantity of TAN applied (kg/ha) [lb/acre]} \times \text{Estimated Percent TAN Available, from Table 15 (\%)} \\
 & + \text{Quantity of Digestate Applied (kg/ha FW) [lb/acre FW]} \times \text{Estimated Percent Organic N Available, from Table 16 or 17, or Formula 2 (\% FW)}
 \end{aligned}$$

Table 15. Estimated Percentage Total Ammoniacal Nitrogen Available from Spring/Summer Applied Digestate⁴¹

Ambient Temperature During Application	Application Method										
	Injected (covered)	Band Spread (Trailing Hose or Trailing Shoe)		Broadcast							
				Incorporated (days)					Not Incorporated		
		With Immediate Soil Cover	No Cover	1	2	3	4	5	Bare Soil	Residue	Standing Crop (below canopy)
Average	100	92	67	75	60	50	45	40	35	50	66
Cool (<10°C)	100	95	75	85	70	60	55	50	45	66	75
Warm (>25°C)	100	90	60	65	50	40	35	30	20	35	55

⁴¹ Adopted from OMAFRA Publication 811E Agronomy Guide for Field Crops, 2017; Chastain, J. 2020. Ammonia loss following application of swine manure. Waste to Worth, Oregon, OH. April 18-22, 2022.

Estimating Percent Organic N Available from Spring/Summer Applied Digestate

Mineralization of organic nitrogen is challenging to estimate because it is a biological process affected by soil and weather conditions and characteristics of the applied digestate. The speed of mineralization increases with warm temperatures and adequate moisture, which promote microbial growth, and will slow down in cool conditions, almost stopping when soil temperatures approach freezing. As described in the *Key Digestate Characteristics* section of this Guide, the predicted rate and amount of mineralization reduces with increasing digestate C:N ratio. Rapid mineralization is predicted if the C:N ratio is below 10. Reduced amount and rate of mineralization is predicted as C:N ratio increases from 10 – 25, beyond which point temporary nitrogen immobilization rather than mineralization may be predicted.

Digestate products with a high proportion of nitrogen in organic form, or with a high C:N ratio, may not mineralize sufficient nitrogen in time to support a growing crop are most suitable for use as late summer/fall applied organic soil amendments, supplying organic matter and crop nutrients in the subsequent growing season.

For digestate products suitable for use as organic fertilizers, the amount of the applied organic nitrogen which will be mineralized and available to crops in the year of application can be estimated from *Table 16* and *Table 17*.

Table 16. Estimated Organic Nitrogen Available from Spring/Summer Applied Whole and Liquid Digestate

DM (% FW)	Organic N (% FW)			
	0.2	0.3	0.4	0.5
2	0.16	0.26	0.36	0.46
4	0.12	0.22	0.32	0.42
6	0.08	0.18	0.28	0.38
8	0.04	0.14	0.24	0.34
10	0	0.1	0.2	0.3

Table 17. Estimated Organic Nitrogen Available from Spring/Summer Applied Solid Digestate

DM (% FW)	Organic N (% FW)				
	0.5	0.75	1	1.25	1.5
20	0.17	0.42	0.67	0.92	1.17
25	0.09	0.34	0.59	0.84	1.09
30	0	0.26	0.51	0.76	1.01
35	0	0.18	0.43	0.68	0.93
40	0	0.1	0.35	0.6	0.85

If actual digestate organic nitrogen or dry matter contents lie outside of the ranges of *Table 16* or *Table 17*, the organic nitrogen available to a crop in the year of application can be estimated from Formula 2⁴² below:

Formula 2: <i>Organic N Available in Year of Application (% FW)</i> = <i>Digestate Org N (% FW)</i> - <i>Digestate Dry Matter (% FW) ÷ A</i>
<i>Where A combines estimates of the carbon content of the digestate, carbon retained by soil life and the C:N ratio of soil life and is 50.93 for whole and liquid digestate and 61.44 for solid digestate.</i>

Ongoing mineralization of the organic nitrogen supplied with a spring/summer application of digestate may provide available nitrogen to crops in subsequent years. This is particularly significant for solid digestate in which organic nitrogen is the predominant form. Nutrient management planning should consider the contribution to available nitrogen from spring/summer digestate applications in previous years, which can be estimated using *Table 18*.

Table 18. Estimated Organic Nitrogen Available in Years Following Spring/Summer Digestate Application

Year	Estimated Percentage of Applied Organic N Available
1 st Year After Application	10%
2 nd Year	5 %
3 rd Year	2 %

Estimating Crop Available Nitrogen from Late Summer/Fall Applied Digestate

The amount of nitrogen available to a crop in the growing season following a digestate application in the preceding late summer or fall can be estimated from Formula 3 below.

Formula 3: <i>Available Nitrogen from Late Summer/Fall Applied Digestate (kg/ha) [lb/acre]</i> = <i>Quantity of Total Nitrogen applied (kg/ha) [lb/acre]</i> x <i>Estimated Percent Total Nitrogen, from Table 19 (%)</i>
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Table F: Estimated Percent Total Nitrogen Available to Crop from Late Summer/Fall Applied Digestate, (whole and liquid) [solid]

⁴² From OMAFRA Publication 811E Agronomy Guide for Field Crops, 2017

Table 19. Estimated Percent Total Nitrogen Available to Crop from Late Summer/Fall Applied Digestate, (whole and liquid) [solid]

Application Timing		Application Method				
		Injected	Broadcast			
			Incorporated (days)			Not Incorporated
			1	2 - 3	4 - 5	Bare soil, standing crop or crop residue
Late Summer		(22) [30]	(22) [30]	(22) [30]	(22) [30]	(22) [30]
Late Summer	with cover crop	(47) [45]	(47) [45]	(36) [45]	(25) [45]	(25) [45]
Early Fall		(38) [40]	(38) [40]	(32) [40]	(25) [40]	(25) [40]
Early Fall	with cover crop	(47) [45]	(42) [45]	(36) [45]	(25) [45]	(25) [45]
Late Fall		(47) [45]	(47) [45]	(36) [45]	(25) [45]	(25) [45]

Estimating Crop Availability of Other Digestate Nutrients

The amounts of other nutrients available to a crop following an application of digestate can be estimated using *Table 20*:

Table 20. Estimated Availabilities of Other Crop Nutrients

Nutrient	Estimated Availability (% of total applied)
Phosphorus	80
Potassium	90
Calcium, Magnesium, Sulfur	50 For early spring applied digestate, sulfur availability may be reduced to 25%
Micronutrients	Availability of micronutrients depends on soil pH, soil microbial activity, organic matter levels, existing fertility and other factors and is difficult to estimate. Crop micronutrient deficiencies are seldom seen in fields with regular applications of organic fertilizers or soil amendments.

Identify other applicable application rate constraints

Be aware of and comply with existing applicable policies limiting the maximum rate of application of manure or other organic fertilizers or soil amendments to agricultural soils. The maximum application rate can be limited by several factors, including:

- Maximum application of nitrogen, typically per application, or phosphorus, typically over a specified time period.
- Maximum addition of PTEs to soil, typically from repeated applications over a defined time period.
- Producer recommended maximum application rate, for example CFIA registered fertilizer products will have a specified maximum application rate to limit PTE accumulation in soil.
- Liquid loading limit to prevent runoff or infiltration to tile drains (preferential flow) or to allow incorporation within 24 hours. Liquid loading limits are determined by soil texture and slope. The heavier the soil texture, and greater the slope, the higher the runoff potential. Fields with high runoff potential have higher risk for liquid movement and therefore lower rates per application. Rate limits may also depend on whether material is surface applied, pre-tilled or injected.

Where Are the Opportunities to Use Digestate Products in Field Crop Systems – Examples

Digestate products can be used as organic fertilizers, supplying crop available nutrients, or organic soil amendments supplying slow-release nutrients and organic matter to sustain or improve soil quality. It can provide a “manure source” for crop farms that do not have access to livestock manure for nutrient and organic matter benefits and for organic farms that have limited sources of nitrogen. Best management practices that incorporate the 4Rs of nutrient management will achieve the most economically and environmentally beneficial use of digestate products.

Digestate utilization is maximized when:

- there are opportunities to apply at various times in the seasons to various crops in a diverse crop rotation
- applied as close to crop needs as possible
 - injected or incorporated as quickly as possible or applied into a standing crop canopy
 - weather conditions co-operate.
- There are no two identical farms, and each will have specific circumstances that impact digestate use opportunities. The five examples presented in this section were selected as they are the most common uses of digestate in Canada. The first four examples illustrate digestate use in various stages of a crop rotation with a focus on maximizing nutrient efficiency. The fifth example illustrates digestate use in an organic production system.
- The characteristics of the liquid and solid digestate products used in the examples and presented in *Table 21*, are representative of the middle of the reported ranges. The liquid product contains immediately available crop nutrients and is well suited for use as an organic fertilizer while the solid product, containing significant organic matter and having a C:N ratio that predicts slower mineralization or organic nitrogen, is best suited for use as an organic soil amendment.

Table 21. Characteristics of Digestate Products Used in Examples

Characteristic	Liquid Digestate	Solid Digestate
pH	8	8
Dry Matter (% FW)	4.5	32.5
Organic Matter (% FW)	2.5	24
Total Nitrogen (% FW)	0.37	0.83
TAN (% FW)	0.225	0.225
C: N Ratio	4	18
Total Phosphorus (% FW)	0.085	0.7
Total Potassium (% FW)	0.15	0.45
Calcium (ppm)	3500	8000
Magnesium (ppm)	300	3250
Sulphur (ppm)	350	1750
Zinc (ppm)	12	-
Manganese (ppm)	8	-
Sodium (ppm)	1200	-
Total Salts (EC) (umhos/cm)	21	25
Density lb/gal(l)	10.4	-
Density kg/m ³	1035	1000

The examples provided are intended only to illustrate the application of 4Rs Principles of Nutrient Management for Digestate to common digestate product utilization scenarios. The information provided in the examples cannot be taken as actual digestate product application or fertility recommendations. Persons competent in crop fertility who also have knowledge of the fields and digestate products to be utilized, and access to available nutrient management planning tools (e.g., AgriSuite in Ontario, Nutrient Management Calculator in B.C.) should be relied upon for recommendations for incorporating digestate as an organic fertilizer or soil amendment in a farm's crop rotation.

Example 1: Digestate Applied After Wheat Harvest with Cover Crop

Description

A crop farm has no access to animal manure but a solid digestate product from a nearby industrial biogas plant is available to local farms. The farmer wants to maintain soil quality and has incorporated a fall application of digestate ahead of seeding a cover crop into the regular crop rotation. The solid digestate product is applied by custom applicators.

Incorporating Digestate for Nutrients and Soil Benefits

Digestate is to be applied in late summer following wheat harvest and ahead of seeding a cover crop. The cover crop will be tilled in late fall. Digestate is applied during the growing season when cover crops can utilize the nutrients and enhance nutrient cycling for subsequent crops. Nutrients in the applied digestate, retained by the cover crop, will support a corn crop seeded the following spring.

Field details

Soil Type: Huron Clay loam

Rotation: Corn, Soybeans, Wheat (yield goal 200, 55, 100 bu/acre respectively)

Application: Scheduled for early August after winter wheat harvest

Soil Test: 15 P; 90 K; pH 7.2 (medium-low P and K fertility levels)

Winter wheat is harvested; straw is baled and solid digestate is surface applied and incorporated later the same day in 2 passes using vertical residue tillage equipment. Following tillage, a cover crop of oats, with small amount of peas and daikon radish, is planted. High total salts (EC) content in digestate can result in root burn if cover crops are planted into freshly applied digestate and where the digestate is applied at high rates onto dry soils. The digestate is utilized by the cover crop over the next few months for cover, carbon storage and enhancing microbial activity in the soil. The cover crop also helps with weed control. The cover crop is tilled in late fall. Seasonal activities are shown in *Figure 18*.

Figure 18. Seasonal Activities – Example 1

Jul		Harvest wheat		
Aug		Apply Digestate Plant cover crop	10 ton/acre CC - Oat/pea/OSR mix	70-257-98 lb/acre N-P-K
Sep				
Oct				
Nov		Fall Tillage		
Dec				
Jan				
Feb				
Mar				
Apr		Spring field preparation		
May		Plant corn	5 gal/acre 6-24-6 liquid starter + 60 lb/acre urea	32-16-4 lb/acre N-P-K
Jun		PSNT to determine additional fertilizer N	15 gal/acre 28%	54 lb/acre N

Where liquid digestate provides available nutrients like a liquid fertilizer, solid digestate is higher in organic (slower release) nitrogen and organic matter and is ideally applied after cereal (wheat harvest) combined with a cover crop. Solid digestate is more economical to transport, easier to store and provides more organic matter and nutrients to the soil. Phosphorus is concentrated in the solids, which will limit the application rate of nitrogen.

Nutrient Management – Determining Rate and Available Nutrients

The rate at which the solid digestate product can be applied is limited by phosphorus addition. At a rate of 10 ton/acre (22.4 tonne/ha) the digestate provides approximately 260 lb/acre (290 kg/ha) of P_2O_5 which is the maximum amount of P_2O_5 permitted for a 3-year rotation (soil test and buildup). Digestate is applied when soil conditions are dry with lower risk of damage from compaction, and nutrients are incorporated to reduce environmental losses.

In spring, after seedbed preparation the corn is planted with a seed-placed 6-24-6 starter and Urea (46-0-0) in a 2x2 inch band to ensure enough N during early season growth when soil conditions may be cold and digestate mineralization is delayed. In late May or early-June, a pre-sidedress nitrogen test (PSNT) is taken to determine how much additional side-dress nitrogen is required in addition to the digestate and starter nitrogen. Based on spring weather conditions and PSNT test results (26 ppm), UAN (28-0-0) is side-dressed to meet corn needs. Crop nutrient calculations are presented in *Table 22*.

Table 22. Crop Nutrient Calculations – Example 1

Crop needs/removal (N-P ₂ O ₅ -K ₂ O)			
	lb/acre 174-84-58	kg/ha 201-94-65	
Digestate Application	lb/acre	kg/ha	Notes:
Application Rate (10 ton/acre)	20000	22420	
Total N	166	186	See Table 16. For late summer broadcast applied solid digestate with rapid incorporation and cover crop, estimated available N is 45% of total N applied.
Total TAN	45	50	
Available N	75	84	
Total P	140	157	See Table 20. Estimated available P is 80% of total P applied
Total P as P ₂ O ₅	321	360	
Available P as P ₂ O ₅	257	288	
Total K	90	101	See Table 20. Estimated available K is 90% of total K applied
Total K as K ₂ O	108	121	
Available K as K ₂ O	97	109	
Available Digestate Nutrients Applied (N-P₂O₅-K₂O)	75-257-97	84-288-109	
Additional fertilizer applied	lb/acre	kg/ha	
Starter (6-24-6) at 5 gallons(l)/acre [density 13.4 lb/gal(l)]	67	75	
Starter (Urea, 46-0-0)	60	67	
Side-Dress (UAN, 28-0-0) at 15 gallons(l)/acre [density 12.8 lb/gal(l)]	192	215	
Total N	85	95	Conversions 2000 lb = 1 tonne 1 lb P = 2.29 lb P ₂ O ₅ 1 lb K = 1.2 lb K ₂ O 1 lb/acre = 1.121 kg/ha 1 ton/acre = 2.242 tonne/ha
Total P as P ₂ O ₅	16	18	
Total K as K ₂ O	4	4	
Total Additional Fertilizer Applied (N-P₂O₅-K₂O)	85-16-4	95-18-4	
Total Crop Available Nutrients Applied (N-P₂O₅-K₂O)	160-273-101	179-306-113	

Estimated nutrients supplied to a crop and estimated nutrient removal are not always equal. There are many variables in nutrient availability and where amendments have been applied with cover crops there is often improved nutrient cycling which can improve crop available nutrients. In this example, a pre-sidedress nitrate test revealed that the nitrogen benefit from the digestate plus cover crop was such that a lesser amount of fertilizer nitrogen was required at side-dress. Nutrients such as phosphorus and potassium are often applied in excess of the crop's needs for the year of application. Amendments applied once in rotation (usually ahead of corn) may supply phosphorus and potassium for subsequent crops and are usually based on soil fertility levels and rotational crop nutrient needs/removal.

Benefits and Challenges

Benefits:

- Heavy clay soils have less opportunity for spring manure or digestate application since they tend to dry and become fit for field work more slowly than medium and coarse-textured soils. Adding wheat into a rotation provides an opportunity after harvest where compaction risk is low and growing season conditions allow significant opportunity for cover crop growth. Workload and storage capacity are maximized and environmental risks are generally lowest at this time of year (late July/August)
- Solid digestate provides nutrient benefit and supplies approximately 2.4 ton/acre (5.3 tonne/ha) of organic matter which, as Effective Organic Matter, will help maintain or increase stable soil organic matter. As well, the nutrients and organic matter from digestate can increase cover crop biomass by 40% and this biomass can supply in the range of 2 – 4 ton/acre (4.5 – 9 tonne/ha) organic matter depending on cover crop species and growing conditions.
- Available Nitrogen supplied by the digestate and retained by the cover crop reduced the need for mineral nitrogen fertilizer by about 50 percent. As well, the digestate supplied sufficient available P and K to meet crop needs.
- Solid digestate provides a nitrogen credit for subsequent crops in rotation. The organic nitrogen portion of the digestate is released slowly over several seasons, providing a nitrogen credit for subsequent crops. The amount of nitrogen credit is higher in solid materials and can be insignificant in low dry matter liquid materials. In this example the nitrogen credit would be 12 lb/acre (14 kg/ha) for the 2nd crop after application and 6 lb/acre (7 kg/ha) for the 3rd crop after application.
- In addition to primary nutrients, the digestate supplied valuable amounts of secondary and micro nutrients to help maintain a soil nutrient balance.

Challenges:

- High pH and ammonium-N content can result in some volatilization loss on the day of application if incorporation is delayed, especially if weather conditions are sunny, warm, and windy.
- Weather conditions in spring can impact how quickly the nitrogen from the digestate and cover crop will be available. Since exact availability is difficult to predict, side-dressing additional fertilizer N can help fine-tune requirements based on spring weather.
- Application is limited by the high phosphorus content of the solid digestate. Depending on soil fertility levels, high rates of solid digestate could increase risk of phosphorus loss to water sources.

Example 2: Digestate Side-Dress Application into Standing Corn

Description

This dairy farm has an on-farm biogas plant that digests all manure plus off-farm feedstocks. The biogas plant includes a screw press for separation of the digestate into liquid and solid products. The farm's cropping system includes digestate application at various times during the growing season to maximize digestate use and minimize the quantity of digestate in storage, particularly during warm temperatures.

Incorporating Digestate for Nutrients and Soil Benefits

The farmer has discovered that the greatest direct economic benefit comes from the use of liquid digestate as an organic fertilizer, applied to growing corn just before corn begins to elongate (8-leaf stage). Digestate is injected using continuous manure application system (drag hose).

Field Details

Soil Type: Donnybrook Sandy Loam

Rotation: Corn, Soybeans, Wheat (yield goal 200, 55, 100 bu/acre respectively)

Application: Scheduled for early June into growing corn crop

Soil Test: 22 P; 125 K; pH 6.7

This field had a longer season soybean variety and did not get harvested in time to plant wheat. As a result, corn will be the subsequent crop. No fall tillage is planned and two passes with vertical tillage equipment will precede planting. Seasonal activities are shown in *Figure 19*.

Figure 19. Seasonal Activities – Example 2

Oct		Harvest soybeans	
Nov			
Dec			
Jan			
Feb			
Mar			
Apr		Seedbed prep (2 passes RTS)	
May		Plant corn 5 gal/acre 6-24-6 10 gal/acre UAN	40-16-4 lb/acre N-P-K
Jun		Inject digestate (standing corn) @ 5,000 gal/acre	140-75-80 lb/acre N-P-K
Jul			
Aug			
Sep			
Oct		Harvest corn	
Nov			

Nutrient Management – Determining Rate and Available Nutrients

Since an organic amendment should not provide the total crop nitrogen needs, a liquid seed-placed starter (6-24-6) and some banded nitrogen (UAN, 28-0-0) will be applied at planting to ensure early season crop needs are met. A few weeks after planting, depending on weather forecasts, digestate will be injected between the corn rows as close to 6 to 8 leaf stage as possible. An application rate of 5,000 gal/acre (56 m³/ha) will provide about ¾ of the crop N needs. Because digestate has a high proportion of ammonium N and the material is injected, the corn crop will be able to utilize the nitrogen from digestate rapidly. Crop nutrient calculations are presented in *Table 20*.

Table 23. Crop Nutrient Calculations – Example 2

Crop needs/removal (N-P ₂ O ₅ -K ₂ O)	lb/acre 174-84-58	kg/ha 201-94-65	
Digestate Application	lb/acre	kg/ha	Notes:
Application Rate (5,000 gal(l)/acre)	52000	58292	
Total N	192	216	
Total TAN	117	131	
Organic N	75	85	Organic N = Total N - TAN
Available TAN	117	131	See Table 16. For injected digestate, estimated available TAN is 100%.
Available Organic N	31	35	See Formula 2. For liquid digestate with 4.5% DM and Organic N = 0.145% FW (Total N - TAN), estimated available N is 0.06% FW.
Total Available N	148	166	
Total P	44	49	See Table 20. Estimated available P is 80% of total P applied
Total P as P ₂ O ₅	101	113	
Available P as P ₂ O ₅	81	91	
Total K	78	87	See Table 20. Estimated available K is 90% of total K applied
Total K as K ₂ O	94	105	
Available K as K ₂ O	85	95	
Available Digestate Nutrients Applied (N-P₂O₅-K₂O)	148-81-85	166-91-95	
Additional fertilizer applied	lb/acre	kg/ha	
Starter (6-24-6) at 5 gal(l)/acre [density 13.4 lb/gal(l)]	67	75	
Starter (UAN, 28-0-0) at 10 gal(l)/acre [density 12.8 lb/gal(l)]	128	143	Conversions
Total N	40	45	2000 lb = 1 tonne
Total as P ₂ O ₅	16	18	1 lb P = 2.29 lb P ₂ O ₅
Total K as K ₂ O	4	4	1 lb K = 1.2 lb K ₂ O
Total Additional Fertilizer Applied (N-P₂O₅-K₂O)	40-16-4	45-18-4	1000 gal(l)/acre = 11.2 m ³ /ha
			1 lb/acre = 1.121 kg/ha
Total Crop Available Nutrients Applied (N-P₂O₅-K₂O)	188-97-89	211-109-99	1 ton/acre = 2.242 tonne/ha

Whole farm management decisions, labour, and equipment accessibility may result in small differences between nutrients applied and removed. Available crop nutrients and nutrients removed at harvest are estimates and will vary with site specific soil and weather conditions. Nutrients applied with digestate in excess of crop needs will supply nutrients to meet the needs of subsequent crops.

Benefits and Challenges

Benefits:

- Digestate is high in quickly available nitrogen, which is ideal for application into standing corn and maximizes nitrogen use efficiency. Even with highly available N from digestate, some nitrogen should come from inorganic sources to ensure early crop needs are provided.
- Side-dressing manure into standing corn allows optimum corn planting date and allows digestate application to occur when soils are often drier and less prone to compaction damage
- Injection before 4-leaf stage of corn could be done using a drag hose system or tanker. At more advanced corn growth using a drag-hose system with hose-humper or a CMA (continuous manure application) system or tanker with injection toolbar can be used for digestate application.
- This timing for digestate is also ideal for organic systems where the crop relies on quickly available nitrogen and where N sources from solid manure often are not available when crop needs are highest.
- Digestate injected into standing corn reduces environmental losses such as volatilization and nitrous oxide losses (which lead to increased GHG emissions). Side-dress timing allows lower N rates (15% reduction compared to total N at planting) since early season losses are avoided. Digestate provides nutrients for subsequent crops in rotation and helps maintain nutrient balance.

Challenges:

- Injection increases time and horsepower requirements, however not significantly more than injecting commercial UAN (28%) nitrogen.
- Prolonged wet conditions could result in small application window.

Example 3: Digestate Spring Applied on Growing Wheat

Description

A crop farm has no access to animal manure but a liquid digestate product from a nearby industrial biogas plant is available to local farms. The farmer's prior experience with the digestate product is that when used as an organic fertilizer it produces good results and is an economical source of crop nutrients.

Incorporating Digestate for Nutrients and Soil Benefits

The digestate is band applied by a local custom applicator with a trailing hose toolbar that can be adapted for drag hose or tankers. Seasonal activities are shown in *Figure 20*.

Field Details:

Soil Type: Bennington Silt Loam

Rotation: Corn, Soybeans, Wheat (yield goal 200, 55, 100 bu/acre respectively)

Application: Scheduled for mid-April to growing winter wheat

Soil Test: 35 P; 175 K; pH 6.8

Figure 20. Seasonal Activities – Example 3

Aug				
Sep		Soybean harvest	50 lb/acre MAP	
Oct		Plant wheat		6-26-0 lb/acre N-P-K
Nov				
Dec				
Jan				
Feb				
Mar		Apply urea potash & sulphur		30-0-120-12S lb/acre N-P-K
Apr		Apply digestate into standing wheat	4,000 gal/acre drop hoses	83-62-65 lb/acre N-P-K
May				
Jun				
Jul		Harvest wheat		

Nutrient Management – Determining Rate and Available Nutrients

Winter wheat is planted late September/early October as soon after soybean harvest as possible with 50 lb/acre of seed-placed MAP (6-26-0) as a starter fertilizer. In mid-late March if/when spring conditions allow, a blend of urea, potash and ammonium sulfate is applied followed several weeks later by 4,000 gal/acre digestate in mid-to-late April or even early May, whenever conditions are suitable for application. Digestate application during freeze thaw reduces risk for compaction but risk for runoff is higher. Ideally, digestate will be applied before wheat begins to elongate (growth stage Zodak 31). Crop nutrient calculations are presented in *Table 24*.

Table 24. Crop Nutrient Calculations – Example 3

Crop needs/removal (N-P ₂ O ₅ -K ₂ O-SO ₄)		lb/acre 110-71-164-24	kg/ha 123-80-184-27	
Digestate Application	lb/acre	kg/ha	Notes:	
Application Rate (4,000 gal(l)/acre)	41600	46634	Organic N = Total N - TAN See Table 16. For band applied digestate without immediate cover, average temperature, estimated available TAN is 67%.	
Total N	154	173		
TAN	94	105		
Organic N	60	68		
Available TAN	63	70	See Formula 2. For liquid digestate with 4.5% DM and Organic N = 0.145% FW (Total N - TAN), estimated available N is 0.06% FW.	
Available Organic N	25	28	See Table 20. Estimated available P is 80% of total P applied	
Total Available N	88	98		
Total P	35	39	See Table 20. Estimated available K is 90% of total K applied	
Total P as P ₂ O ₅	80	90		
Available P as P ₂ O ₅	64	72	See Table 20. Estimated available S is 25% of total S applied.	
Total K	62	70		
Total K as K ₂ O	74	83		
Available K as K ₂ O	67	75		
Total S	15	17		
Total S as SO ₄	45	50		
Available S as SO ₄	11	12		
Available Digestate Nutrients Applied (N-P₂O₅-K₂O-SO₄)	88-64-67-11	98-72-75-12		
Additional fertilizer applied	lb/acre	kg/ha		
Planting (MAP, 6-26-0)	50	56	Conversions 2000 lb = 1 tonne 1 lb P = 2.29 lb P ₂ O ₅ 1 lb K = 1.2 lb K ₂ O 1 lb S = 3 lb SO ₄	
Spring (30-0-120-12)	100	112		
Total N	33	37		
Total P as P ₂ O ₅	13	15		
Total K as K ₂ O	90	101		
Total S as SO ₄	12	13		
Total Additional Fertilizer Applied (N-P₂O₅-K₂O-SO₄)	33-13-90-12	37-15-101-13		
			1000 gal(l)/acre = 11.2 m ³ /ha	
			1 lb/acre = 1.121 kg/ha	
Total Crop Available Nutrients Applied (N-P₂O₅-K₂O-SO₄)	121-77-157-23	135-87-176-25	1 ton/acre = 2.242 tonne/ha	

Whole farm management decisions, labour, and equipment accessibility may result in small differences between nutrients applied and removed. Available crop nutrients and nutrients removed at harvest are estimates and will vary with site specific soil and weather conditions. Nutrients applied with digestate in excess of crop needs will supply nutrients to meet the needs of subsequent crops.

Benefits and Challenges

Benefits:

- Digestate is high in quickly available nitrogen, which is ideal for wheat crops where crop nitrogen needs occur earlier than for corn and when soil conditions are generally cooler and wetter. Even with highly available N from digestate, a small portion (~25%) of nitrogen should come from inorganic sources to ensure crop availability when crop needs are highest. Digestate is also a good source of sulphur (S), however the majority is in elemental form. Conversion to sulphate form takes time and will often not occur in time to meet crop needs. Generally about 20 lb/acre of sulphate is applied to a winter wheat crop with the N application.
- This timing for digestate is also ideal for organic systems where the crop relies on quickly available nitrogen and where N sources from solid manure often are not available when crop needs are highest.
- Digestate applied to growing crops reduces environmental losses such as volatilization and phosphorus loss, especially when there is some crop canopy. If application occurs during freeze-thaw conditions, the freeze-thaw action helps incorporate nutrients into the soil.
- Digestate provides nutrients for subsequent crops in rotation and helps maintain nutrient balance.

A dribble bar/trailing shoe or drop hose system on a 60 ft or greater boom will place digestate on the surface in narrow bands allowing for more uniform application, more rapid infiltration and reduced compaction and horsepower requirements when compared to injection.

Challenges:

- Surface application where there is topography, can increase the risk of nutrient loss and/or nutrient movement from runoff and/or erosion. Incorporation into a standing crop is ideal, but is difficult to achieve for crops such as winter wheat or legume forages. Banding places the digestate at the surface without splashing (with or without a trailing shoe, which creates a small trench to enhance infiltration) but with banding there is still some ammonium exposed that can be volatilized. Crop canopy, temperature and windspeed will affect how much ammonium volatilization can occur. Uniform application and maintaining the target application rate is important to prevent wheat lodging, which occurs when there is too much available N.
- Prolonged wet conditions could result in small application window.

Example 4: Spring Digestate Application Ahead of Planting Corn

Description

A crop farm has no access to animal manure but a liquid digestate product from a nearby industrial biogas plant is available to local farms. The farmer's prior experience with the digestate product is that when used as an organic fertilizer it produces good results and is an economical source of crop nutrients.

Incorporating Digestate for Nutrients and Soil Benefits

Digestate is applied as an organic fertilizer to supply available N, P and K to a growing corn crop. Digestate is broadcast applied by a custom applicator and incorporated by the farmer. Seasonal activities are shown in *Figure 21*.

Field Details

Soil Type: Maplewood Silt loam

Rotation: Corn, Soybeans, (yield goal 200, 55 bu/acre respectively)

Application: Scheduled for mid-April ahead of planting corn crop

Soil Test: 22 P; 125 K; pH 6.7

Figure 21. Seasonal Activities – Example 4

Oct		Harvest soybeans	
Nov			
Dec			
Jan			
Feb			
Mar			
Apr		Apply Digestate @ 6,000 gal/acre ~115-94-97 lb/acre N-P-K Seedbed prep (2 passes)	
May		Plant corn 5 gal/acre 6-24-6 10 gal/acre UAN	40-16-4 lb/acre N-P-K
Jun			
Jul			
Aug			
Sep			
Oct		Harvest corn	
Nov			

Nutrient Management – Determining Rate and Available Nutrients

The preceding crop was a longer season soybean variety that did not get harvested in time to plant wheat and as a result, corn will be the subsequent crop. No fall tillage occurred. A few weeks before planting, digestate is broadcast applied at a rate of 6,000 gal/acre (67 m³/ha). Since an organic fertilizer should not provide the total crop nitrogen needs, the digestate will supply about ¾ of the crop N needs. Two days following application, the digestate is incorporated with two passes with vertical residue tillage equipment to incorporate the digestate and prepare the seedbed for planting.

A liquid seed-placed starter (6-24-6) and some banded nitrogen (UAN, 28-0-0) is applied at planting to ensure early season crop needs are met. The weather conditions from application to incorporation are warm and wet and, because digestate has a high proportion of ammonium N and a high pH, nitrogen losses could be higher than estimated. A pre-side-dress nitrogen test (PSNT) is taken to determine if and how much additional nitrogen is required in a side-dress application. Good early season growing conditions resulted in a PSNT test of 30 ppm and combined with good organic matter levels and residual nitrogen from solid manure applications made to previous crops, it was determined no additional N was required for sidedress application. Crop nutrient calculations are presented in *Table 25*.

Table 25. Crop Nutrient Calculations – Example 4

Crop needs/removal (N-P ₂ O ₅ -K ₂ O)		lb/acre 156-84-58	kg/ha 175-94-65	
Digestate Application	lb/acre	kg/ha	Notes:	
Application Rate (6,000 gal(l)/acre)	62400	69950	Organic N = Total N – TAN See Table 16. For broadcast applied digestate incorporated in 2 days, warm conditions, estimated available TAN is 50%.	
Total N	231	259		
Total TAN	140	157		
Organic N	90	101		
Available TAN	70	79		
Available Organic N	37	42	See Formula 2. For liquid digestate with 4.5% DM and Organic N = 0.145% FW (Total N - TAN), estimated available N is 0.06% FW.	
Total Available N	108	121	See Table 20. Estimated available P is 80% of total P applied	
Total P	53	59		
Total P as P ₂ O ₅	121	136		
Available P as P ₂ O ₅	97	109	See Table 20. Estimated available K is 90% of total K applied	
Total K	94	105		
Total K as K ₂ O	113	127		
Available K as K ₂ O	102	114	Conversions 2000 lb = 1 tonne 1 lb P = 2.29 lb P ₂ O ₅ 1 lb K = 1.2 lb K ₂ O 1000 gal(l)/acre = 11.2 m ³ /ha 1 lb/acre = 1.121 kg/ha 1 ton/acre = 2.242 tonne/ha	
Available Digestate Nutrients Applied (N-P₂O₅-K₂O)	108-97-102	121-109-114		
Additional fertilizer applied	lb/acre	kg/ha		
Starter (6-24-6) at 5 gal(l)/acre [density 13.4 lb/gal(l)]	67	75		
Starter (UAN, 28-0-0) at 10 gal(l)/acre [density 12.8 lb/gal(l)]	128	143		
Total N	40	45		
Total as P ₂ O ₅	16	18		
Total K as K ₂ O	4	4		
Total Additional Fertilizer Applied (N-P₂O₅-K₂O)	40-16-4	45-18-4		
Total Crop Available Nutrients Applied (N-P₂O₅-K₂O)	148-113-106	166-127-118		

Whole farm management decisions, labour, and equipment accessibility may result in small differences between nutrients applied and removed. Available crop nutrients and nutrients removed at harvest are estimates and will vary with site specific soil and weather conditions. Nutrients applied with digestate in excess of crop needs will supply nutrients to meet the needs of subsequent crops.

Benefits and Challenges

Benefits:

- Digestate is high in quickly available nitrogen and is best applied into growing crops or as close to planting crops as possible to maximize nitrogen use efficiency. Even with highly available N from digestate, some nitrogen should come from inorganic sources to ensure early crop needs are met and to prevent over application of phosphorus or potassium.
- This timing for digestate is also favorable for organic systems where the crop relies on quickly available nitrogen and where N sources from solid manure often are not available when crop needs are highest.
- Digestate (especially solid digestate) provides nutrients for subsequent crops in rotation and helps maintain nutrient balance.

Challenges:

- Prolonged wet conditions could result in application into wet soils and increasing compaction damage and lead to a delay in planting corn during ideal dates.
- Digestate has a high proportion of ammonium N and in most scenarios, it has high pH. Warm and wet spring weather conditions at the time of, and from application to incorporation, could result in higher nitrogen losses (denitrification, nitrous oxide).

Example 5: Organic Farm; Split Application of Digestate

Description

This farm is a certified organic farm. Organic farms must rely on organic nutrients such as manure and digestate to provide all the fertility required for a corn crop. The farm raises hogs and have some beef cattle that provide manure, but the manure does not provide enough nutrients for the entire crop acreage. To obtain additional crop nutrients, the farmer secures certified organic solid and liquid digestate products from a nearby industrial biogas plant.

Incorporating Digestate for Nutrients and Soil Benefits

An alfalfa field is being terminated in its 4th full production year in mid-to-late October and a corn crop will be planted the following spring. The field is at a location separate from the home farm and manure storage, and therefore digestate applied by custom applicators is the preferred nutrient source for this field. Solid digestate is applied in the fall to supply spring nitrogen to the seeded corn crop and to maintain soil fertility and organic matter. A pre-sidedress nitrate test (PSNT) determines the application rate for a side-dress application of liquid digestate to supply the available nitrogen required by the growing corn crop. Seasonal activities are shown in *Figure 22*.

Field Details

Soil Type: Guelph Loam

Rotation: Alfalfa, Corn, Soybeans, Wheat (yield goal 80, 180, 45, 90 bu/acre respectively)

Application: Scheduled for late November after corn harvest

Soil Test: 22 P; 125 K; pH 6.7

Figure 22. Seasonal Activities – Example 5

Oct		Apply Solid Digestate @ 5.5 ton/acre 40-140-55 lbs/acre N-P-K	Incorporate solid digestate while working down the alfalfa crop
Nov		Alfalfa – terminated after 4 yrs (10 harvests). Nitrogen credit of ~50 lbs	
Dec			
Jan			
Feb			
Mar			
Apr		Spring field preparation	
May		Plant corn	
Jun		PSNT to determine appropriate digestate rate PSNT = 20 ppm requires ~138 lbs/acre N)	Inject digestate @ 5,000 gal/acre into standing corn early/mid June 113-78-81
Jul			
Aug			
Sep			

Nutrient Management – Determining Rate and Available Nutrients

Before tillage of the alfalfa field in mid-to-late October, 5 ton/acre of solid digestate is applied and incorporation occurs within 2 days after application. The following May, the field is planted to corn after spring tillage has adequately prepared the seedbed. A PSNT nitrate sample result of 20 ppm reflects the cool and wet conditions from early/mid-May and suggests that the corn needs about 140 lbs N/acre (157 kg/ha) to maximize yield. Although solid digestate was applied in the fall, cool temperatures may have slowed the mineralization of organic N to TAN and nitrate. Between the 4 and 8 leaf stages of the corn crop in early/mid-June, liquid digestate is band applied at 5,500 gal/acre (62 m³/ha) using a trailing shoe toolbar supplied by a continuous manure application system on a draghose. Crop nutrient calculations are shown in *Table 26*.

Liquid digestate, with its high TAN content will provide N and with injection can help to limit weeds, compared to nutrients covering the full surface. With injected digestate, the crop nutrient needs for the corn crop will be met with some additional P and K supplied for subsequent crops. The soil fertility in this field is adequate with some room for buildup and withdrawal. However, the potassium removed by the crops in rotation – especially the alfalfa hay crop (which removes about 50 lbs P/acre and 250 lbs K/acre per season) cannot be met with only digestate. The difficulty in an organic production system is to supply all the nutrients needed by the crop without over-applying a single nutrient such as phosphorus. A solid manure (solid beef manure) with higher potassium levels could be included to maintain a balance in soil fertility levels.

Table 26. Crop Nutrient Calculations – Example 5

Crop needs/removal (N-P ₂ O ₅ -K ₂ O)	lb/acre 138-84-58	kg/ha 155-94-65	In determining crop requirements, a 50 lb/acre nitrogen credit from the previous alfalfa crop was included.
Fall Solid Digestate Application	lb/acre	kg/ha	Notes:
Application Rate (5.5 ton/acre)	11000	12331	
Total N	91	102	See Table 19. For early fall broadcast applied solid digestate with rapid incorporation and no cover crop, estimated available N is 40% of total N applied.
Total TAN	25	28	
Available N	41	46	
Total P	77	86	See Table 20. Estimated available P is 80% of total P applied
Total P as P ₂ O ₅	176	197	
Available P as P ₂ O ₅	141	158	
Total K	49.5	55	See Table 20. Estimated available K is 90% of total K applied
Total K as K ₂ O	59	66	
Available K as K ₂ O	53	59	
Available Digestate Nutrients Applied (N-P₂O₅-K₂O)	41-141-53	46-158-59	
Liquid Digestate Side-dress Application	lb/acre	kg/ha	
Application Rate (5,000 gal(l)/acre)	52000	58292	
Total N	192	216	
Total TAN	117	131	
Organic N	75	85	Organic N = Total N - TAN
Available TAN	78	88	See Table 16. For band applied digestate with no soil cover, average temperature, estimated available TAN is 67%.
Available Organic N	31	35	See Formula 2. For liquid digestate with 4.5% DM and Organic N = 0.145% FW (Total N - TAN), estimated available N is 0.06% FW.
Total Available N	110	123	
Total P	44	49	See Table 20. Estimated available P is 80% of total P applied
Total P as P ₂ O ₅	101	113	
Available P as P ₂ O ₅	81	91	
Total K	78	87	See Table 20. Estimated available K is 90% of total K applied
Total K as K ₂ O	94	105	
Available K as K ₂ O	85	95	
Available Digestate Nutrients Applied (N-P₂O₅-K₂O)	110-81-85	123-91-95	Conversions
			2000 lb = 1 tonne

Total Crop Available Nutrients Applied (N-P ₂ O ₅ -K ₂ O)	151-222-138	169-249-154	1 lb P = 2.29 lb P₂O₅ 1 lb K = 1.2 lb K₂O 1000 gal(l)/acre = 11.2 m³/ha 1 lb/acre = 1.121 kg/ha 1 ton/acre = 2.242 tonne/ha
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Whole farm management decisions, labour, and equipment accessibility may result in small differences between nutrients applied and removed. Available crop nutrients and nutrients removed at harvest are estimates and will vary with site specific soil and weather conditions. Nutrients applied with digestate in excess of crop needs will supply nutrients to meet the needs of subsequent crops.

Benefits and Challenges

Benefits:

- Digestate is high in quickly available nitrogen and is best applied into growing crops or as close to planting crops as possible to maximize nitrogen use efficiency. This is especially true in organic crop production where commercial fertilizer is not used. Often, split applications of manure will help to ensure early crop needs are met. A variety of manure sources can help balance nutrient needs so that one nutrient is not over supplied.
- Injection of liquid digestate is also favorable for organic systems where the crop relies on quickly available nitrogen and where N sources from spring applied solid manure often are not available when crop needs are highest.
- Digestate (especially solid digestate) provides nutrients for subsequent crops in rotation and helps maintain nutrient balance.

Challenges:

- In an organic production system, it is important for soil fertility levels to be at medium-high levels (P 20-30 ppm and K 120 + ppm). Building low soil fertility and keeping nutrients balanced is difficult without the addition of commercial fertilizers.
- Timing of nutrient availability for crops with high fertility needs can be difficult in organic production systems. Nutrients in manure are not balanced as required by crops and cannot be changed to match a specific commercial fertilizer blend.
- Manure feeds weeds. Weed control is difficult in organic production systems, where use of pesticides is not permitted, however, the use of cover crops for protecting soil from weed infestations is important, in addition to the benefits cover crops contribute to nutrient cycling.
- Where there are forages in the rotation, the potassium removed with the hay or haylage can not be adequately replaced with digestate. Planning ahead to find other organic amendments that have a higher K content (relative to N and P) could help to balance soil fertility levels.

Right Place

Right place means choosing fields that will benefit the most from receiving digestate as an organic fertilizer or soil amendment. Typically, the greatest benefit can be realized when digestate is applied to soil with low fertility and organic matter. Right place also means considering nutrient requirements of the intended crop and determining whether or how to ensure that an application of digestate is suitable.

The topography of a field may indicate areas which are not suitable for digestate application due to the risk of ground or surface water pollution. Local requirements or guidance in this regard for manure application are usually considered appropriate for digestate. Typically, to be suitable the intended application area must satisfy minimum separation requirements from ground and surface water features including ponds, streams, wells and drain inlets and must not have features which indicate a significant risk of pollution due to infiltration such as sandy soils overlaying drainage tiles or a shallow groundwater table. It is recommended that digestate users familiarize themselves with local requirements and seek guidance from an appropriate provincial agriculture ministry representative to resolve any questions.

Some questions to consider when evaluating if digestate is right for the crop include:

Which fields can benefit the most from receiving digestate?

- fields with low fertility will have highest economic benefit from using digestate;
- ensure the nitrogen index is at an appropriate level and will not indicate nitrogen loss during the non-growing season; and
- use phosphorous application calculation tools to reduce P losses.

How to ensure that digestate is suitable for the intended crop?

- the intended crop requires nutrients that can be supplied by the digestate product;
- generally, digestate is not recommended for soybeans, edible beans (no more than 50-75 lbs N), and horticulture crops such as strawberries that require low N for dormancy; and
- consider if digestate can be safely used with the intended crop – see *Table 27 – Digestate Suitability Matrix* for considerations.

Table 27. Digestate Suitability Matrix

Crop		Suitability Recommendations
Fresh Produce	Group 1 ¹	Fresh produce crops present a potential future use opportunity however at present there is very little Canadian experience with the use of digestate as an organic fertilizer source for these crops.
	Group 2 ²	
	Group 3 ³	
	All Groups	
Field	Corn	- Digestate organic fertilizer and organic soil amendment products are suitable for use with field crops when best management practices are applied. - Producers should check with markets when products are intended for export.
	Oil Seeds	
	Grains	
	Dry Beans ⁴	
Grassland and Forage		- Digestate organic fertilizer and organic soil amendment products are suitable for use with grassland and forage crops when best management practices are applied. - Observe recommended waiting periods following application of unpasteurized⁵ digestate - For grazing – 2 month (cattle) 6 month (hogs, sheep, goats, horses) - For harvest – 3 weeks - No product that has any risk of glass or other foreign material. - Digestate containing Prohibited Material as defined by the <i>Canadian Health of Animals Act and Regulations</i> is not to be used on pasture land or other grazing areas for ruminants.
Cover Crops		Digestate organic fertilizer and organic soil amendment products are suitable for use with cover crops when best management practices are applied

Notes

1. Eaten raw. Without protective skin removed before eating. Has risk or history of pathogen contamination.
2. Eaten raw. With a protective skin or grow clear of the ground. Has no history of pathogen contamination.
3. Eaten cooked.
4. Dry Beans includes white beans, kidney beans, lentils
5. Pasteurization according to local jurisdictional requirements, typically requiring the feedstock materials or digestate be heated to 50°C for 20 hours or 70°C for one hour.

Right Time

Right time for using digestate as an organic fertilizer or soil amendment means applying digestate when:

- the digestate will supply nutrients to growing crops;
- the recommended waiting periods between digestate application and harvest or grazing can be achieved, see *Table 27 – Digestate Suitability Matrix*; and
- not applying digestate when weather or soil conditions are unsuitable.

Apply when digestate will supply nutrients to growing crops

The best results and highest nutrient use efficiency can be achieved when digestate nutrients can be taken up by growing crops. Crops differ in the timing of their nutrient requirements. *Table 28 – Digestate Application Calendar* indicates when specific crops can utilize nutrients and when a low or absent requirement for nutrients recommends against digestate application. It is recommended to not apply in late summer or early fall without a winter cereal crop or cover crop.

Apply when waiting periods can be achieved

A waiting period between the application of a digestate and harvesting certain crops or grazing is recommended when the digestate has not been successfully treated by pasteurization or other approved process to eliminate pathogens, or where the treated digestate may have been contaminated during storage or handling. Recommended waiting periods are indicated in *Table 27 – Digestate Suitability Matrix*.

Do not apply when weather or soil conditions are unsuitable

Digestate should not be applied to crops when the following weather or soil conditions are present:

- in winter to frozen or snow-covered ground;
- on hot, windy days since NH_3 loss increases as temperatures increase over 10°C ,) surface application later in the day to help reduce loss when incorporation occurs the following day;
- when there is significant precipitation event in the forecast (i.e., greater than 15 mm rain); and
- saturated soil or when post-application, the soil will be too wet to allow incorporation within 24 hours.

The crops in this calendar (see *Table 28*) represent the time they are growing during spring and summer. After typical harvest date the same crop as if intended for the following crop. The black line represents typical harvest. Application to cover crops will depend on which cover crop.

Table 28. Digestate Application Calendar

Crop		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Field	Corn												
	Oilseeds – soybeans **												
	Dry beans/lentils												
	Oilseeds – canola												
	Winter Grains												
	Summer Grains												
Grassland and Forage	Pasture (rotational grazing)												
	Hay/Haylage – legumes **												
	Hay/Haylage – grasses												
Cover Crop													

Legend:

- No winter application
- Crop nutrient utilization**
- High
- Medium
- Low
- Application not practical/recommended
- **Utilize nutrients but not always nitrogen
- Typical harvest

Right Method

Right method means digestate nutrients are placed where crops can use them and in such a manner as to minimize losses to the atmosphere and ground and surface waters.

Methods for applying slurry and solid manure can also be used for digestate. Available methods enable digestate to be used as an organic fertilizer in pre-plant and top-dress and side-dress applications. The different application methods have different performance characteristics in terms of effectiveness, efficiency, field impacts, and potential for emissions and other losses. Choosing the appropriate method requires consideration of a number of factors specific to each digestate application. However, since digestate has a greater potential for nitrogen loss compared to manure, low NH_3 emission methods should be used whenever practical.

Digestate application methods are described in the following sections. *Figure 23* provides more detail on these methods and *Table 29* summarizes performance characteristics of these methods. Additional information on application technologies is provided in *Appendix C*.

It is recommended to calibrate equipment to apply the rate that meets the crop needs and ensure a uniform application to the soil surface.

Application Methods for Whole and Liquid Digestate

Injection

Injection methods place whole or liquid digestate below the soil surface, locating the nutrients closer to plant roots and reducing NH_3 emissions by decreasing the digestate surface area exposed to the air. They are generally more effective for reduction of NH_3 emission than band spreaders. There are three types:

1. **Shallow (or slot) injectors:** These cut narrow slots (typically 4–6 centimetres (cm) deep and 25–30 cm apart) in the soil that are filled with digestate. They are most commonly used on grassland. Different abatement results are achieved depending on whether open- or closed-slot injectors are used. Application volumes may be limited by the volume of the slots.
2. **Deep injectors:** These apply digestate to a depth of 10–30 cm in the soil using injector tines spaced about 50 cm or even 75 cm apart. The tines are often fitted with lateral wings to aid dispersion in the soil and to achieve high application rates. They are most suited for use on arable land because of the risk of mechanical damage to grass swards.
3. **Arable injectors:** These are based on spring or rigid-tine cultivators and are for use on arable land only.

Band Spreading

Band spreading methods place whole or liquid digestate in a narrow band directly on or slightly below the soil surface. Band spreading methods reduce NH_3 emissions by decreasing the surface area of digestate exposed to the air and by promoting infiltration. The efficiency of these methods can vary depending on the height of the crop. There are two main types:

1. **Trailing hoses:** Digestate is discharged at ground level to grass or arable land through a series of flexible hoses. Application between the rows of a growing arable crop is feasible.
2. **Trailing shoes (or feet):** Digestate is normally discharged through rigid pipes which terminate in metal “shoes” designed to ride along the soil surface, parting the crop so that digestate is applied directly to the soil surface and below the crop canopy. Some types of trailing shoes are designed to cut a shallow slit in the soil to aid infiltration.

Injection and band-spreading methods increase the number of spreading days and have less impact on surface vegetation than broadcast methods.

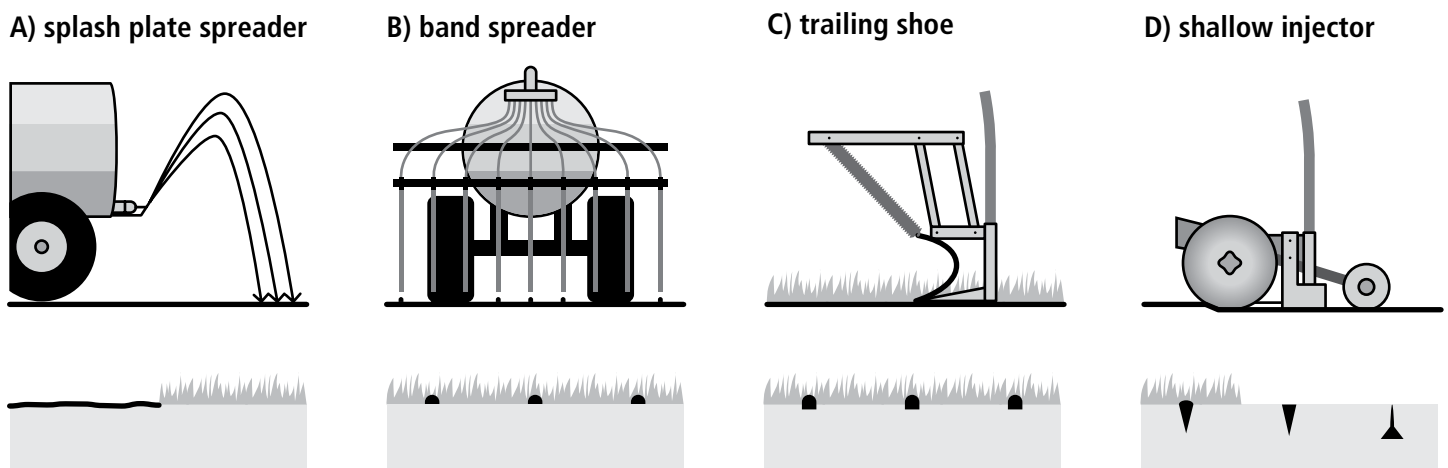
Broadcast Spreading with Incorporation

Broadcast incorporation methods place the digestate on the soil surface across an entire field followed by incorporation through plowing or disking. Plowing is considered better in terms of nutrient availability, as it creates a nutrient-rich zone a few inches below soil surface (where developing plant roots can absorb it).

The aim should be to incorporate digestate into the soil as rapidly as possible after spreading on the surface. The most effective abatement is achieved by incorporation immediately after spreading (i.e., within a few minutes). Completely burying the digestate by ploughing is a slow operation and, in many cases, the use of a tine or disc cultivator may be as effective because the digestate will remain exposed on the surface for a shorter time before being well mixed with the soil by cultivation.

Figure 23. Application Methods for Whole and Liquid Digestate⁴³

Principles for the four major types of slurry application methods and the associated slurry distribution within the crop-soil after application:



⁴³ From EIP-AGRI 2017. Mini-paper: Assessing the environmental affects of nutrient recycling from organic materials used as fertilizers. EIP-AGRI Focus Group Nutrient

Table 29. Performance Characteristics of Whole and Liquid Digestate Application Methods⁴⁴

Characteristic	Surface Broadcast With Incorporation	Band Spreading		Injection
		Trailing Hose	Trailing Shoe	
Distribution of digestate	Very uneven	Even	Even	Even
Risk of ammonia volatilisation	Medium to high depending on timing and effectiveness of incorporation	Medium	Medium	Low or none
Risk of contamination of crop	High	Medium	Low	Low
Risk of wind drift	High risk	No risk	No risk	No risk
Risk of odour	High	Medium	Medium	Low or none
Spreading capacity	High	High	Low	Low
Working width	6-10 m	12-28 m	6-16 m	6-12 m
Mechanical damage of crop	None	None	Medium	High
Cost of application	Low	Medium	High	High
Amount of digestate visible	Most	Some	Some	Little or none
Suited / recommended for	All	Winter crops Corn Trailing hose banding in no-till crops and for forages, winter wheat, cover crops	Grass	Grass, bare soil Corn, after wheat harvest with cover crops, after fall harvest, spring when soil conditions are suitable

Application Methods for Solid Digestate

Broadcast Application with Incorporation

Broadcast incorporation methods place the digestate on the soil surface across an entire field followed by incorporation through plowing or disking.

Rapid incorporation into the soil is the only practical technique for reducing NH_3 emissions from solid digestate. Most of the NH_3 is released from solid digestate within a few hours of spreading. It is recommended, therefore, that incorporation should take place within a few hours after spreading. The manure should be completely mixed with soil or buried for maximum abatement and it is often more difficult to achieve this with some solid digestates containing large amounts of fibre. Incorporation of solid manures by plough is always more effective than incorporation by disc or tine, despite the slower work rate of ploughing.

⁴⁴ Adopted from EIP-AGRI 2017. Mini-paper: Towards increasing the mineral fertiliser replacement value of bio-based fertilizers

Appendices

Appendix A – Resources

Digestate Production

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Appendix B – Digestate Transformation Technologies

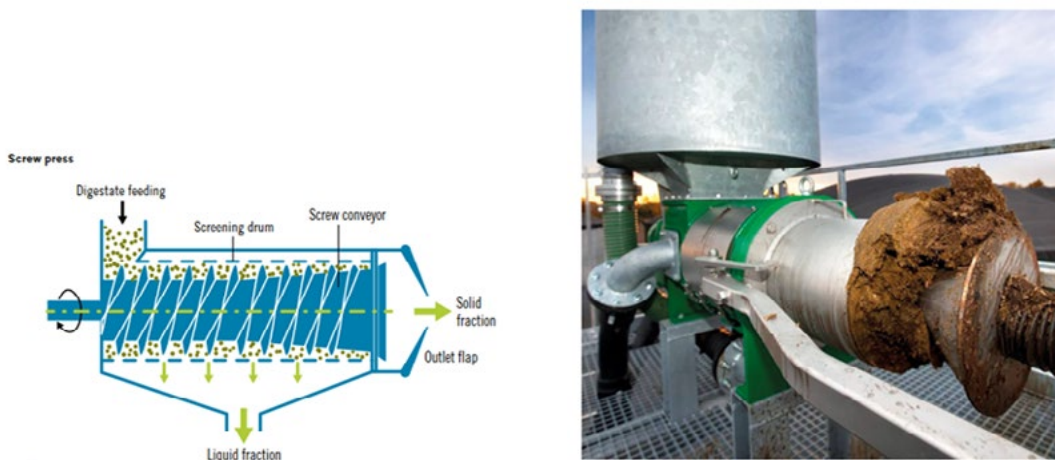
The below information is presented with the permission of the German Biogas Association.

Transformation of Whole Digestate

Liquid – Solid Separation

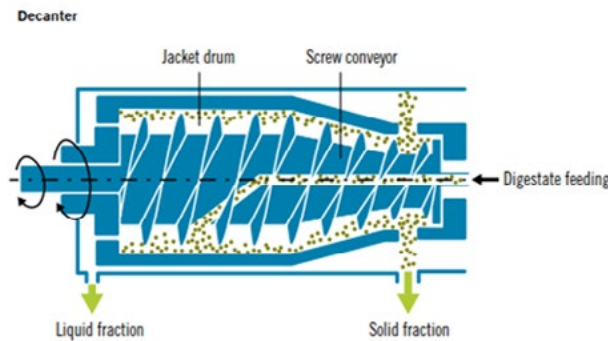
Screw Press

The screw press is the most commonly used technique for solid liquid separation. This is when a rotating screw conveyor which sits in a screening drum presses the digestate against an outlet flap from which the solid fraction can exit. The liquid fraction is separated by the screening drum with a defined hole width of 0.5-1mm. Contact pressure, hole width, and back pressure of the outlet flap determine the degree of separation. The technology is mature, robust, and simple. The power consumption ranges between 0.2-0.6 electrical kilowatt hours per cubic metre (kWhel/m³) input, depending on version and size.



Decanter Centrifuge

The decanter centrifuge has a fast-rotating screw conveyor located in a slower rotating jacket drum. Due to the higher density and inertia, the solid digestate is pressed against the jacket drum and transported away. The liquid fraction can exit between the screw conveyor and the jacket drum. The degree of separation can be varied via the speeds of the screw conveyor and the jacket drum as well as via the throughput. The centrifuge has a very high degree of separation. The power consumption is 2 – 5 kWhel/m³ input. Centrifuges present a much greater separation performance but are costly to operate and not adapted to digestates with big particles and long fibers.



Belt Filter Press

In belt filter presses, the digestate is compressed as wedge-shaped between two filter belts and water is pressed out through the belts. The belts are guided via deflection rollers, thus gradually increasing the pressure. The degree of separation can be adjusted via the contact pressure, running speed, and condition of the filter belts as well as the number of deflection rollers. Flocculants are usually added. The power consumption is 1.5 – 5 kWhel/m³ input.

Screens

Screens (e.g., a vibrating sheet or drum screens) for the separation of solids (or impurities) can also be used in combination with the aforementioned techniques. The liquid fraction passes through the screens and the solid fraction is retained and transported to the outlet. The degree of separation is set via the hole width, the angle of inclination, and the frequency of rotation or vibration.

Flotation

Flotation takes advantage of the effect that particles adhere to rising air bubbles and can float with them. Air-enriched liquid is introduced into the flotation tank for this with the addition of flocculants. A flotation sludge forms on the surface of the basin where it can be skimmed off. The advantage of flotation is the very pure, almost particle-free liquid fraction, which can be easily used in membrane filtration, for example. The flotation sludge has a very high-water content and may have to be thickened further. The power consumption is about 0.2kWhel/m³ input.

In order to achieve higher solids separation, flocculants can be used in the presented methods as flocculants or flocculation aids. This creates an agglomeration of the particles contained in the digestate and thus considerably improves the separation. The addition of flocculants is associated with further expenditure, but may be necessary in certain cases e.g., with a very low dry matter content of the digestate to be separated or if a particle-free liquid fraction is required for further processing.

Transformation of Solid Digestate

The drying of the solid fraction and, if necessary, the granulation or pelletisation of the dried digestate solids are well established techniques. The focus here is on improving the appearance, handling, storage suitability, and marketability. During pelletising, the individual nutrients or other mineral and organic additives obtained from the liquid fraction can be added in order to adjust the nutritional compositions for the customer. This is an interesting perspective for a future market for fertilizers that can be produced from digestate.

Especially with the digestion of municipal biowaste, composting is carried out downstream in many countries. Marketing composts is established in many countries and the application leads to a very high humus supply. In some cases, the liquid digestate from these plants is introduced into a wastewater treatment plant (WWTP) together with municipal waste water by converting the nitrogen contained into atmospheric nitrogen N_2 and thus is no longer available as nutrients.

In any case, the goal should be responsible optimisation of nutrient management, which can certainly be associated with a reduction in costs or increase in added value. A sustainable decision should, therefore, also be made with regard to NH_3 emissions from the individual processes, which can be implemented by appropriate technologies, such as acid scrubbers. The ammonium sulphate solution produced can then be used agriculturally as mineral fertilizer or marketed externally.

Drying

The goal of drying is to evaporate water and produce dried digestate. Dried digestate products can be transferred to new sales areas such as earthworks or fertilizer production or used as bedding in animal stables. Drying is also required prior to pelletisation.

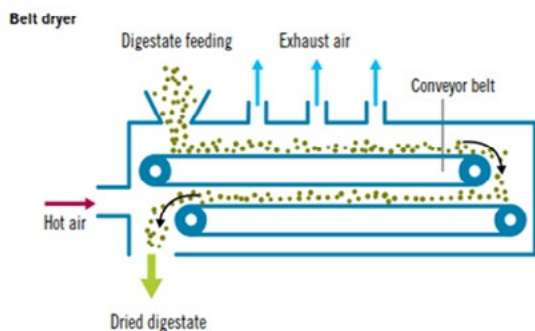
Hot air, e.g., from the CHP of the biogas plant, is conducted through or over the digestate to be dried. Many types of thermal dryers are available in the market. The most common for digestate treatment are rotary, disk and belt dryers. Belt dryers are usually the best approach for digestates with large particles.

Most frequently, belt dryers are used in which the digestate is placed on a conveyor belt and dried at temperatures of 60-150°C for about 2 hours. Multiple bands can also be arranged one above the other. A similar principle applies to push-turn, fluid bed, and drum dryers, in which the digestate is transported through the hot air by movement of vanes, air injection, or a rotating drum. With trailer or container dryers, hot air is blown through a motionless pile. In solar-assisted drying, the digestate is distributed on the floor of a large greenhouse and rearranged by a self-propelled turning trolley. Warm air at around 40°C is blown onto the digestate layers by fans. Drying is supported by solar radiation into the greenhouse.

All drying technologies require high thermal energy and intensive air treatment for safe air disposal and to avoid atmosphere ignition. An explosive atmosphere due to organic dust can be a constant threat for operators, especially in the case of mixing-drying equipment such as rotary driers. In some cases, the fire risk can be aggravated by intensive self-heating of dried digestate. To avoid NH_3 emissions, the exhaust air from the drying process should be cleaned with an acid scrubber with the production of ammonium sulphate solution at the same time. Alternatively, NH_3 emissions can be avoided by acidifying the digestate before drying.

The quantity of digestate to be dried and the final moisture content depend on the available heat from cogeneration. Depending on the technology used, the heat requirement is 750-1,200 kilowatt hours of thermally evaporated water per cubic metre (kWh_{therm}/m^3H_2O). In biogas plants, the heat from cogenerators is normally not enough to dry the whole digestate flow. It usually only allows drying for less than half of the whole digestate flow.

Dried digestate products should achieve dry matter content of 75%–85% to achieve long term stability. The desired dry matter content (up to over 90%) can be set via drying time and temperature. Depending on the residual moisture, they are stable in storage and transport, but may have to be compacted further to avoid dust emissions and spontaneous combustion and to decrease transport costs. Alternatively, dried digestate might be mixed back into the liquid starting fraction to produce granules during drying.



Pelletising

The goal of pelletising is to compact the dried digestate into digestate pellets in order to improve the density as well as handling and appearance. This requires a dry matter content of the dried digestate of 85-90%. The digestate is pressed through under high pressure. This results in very high temperatures on the surfaces, which means that the digestate pellets melt on the outside and have a glassy shine.

In the ring die, the digestate is pressed from inside to outside through the annular die from inside rollers. Alternatively, the digestate can be fed to a pair of hollow rollers and pressed into the interior of the dies or through a folding die of bollards above. The power consumption for pelletising dried digestate is about 30-50kWh/tonne.

Loose dried digestate has a bulk density of 250-350kg/m³. Pelletising produces pellets with a bulk density of 700-750kg/m³ and thus considerably decreases transport costs and increases storage suitability.

The digestate pellets can be optimally marketed in smaller packages in garden centres and hardware shops. Because of their cleanliness, they are easy to use for the end customer. In addition, larger quantities can be sold in new spreading areas, such as vineyards, where conventional spreading of liquid digestate is not common. The digestate pellets dissolve when exposed to moisture, which means that the nutrients contained are provided to the plant. At present, only a few biogas plants pelletise dried digestate and subsequently market it outside the agricultural sector, although the potential is estimated to be very high. Digestate pellets can additionally be refined to special fertilizers with mineral or organic additives.



Aerobic Composting

When digestate is used as a feedstock in the composting process, it can create a high-quality finished product. In Ontario, compost is categorized as AA, A and B, and we use digestate in our composting blends that produce the highest quality, AA compost. AA compost is unrestricted in Ontario and can be used in many applications such as landscaping and retail products. By composting digestate, it increases the value of the product, and opens up many possibilities for end markets.

As an ingredient, digestate has a low C:N ratio (approximately 1:10), and therefore is a great nitrogen source. It replaces ingredients such as SSO in composting recipes.

When digestate has arrived at a composting facility, it has already gone through some initial phases of biodegradation. Therefore, when digestate is blended with other organic materials, composting windrows take less time to mature and stabilize, creating more compost fines and a higher quality compost produce at the end of the process.

For composting facilities to manage digestate properly, it should arrive at the facility dewatered and with minimum contaminants.

Facilities are also required to test the feedstock before accepting the material to ensure it complies with heavy metal concentration limits set out in Ontario's Compost Quality Standards.

Digestate has a high bulk density, and therefore requires proper bulking to ensure composting windrows do not go anaerobic and oxygen can move through the composting mix freely.

While digestate is less odourous compared to manure, it still might have slight odour and feedstock can be managed to minimize this. However, from our experience, digestate is odorous when it comes into the facility, but takes less time to mature and stabilize, therefore odours are reduced more quickly compared to other feedstocks that have just begun their active rot. In other words, when composting windrows have digestate as an ingredient, those windrows produce less odours at the 4-6 week stage compared to other mixes that use feedstocks such as SSO.

Digestate can have small fragments of foreign matter, and quality inspections are required to ensure that the fragments will not negatively affect the finished compost quality.

In Ontario, when digestate is accepted at an approved composting facility, it must meet feedstock and finished compost quality criteria set out in Ontario's Compost Quality Standards. Finished compost is categorized as AA, A and B. AA compost has unrestricted use in Ontario and has multiple markets including retail, landscaping, greenhouses and nurseries. Composting facilities are typically designed and operated to produce AA compost and are able to meet and exceed those standards using digestate as a feedstock.

Transformation of Liquid Digestate

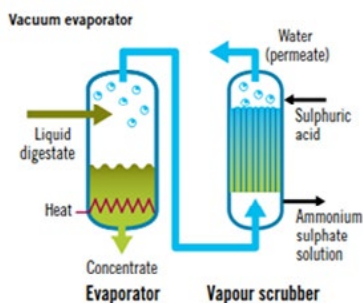
The goal of liquid digestate treatment is to achieve a significant volume reduction (up to 50%) by separating the water. The solids or nutrients are concentrated in a viscous solution with a dry matter content of up to 15%. Concentration can be achieved by thickening under normal pressure (atmospheric evaporation), in a closed system under negative pressure (vacuum evaporation), or by filtration in a membrane process. Prior separation is not imperative for atmospheric evaporation. However, it is for vacuum evaporation and the membrane filtration. These procedures are much more technically demanding and sensitive. They are established in water treatment and other industrial processes, for example, but their use in transforming digestate is not yet common practice.

The concentrated nutrient solutions (concentrate) can be applied like liquid digestate, but the workload and transport costs are reduced as less water has to be moved and more agricultural area can be fertilized in a shorter time. The produced water (permeate) can be discharged into water bodies or the sewage system, or rained over agricultural land depending on the achieved quality and local requirements. The ammonium sulphate solution from the exhaust air treatment of atmospheric or vacuum evaporation can be used or marketed as mineral fertilizer. Alternatively, the pH value can be reduced by acidifying the digestate so that nitrogen is bound in the concentrate.

Evaporation

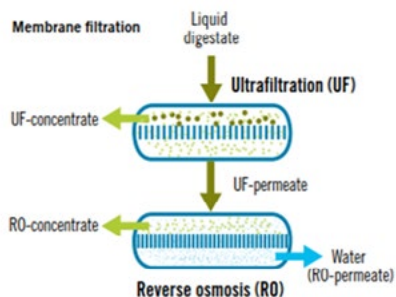
Atmospheric evaporation is similar to drying, with the difference that no dried digestate is produced, but instead thickened liquid nutrient solutions. The aim is to create the largest possible surface area for evaporation by distributing the liquid digestate over lamellas, filter belts, discs, and drums. The heat requirement is 1,000-1,500 kWh/therm per m³ of evaporated H₂O.

Vacuum evaporation occurs in a closed system which means that no exhaust air is produced. The liquid digestate is distributed in the inner surface of the evaporator, the internal heat plates, or the heat exchangers, e.g., by brushing or over-flow. The reduced pressure reduces the boiling temperature to 40-75°C, which means that H₂O, CO₂, NH₃ (with the pH value not reduced) leave the liquid fraction. This steam mixture is cleaned of acids and NH₃ in a subsequent vapour scrubber and if necessary condensed. The liquid digestate should have a dry matter content of less than 3% and be free of large particles to avoid fouling heat exchangers. The power requirement is 10-13 kWh_e/m³ input and the heat requirement is 600-1,000 kWh/therm/m³ evaporated H₂O in a single-stage process. Several units are often connected in a series (multi-stage process) in order to use the heat from the steam mixture for the next stage. In the 4-stage process, the power requirement can be reduced to 5 kWh_e/m³ input and the heat requirement to 250 kWh/therm per m³ of evaporated H₂O.



Membrane Filtration

In membrane filtration, different membranes with incrementally decreasing pore sizes are usually used (micro, ultra, nanofiltration, and finally reverse osmosis). Ultrafiltration (UF) with a pore size of 0.01 – 0.05 micrometres (μm) and reverse osmosis (RO) with a pore size of 0.0005 – 0.005 μm are usually used for treating liquid digestate. Since membranes are very sensitive to solids, using flocculants during separation and/or flotation before membrane filtration is usually necessary to produce a liquid fraction that is as particle-free as possible; less than 1% dry matter is typically required. As membrane clogging increases over time, the associated energy requirement rises sharply due to frequent cleaning intervals and the throughput decreases. The power consumption is typically between 10 – 30 kWhel/ m^3 input.



Appendix C – Digestate Application Technologies and Practices

The below information is presented with the permission of the German Biogas Association.

In contrast to mineral fertilizers, organic fertilization requires greater technical effort to actually supply the plant with nutrients. Organic fertilizer losses to groundwater and air must be minimised.

The high NH_4 content in conjunction with higher pH values carries the risk of losses in the form of ammonia (NH_3) during storage and application of the digestate. The risks can be minimised by low-loss application and immediate incorporation, which then result in an increase in the nutrient use efficiency. The best possible use of nutrients is as the basis of the fertilizer value of digestate. If technical and organisational measures are observed, the NH_4 effect can be approximated by digestate to that of the effect of mineral fertilization.

Techniques for spreading liquid digestate that best meet the requirements mentioned above are processes with drag hose, drag or slit-shoe distributors as well as flat injection processes. Although a wide distribution allows for low-emission application, it is very weather-dependent. Good results can only be expected at cool temperatures in combination with subsequent rainfall. When choosing the technique, a crucial aspect is whether it is transferred to the stock or not.

The wide distribution by means of an upward deflecting baffle plate (see illustration: “Wide distribution”) was common for a long time and very susceptible to loss. It has been banned in Germany since 2016. As a cost-effective spreading technique, an impact element is still permitted, which guarantees a horizontal or, better, downward-directed spreading of the digestate. This makes it possible to keep NH_3 losses low in comparison. Nevertheless, the distribution accuracy suffers from external weather conditions, especially wind. Immediate incorporation into the soil is essential, especially at warm temperatures. The advantage of this technology is, in addition to the affordable purchase price, the potential application in growing stock and on grassland as well.

Significantly better lateral distribution and lower NH_3 losses during digestate spreading are achieved by attaching drag hoses to a linkage, which means that the digestate is fed directly to the soil at regular intervals.

Thanks to the simple technology and the light-weight, large working widths, high power output can be achieved. Since no pressure is exerted on the hoses, the digestate is partly deposited on plants in growing crops or on grassland, which can lead to damage to the plants in unfavourable weather conditions.

In addition to spreading with drag hoses, the use of drag or slit-shoe distributors is particularly suitable for existing crops. Pressure is exerted on the ground here by means of the attached steel springs. However, this should not be confused with an injection that requires much more ground pressure. The soil skids on the underside of the tractors open the crop and easily break up the soil (depending on the type and density of the soil), which favours infiltration of the digestate into the soil. At the same time, damage to the plants and the grass cover is largely prevented. Direct ground contact also reduces the potential for loss. However, the technical effort is higher and is noticeable in terms of weight and capital expenditure.

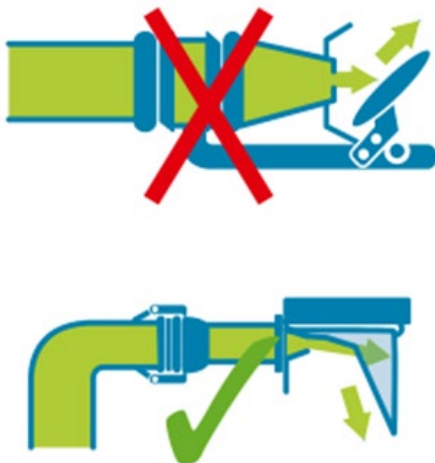
The injection with slitters, in which the digestate is introduced directly into the soil, is optimal with regard to losses and thus also plant availability. This procedure is also possible in the growing stock. In grassland in particular, the danger of excessive damage to the grass cover can be seen here. A method frequently used in biogas plants is underfoot fertilization by injection prior to maize sowing as a nutrient depot. Due to the complex technology and the great need for tractive power, such systems are mainly used on an inter-company basis and as self-propelled vehicles.

A variant of the slitter is called the slurry cultivator, where the digestate is spread and mixed with the soil in one operation. As with the slitting unit, this technology requires higher investments and enables comparatively small working widths. The liquid manure cultivator can only be used in uncloaked fields, which require different application techniques compared to growing crops. At the same time, it is in direct competition with drag hose application and subsequent incorporation with the conventional cultivator. The farmer, therefore, has two options: one pass with a small working width or two passes with a large working width? The criteria have again been listed in the figure “Properties of the different application techniques”.

The technique for spreading solid or separated digestate is carried out by the universal manure spreader. Systems with vertical or horizontal rollers are available. These spreaders can also be used to spread dried and pelletized digestate. In addition to the application technique, organisational measures can also contribute to achieving optimum nutrient utilisation. As previously mentioned, immediate incorporation is urgently required on non-grown soils. On grown soils, weathering also plays a major role in preventing NH_3 losses if the digestate is not introduced directly into the soil. Cool, humid conditions are ideal, followed by rainfall.

The NH_3 loss potential correlates with the pH value. One way to reduce it is to reduce the pH value by acidifying the digestate. Here, for example, ammonium sulphate solution with a pH value of about 5 can be used, which generally occurs in some treatment processes. Alternatively, sulphuric acid can be used. This method is also used in various digestate treatment processes to minimise emissions during the treatment and storage of dried digestate in particular. Digestate has a higher NH_4 content, which is converted to nitrate in the soil over time. This can lead to the loss of this nitrogen during periods of greatly reduced nutrient uptake by plants. In order to avoid this and to allow early “reservoir fertilization”, nitrification inhibitors (e.g., Piadin) can be used to slow down these conversion processes. An example of such storage fertilization is the previously presented underfoot fertilization before planting maize, in which a digestate depot is deposited in the soil.

Wide distribution





Appendix D – Presentation of Analytical Results

Digestate Product Analysis – Agricultural Use Information

Parameter	Units	Analysis Results	Applicable Quality Requirements	Quantity Applied	
				Lb per tonne applied (or per 1000 Imperial Gallons applied)	Kg per tonne applied (or per cubic meter applied)
Dry Matter	%				
Moisture Content	%				
Organic Matter	%				
Total Organic C	%				
Carbon to Nitrogen Ratio C : N	Ratio				
pH	Units				
Sodium Adsorption Ration (SAR)	Ratio				
Conductivity	(mS/cm @ 25°C)				
Bulk Density	kg/m ³ (as is)				
Total Nitrogen (N)	%				
NH ₄ -N	%				
NO ₃ -N	%				
Total Phosphorus (P)	%				
Phosphate (P as P ₂ O ₅)	%				
Available P (as P ₂ O ₅)	%				
Total Potassium (K)	%				
Potash (K as K ₂ O)	%				
Available K (as K ₂ O)	%				
Total Sulfur (s)	%				
Sulfur (as SO ₄)	%				
Available S (as SO ₄)	%				
Calcium (Ca)	%				
Available Ca	%				
Magnesium (Mg)	%				
Available Mg	%				
Sodium (Na)	%				
Available Na	%				
Total Boron (B)	ppm				
Total Chloride (Cl)	ppm				
Total Copper (Cu)	ppm				

Parameter	Units	Analysis Results	Applicable Quality Requirements	Quantity Applied	
				Lb per tonne applied (or per 1000 Imperial Gallons applied)	Kg per tonne applied (or per cubic meter applied)
Total Iron (Fe)	ppm				
Total Manganese (Mn)	ppm				
Total Molybdenum (Mo)	ppm				
Total Zinc (Zn)	ppm				

Digestate Product Analysis – Safety Information

Potentially Toxic Elements (PTEs)

Parameter	Units	Analysis Results	Applicable Quality Requirements	CFIA Max acceptable cumulative addition to soil over 45 years	
				kg/ha	
Arsenic (As)	ppm			15	
Cadmium (Cd)	ppm			4	
Chromium (Cr)	ppm			210	
Cobalt (Co)	ppm			30	
Copper (Cu)	ppm			150	
Lead (Pb)	ppm			100	
Mercury (Hg)	ppm			1	
Molybdenum (Mo)	ppm			4	
Nickel (Ni)	ppm			36	
Selenium (se)	ppm			2.8	
Zinc (Zn)	ppm			370	

Foreign Materials

Parameter	Units	Analysis Results	Applicable Quality Requirements
Total Foreign Material	% dry weight		
Total Plastic	% dry weight		

Pathogens and Indicators

Parameter	Units	Analysis Results	Applicable Quality Requirements
Fecal Coliform			
E. Coli			
Salmonella			

Appendix E – Summary of Relevant Federal and Provincial Policies

Federal

CFIA Fertilizer Registration Program

Regulatory management of digestate is generally defined on a provincial level. However, Agriculture and Agri-Food Canada, through the Canadian Food Inspection Agency (CFIA), administer the national [*Fertilizers Act*](#) and the fertilizer registration program. Digestate may be, but is not always, managed under the *Fertilizers Act* in Canada. Digestate producers may choose to market their product as a Fertilizer under the requirements of this legislation but would have to consider other environmental approvals issues by the local provincial environmental regulator. For example, Fertilizer (as registered under the Act), is explicitly recognized in the Province of Ontario within the provincial *Nutrient Management Act*, and as such Fertilizer is explicitly permitted for application to the land. Producers in Ontario have used this recognition to secure formal permission from their local environmental regulators to use this Fertilizer registration as their approved method of marketing their digestate. Not all provinces provide this regulatory connection, and producers should engage with their local environmental regulator before pursuing this strategy. At the time of writing, the only biogas facilities with digestate registered as fertilizer under the CFIA are located in Ontario.

The *Fertilizers Act and Regulations* requires that all regulated fertilizer and supplement products imported into or sold in Canada must be safe for humans, plants, animals, and the environment. They must also be properly labelled to ensure safe and appropriate use.

Fertilizer registration is granted if the fertilizer or supplement does not present a risk of harm to human, animal or plant health or the environment, except pests, if it is used as specified in its directions for use or in an amount that is not in excess of the amount that is necessary to achieve its intended purposes. The fertilizer registration must be renewed every 60 months.

A summary of requirements for fertilizers under the *Fertilizers Act* are as follows:

- A fertilizer or supplement must not contain:
 - Any substance or mixture of substances that would leave in the tissues of a plant a residue of a poisonous or harmful substance
 - Major plant nutrients, secondary nutrients or micronutrients that are present at toxic levels
 - Proteins derived from specified risk material, in any form, unless this use is authorized under a permit issued under section 160 of the Health of Animals Regulations
- Guaranteed analysis:
 - Minimum amount of total nitrogen, available phosphoric acid and soluble potash expressed in percent
 - Minimum amounts of secondary and micronutrients expressed in percent on an elemental basis
 - If organic matter is represented; the amount of organic matter expressed in percent, and
 - Moisture content expressed in percent

- Labelling
 - manufacturer's name and address, registration number, lot number, weight, guaranteed analysis
 - statement setting out any precaution that is necessary to mitigate a risk of harm to human, animal or plant health, or the environment (other than pests)
 - if the fertilizer or supplement is or contains prohibited material as defined in subsection 162(1) of the Health of Animals Regulations, statements that indicate that (i) feeding the fertilizer or supplement to cattle, sheep, deer or other ruminants is prohibited and punishable under the *Health of Animals Act*, (ii) the fertilizer or supplement is not to be used on pasture land or other grazing areas for ruminants, (iii) the fertilizer or supplement is not to be ingested, and (iv) a person must wash their hands after they use the fertilizer or supplement.
- Metals Limits
 - Digestate required to comply with maximum concentration requirements for 11 metals: arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). The specific concentration limits are product specific and are based on the expected annual application rate. The limits are conservative and are intended to account for long-term cumulative effects of metals on plant, animal and human health.
- Pathogens
 - Testing for the presence of Salmonella and Faecal Coliform is required to confirm the efficacy of pathogen reducing or sterilizing processes.

Organic Certification

CFIA regulates the [Canada Organic Regime](#). Part 13 of the [Safe Food for Canadians Regulations](#) (SFCR) outlines the Canada Organic Regime organic certification system. The purpose of the Canada Organic Regime is to regulate all parties involved in the certification of organic products (including operators, Certification Bodies and Conformity Verification Bodies) and to verify all applicable regulatory requirements, standards and guidance documents are being met.

Since 2015, digestate has been accepted for use in Certified Organic farming in Canada and is listed as a 'permitted substance', which may be employed in the operation of Certified Organic farms. Organic certification is performed by private, 3rd parties and is independent from any government registrations and/or approvals. To access this market, digestate producers would have to approach one of the approved organic certifying agencies, which operate in their Province and apply to have their particular digestate certified for this purpose.

The Centre for Systems Integration (CSI) is a division of Seeds Canada and is an organic Certification Body for the Canada Organic Regime accredited by the CFIA. At the time of writing, three digestate products are approved under CSI. The CSI operators producing inputs for organic production have been inspected and their products reviewed by CSI to verify that their input products meet the Canada Organic Regime (COR) requirements for the described use. CSI input approvals include products for use as crop fertility inputs, crop protection inputs, livestock feed inputs, livestock healthcare inputs, etc.

Provincial

Digestate management regulations vary from province to province and are often dependent on the feedstock mix and characteristics. Summaries of regulations are provided below for provinces in Canada with the most biogas development. It is recommended that digestate producers engage with their local environment regulator for specific regulatory requirements.

Quebec

The digestate is regulated via Quebec guidelines call [Guide des MRF'](#). The document refers to the current regulations for all fertilizing residual materials (MRF in Quebec, matières résiduelles fertilisantes).

This Guide regulates all types of anaerobic digestion (agricultural, municipal, industrial) using the same rules. To be able to be spread on land, the digestate needs to meet the requirements of the Guide.

Based on the classification of municipal biosolids, the digestate requirements are as follows:

- Should meet the contaminant, pathogens and other chemical requirements (table on page 86 in "Guide des MRF")
- Allowed to be spread to fertilize the cultures for animal use, silviculture and revegetation.
- Should be stored during maximum of 6 months in airtight tanks, 500 m from any residential areas
- Limit of 13.2 tonne of digestate per ha per 3 years

The plant operator can ask for a change of classification once is biogas plant is operating and can prove the quality of the digestate.

At the time of writing, the Bureau de normalisation du Quebec is proceeding to development on a standard for digestates produced by biomethanization (anaerobic digestion).

Ontario

Management of digestate in Ontario is regulated under the [Nutrient Management Act, O.Reg. 267/03](#).

Digestate is considered agricultural source material (ASM) if it is from a mixed AD facility that treated both on-farm and off-farm feedstocks, and at least 50 percent, by volume were on-farm AD materials. ADM materials can be applied by meeting the following conditions:

- Meet every requirement in Part VI of O. Reg. 267/03 that governs land application of agricultural source materials, prescribed materials or nutrients.
- Not apply this material to land within 150 m of the top of the bank of surface water if the maximum sustained slope of the land is 25 per cent or greater.
- Not use a high trajectory irrigation gun capable of spraying liquid more than 10 m unless the output is an aqueous solution or suspension containing more than 99 per cent water by weight.
- If direct flow land application systems are used, the requirements of section 50 in O. Reg. 267/03 for non-agricultural source materials will apply to anaerobic digestion output.

If the digestate is not from a regulated mixed anaerobic digestion facility (RMADF) under the *Nutrient Management Act*, the nutrient management plan for the farm unit must be followed for application of the digestate. If the farm is not required to have a nutrient management plan, land application of AD output on the farm land must be in accordance with the following rules:

- During any consecutive five-year period, the application rate must be such that the total available phosphate, per hectare, from all prescribed materials applied to land must not exceed the greater of:
 - crop production requirements per hectare for the five years plus 85 kilograms (kg) of phosphate per hectare, or
 - the phosphate removed from the land per hectare in the harvested portion of the crop during the five-year period plus 390 kg of phosphate per hectare
- During any 12-month period, the application rate occurs at such a rate that the total plant-available nitrogen from all prescribed materials applied to land must not exceed 200 kg of plant-available nitrogen per hectare.

Alberta

In Alberta biogas facilities where more than 50% of the feedstock by weight is manure will be governed by land application rules governed by [Agricultural Operations Practices Act](#) (AOPA) which is enforced by the Natural Resources Conservation Board.

In 2015, Alberta Environment and Sustainable Resource Development, Alberta Agricultural and Rural Development. And the Natural Resources Conservation Board came to a [Memorandum of Understanding](#) regarding on-farm storage and land application of digestate. They agreed that the Natural Resources Conservation Board assumed regulatory responsibility for the activities under AOPA as long as:

- Manure comprised at least 50% by weight of the feedstock, and
- The remained of the feedstock consists entirely of one of more feedstocks in a predetermined list (manures, fats, oils, and greases, food processing residues, kitchen and market residues, other organics)

British Columbia

Under the [Environmental Management Act](#), the B.C. Ministry of Environment (MoE) requires agricultural biogas plants to have a permit for releasing waste, such as upgrader and boiler exhaust emissions, air from storage tanks, and land application of digestate, into the environment. Biogas plants may also be required to apply for authorization under the regional district's waste management plan, which outlines how large amounts of waste will be managed including estimates of waste type, volume, and management method. As with the application for building on land zoned as agricultural, each regional district decides what is required in the authorization process, and the process, information required and time it takes can vary greatly between regional districts.

If a facility processes 100% manure, The [Code of Practice for Agricultural Environmental Management](#) (AEM Code) sets requirements on the use of nutrients supplied to crops to make sure nutrients are applied at the right amount and right time to optimize crop growth and minimize risks to the environment.

Glossary

Acidification – reducing the pH of digestate through the controlled addition of acid or other substance for the purpose of reducing ammonia emissions or biogas generation.

Anaerobic Digestion (AD) – The biodegradation or decomposition of organic matter by naturally occurring microorganisms in an oxygen-free environment. As a result of this biodegradation, the microbes generate biogas and digestate. The biogas generated through anaerobic digestion can be used primarily to 1) fuel electrical generators, or 2) it can be further processed into renewable natural gas. The digestate can be used in agricultural and horticulture operations as an organic fertilizer or organic soil amendment either directly or following treatment by aerobic composting or other process.

Anoxic – An environment where no oxygen is available.

Best Management Practices – Proven, practical and efficient approaches for maximizing the benefits of using digestate as an organic fertilizer or soil amendment while protecting health and the environment. Best management practices are described in *Part 4* of this Guide.

Biodegradability – The extent to which an organic material can be broken down by biological processes. The biodegradability of specific feedstock materials by anaerobic digestion can be estimated from laboratory measurements of COD and BMP.

Biogas – A gaseous by-product of the anaerobic digestion process. The major components of biogas are methane (CH_4) and carbon dioxide (CO_2). Biogas normally consists of 50-60 percent methane.

Biological Oxygen Demand or Biochemical Oxygen Demand (BOD) – A laboratory test for determining how much oxygen biological microorganisms use up in a body of water over a period of time. The oxygen is used to oxidize organics and other waste materials. The standard test duration in most regulations is a five-day test, referred to as the BOD5.

Biomethane – another term used for Renewable Natural Gas, see Renewable Natural Gas.

Biochemical Methane Potential (BMP) – A laboratory test for determining how much biogas and how much methane a specific feedstock can generate under ideal laboratory conditions. This test assesses the suitability of organic waste streams for anaerobic digestion and biomethane production.

Biosolids – The organic material resulting from the treatment of municipal sewage sludge. Biosolids are nutrient-rich and are often recycled as a fertilizer and soil amendment.

Bovine Spongiform Encephalopathy (BSE) – Informally called mad cow disease, is a fatal disease of cattle. Residuals from cattle slaughter that may contain BSE infected materials are called Specified Risk Materials (SRM) and are subject to regulation by the Canadian Food Inspection Agency (CFIA). SRM is a prohibited feedstock unless preprocessed in a CFIA approved treatment system.

Carbon Intensity (CI) – The emission rate of carbon relative to a unit of production or activity. This value is a score for a facility that is created by modeling a full life cycle analysis of the project, including feedstock, biogas upgrading, coproducts, energy consumption, finished fuel delivery, and many other factors. The Carbon Intensity is used in relation to the sale of RNG to California and other jurisdictions. For an AD facility, this could be carbon per tonne processed or per GJ of energy produced.

Carbon to Nitrogen (C:N) Ratio – The quotient of the weight of organic carbon to the weight of total nitrogen present in a material. For materials intended or expected to undergo biological decomposition, the C:N ratio is a useful indicator of the rate of decomposition. For organic soil amendments, the C:N ratio is a useful indicator of nitrogen dynamics in the treated soil.

Certified Crop Advisor – A person who holds a current Certified Crop Advisor or similar certification issued by an authorized institution or professional organization.

Chemical Oxygen Demand (COD) – A laboratory test that measures the amount of organic matter in a sample. The COD is the total amount of oxygen required to chemically oxidize the organic material in a sample. This is one way to measure the fuel value of feedstock. In the digester, a portion of the feedstock COD is converted to biogas. The amount of methane produced per kilogram of COD converted in the digester is constant, regardless of the type of feedstock.

Circular Economy – An economic system where, ideally, waste does not exist. In practice, the value of products and materials is maintained for as long as possible. Waste is minimized and resources including nutrients continue to re-circulate within the economy, to be used again to create further value.

Cover Crop – A crop grown for the protection or enrichment of the soil.

Delivery Documentation – Documentation provided by a digestate producer to inform a digestate user of the origin and characteristics of the digestate and providing instructions for safe handling, storage and use.

Digestate – The material resulting from the anaerobic digestion of feedstock materials at a biogas plant. Digestate can be used in agricultural and horticulture operations as an organic fertilizer or organic soil amendment either directly or following treatment by aerobic composting or other process. See also Whole Digestate, Liquid Digestate and Solid Digestate.

Dry Matter – The matter remaining after removal of water by drying. Laboratory methods for measuring the Dry Matter content of a substance typically require heating to 105°C for a specific period of time or until a constant weight is reached. Also referred to as Total Solids.

Effective Organic Matter (EOM) – The proportion of the applied organic matter remaining in soil one year following application.

Feedstock – A source of plant or animal origin organic matter that can be effectively converted by anaerobic digestion into biogas and digestate meeting applicable quality requirements for use as an organic fertilizer or soil amendment.

Fats, Oil, and Grease (FOG) – A laboratory test that measures the total amount of fats, oils, and greases in a sample. FOG concentrations in a feedstock or in the digester are measured to allow the digester operator to understand the composition of their feedstock and maintain stable digester health.

Global Warming Potential – The amount of energy the emissions of a gas will absorb over a given period compared to the energy absorbed by an emission of the same mass of carbon dioxide.

Greenhouse Gases (GHGs) – Gases that trap heat in the atmosphere.

Guaranteed Analysis – The minimum amounts of crop nutrients claimed to be present in a fertilizer product, usually expressed as a percentage of the weight of the fertilizer product.

Heavy Metals – see Potentially Toxic Elements.

Hydraulic Retention Time (HRT) – The average time interval over which material is retained within the anaerobic digestion vessel, which is determined by the loading rate and operational digester capacity.

Hydrolysis – The chemical breakdown of a compound due to reaction with water.

Immobilization – The conversion of inorganic compounds to organic compounds by micro-organisms or plants by which the compounds become inaccessible to plants. Immobilization is the opposite of mineralization.

Liquid Digestate – The liquid fraction resulting from digestate conditioning by mechanical liquid-solid separation processes.

Long-Chain Fatty Acids (LCFAs) – A laboratory test that measures the amount and type of different organic fatty acids, for example, palmitic acid and oleic acid. LCFA concentrations indicate the amount of saturated and unsaturated fats in a feedstock or in the digester and allow for the digester operator to understand the composition of their feedstock in order to maintain stable digester health.

Mesophilic – Anaerobic digestion operated within the temperature range 30 °C to 45 °C.

Microbial biomass – The mass of living microorganisms including bacteria and fungi. The living component of soil organic matter.

Micronutrients – A chemical element or substance required in trace amounts for the normal growth and development of living organisms.

Mineral Fertilizer – Fertilizers containing only inorganic materials produced from extracted and non-renewable resources.

Mineralization – the decomposition (i.e., oxidation) of the chemical compounds in organic matter, by which the nutrients in those compounds are released in soluble inorganic forms that may be available to plants. Mineralization is the opposite of immobilization.

Organic Carbon – The carbon present in organic matter.

Organic Fertilizer – Fertilizer products derived from plant and animal materials and containing useful amounts of plant nutrients.

Organic Matter or Organic Material – A large group of carbon-based compounds including proteins, carbohydrates, lipids, hemi-cellulose, cellulose and lignin present in plant and animal tissue and animal feces. Soil organic matter is the fraction of the soil that consists of organic matter including organic matter in various stages of decomposition and compounds synthesized by soil organisms such as humus.

Organic Nitrogen – The nitrogen present in organic matter, particularly in proteins and amino acids.

Organic Soil Amendment – Materials of plant or animal origin applied to improve the physical, biological and fertility properties of soil.

pH – A measurement of the intensity of the alkaline or acidic strength of water. Values normally range from 0 – 14, where 0 is the most acidic and 14 is the most alkaline and 7 is neutral.

Pasteurization – A process to inactivate pathogenic organisms in a material by exposure to elevated temperatures for specified periods. Time and temperature requirements are set out in applicable regulations. Typical requirements are at least one hour at no less than 70°C or at least 20 hours at no less than 50°C.

Pathogens – A bacterium, virus, fungus or other microorganism that can cause disease.

Potentially Toxic Elements (PTEs) – A group of elements identified in regulations for the purpose of limiting their application to or concentration in soil. The commonly regulated heavy metals are: arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se), Zinc (Zn). Also referred to as Heavy Metals.

Pre-Sidedress Nitrate Test (PSNT) – A procedure to measure the amount of nitrate nitrogen in the surface 30 cm of soil prior to a sidedress fertilizer application to a growing corn crop.

Primary Nutrients – Nitrogen (N), Phosphorus (P) and Potassium (K).

Prohibited Material – As defined in the *Health of Animals Act and Regulations 2021* and means anything that is, or that contains any:

- protein that originated from a mammal, other than a porcine or equine; milk or products of milk;
- gelatin derived exclusively from hides or skins or products of gelatin derived exclusively from hides or skins;
- blood or products of blood; or
- rendered fats, derived from ruminants, that contain no more than 0.15% insoluble impurities or their products.

Prohibited material that has been treated in a manner approved by the Minister to inactivate the agents that cause transmissible spongiform encephalopathies is no longer prohibited material.

Renewable Natural Gas (RNG) or biomethane – A biogas which has been upgraded to a quality that meets the quality requirements for injection into the natural gas grid. RNG is similar to fossil natural gas and typically has a methane concentration of 95 percent or greater.

Salinity – An indication of the total salt content of a material.

Secondary Nutrients – Calcium (Ca), Magnesium (Mg), Sulfur (S).

Sidedress – An application of fertilizer between the rows of growing crops.

Sludge – Is a slurry mixture of water and solids. Sludge can be of different consistencies, although most sludges are typically considered to be pumpable.

Solid Digestate – The solid fraction resulting from digestate conditioning by mechanical liquid – solid separation processes.

Source Separated Organics (SSO) – Organic waste that has been separated from other waste by the waste generator, generally under a program (for example, a municipal green bin program). Typically, SSO includes food waste, both avoidable and unavoidable, non-recyclable paper such as tissue and paper-toweling, and may contain leaf and yard waste. A minority of municipal green bin programs also allow diapers, pet waste, and sanitary products. The composition of each SSO stream is unique to the input components collected in the respective program.

Specified Risk Material (SRM) – As defined in the *Health of Animals Act and Regulations 2021* means specific organs and other material left over from cattle slaughter that may contain BSE infectivity. Special guidelines are in place for this material to prevent BSE from entering the human food chain, including the production of animal feed, pet food, and fertilizers. SRM is a prohibited feedstock unless preprocessed in a CFIA approved treatment system. Refer directly to appropriate CFIA references for the precise technical definition of SRM materials and SRM management protocols.

Stability – The degree to which the rate of biological activity has slowed to an acceptably low and consistent level and will not significantly increase under favourable, altered conditions.

Soil Organic Matter – See organic matter.

Synthetic Fertilizer – See mineral fertilizer.

Thermophilic – Anaerobic digestion operated within the temperature range 45 °C to 80 °C

Topdress – Application of fertilizer to the surface layer of soil, often as a second round of nitrogen following a pre-plant fertilizer application.

Total Ammoniacal Nitrogen (TAN) – Nitrogen in the forms of ammonia (NH₃) and ammonium (NH₄).

Total Kjeldahl Nitrogen (TKN) – Organic nitrogen plus total ammoniacal nitrogen.

Trace Organic Contaminants – Natural and manufactured chemicals or by-products of industrial processes that are characterized by their persistence and movement in the environment, their ability to bioaccumulate, and their ability to cause toxic effects in humans and animals at low concentrations.

Total Solids – See Dry Matter.

Vector and Vermin – A vector is an organism that can transmit infection. For example, insects such as fleas, flies, and mosquitoes can be vectors. Rodents are generally considered “vermin”, and these can serve as hosts for vectors; for example, a disease carrying flea (vector) living and moving on a rat (vermin) host.

Volatilization – The conversion of a liquid chemical into a vapor, which escapes into the atmosphere.

Volatile Organic Compounds (VOC) – Organic compounds that have a low boiling point and high vapor pressure at room temperature – traits which are referred to as volatility. VOCs are a major contributor to odours typically associated with manure and other organic fertilizers or soil amendments.

Volatile Solids (VS) – Volatile solids is a laboratory measurement whereby the solids that are lost, or “burned off,” on ignition of dry solids at 550° Celsius are measured. The volatile solids measurement is a simplified way to estimate the organic matter, and hence the fuel value, of a specific feedstock. The amount of methane produced per kilogram of VS in the feedstock depends on the type of feedstock.

Volatile Fatty Acids (VFAs) or Short-Chain Fatty Acids (SCFAs) – A laboratory test that measures the amount and type of organic acids, for example, acetic acid (commonly called vinegar) in a sample. Organic acids are produced by microbes during the early part of the anaerobic digestion process. These organic acids are also produced in silage from sugars and other carbohydrate sources. Volatile fatty acids are volatile, which means that they will volatilize in air, depending on temperature. If released into the air, VFAs can be quite odourous.

Whole Digestate – Digestate that has not been transformed by mechanical liquid-solid separation or other process.

Abbreviations

AD – Anaerobic Digestion
BMP – Biochemical Methane Potential
BOD – Biochemical Oxygen Demand
BSE – Bovine Spongiform Encephalopathy, informally called “mad cow disease”
C:N ratio – Carbon to Nitrogen Ratio
CFIA – Canadian Food Inspection Agency
CI – Carbon Intensity
COD – Chemical Oxygen Demand
DM – Dry Matter
FOG – Fats, Oils, and Grease
FW – Fresh Weight
GHG – Greenhouse Gas
HRT – Hydraulic Retention Time
LCFA – Long-chain fatty acids
N-P-K – Nitrogen, Phosphorous, Potassium
PPM – Parts per Million
PSNT – Pre-Sidedress Nitrate Test
PTE – Potentially Toxic Element
RNG – Renewable Natural Gas
SSO – Source Separated Organics
TAN – Total Ammoniacal Nitrogen
TOC – Trace Organic Contaminant
TS – Total Solids
VFA – Volatile Fatty Acids
VOC – Volatile Organic Compound
VS – Volatile Solids

Chemical Symbols

CO₂ – Carbon Dioxide
H₂S – Hydrogen Sulfide
H₂SO₄ – Sulfuric Acid
HCl – Hydrochloric Acid
HNO₃ – Nitric Acid
K₂O – Potash
N₂O – Nitrous Oxide
NH₃ – Ammonia
NH₄ – Ammonium
NO₃ – Nitrate
P₂O₅ – Phosphorus Pentoxide
PO₄³⁻ – Phosphate, also known as Orthophosphate
SO₄²⁻ – Sulfate