6. Organic Nutrient Sources: Manure, Biosolids, Legumes

Organic nutrient sources are materials that contain carbon and were once part of a living organism. The most commonly used organic nutrient sources on Ontario farms are livestock manure and residues from crops like forage legumes. There are also materials from municipal or industrial sources known collectively as non-agricultural source materials (NASM) that are suitable for land application (e.g., biosolids). Urea fertilizer, while it contains carbon in its chemical structure, is manufactured, and so it is not normally considered to be an organic nutrient source.

For management purposes, organic nutrient sources can be divided into two groups: land-applied materials and crop residues. The land-applied materials, such as manure, biosolids and compost, can be applied at different rates, timings and locations to meet the nutrient requirements of a particular crop in a field. In contrast, crop residues are limited to the field where they were grown. While any type of crop residue will influence the cycling of nutrients through the soil, forage legumes provide the greatest quantity of nutrients to the following crop. Cover crops may also be used to capture excess nutrients and relay them to the next crop.

Organic Nutrients — Not just for organic agriculture

While organic agriculture uses organic nutrient sources, these materials fit just as well in a conventional cropping system. The key in both systems is managing the organic materials to provide nutrients, in available forms, to the crop while avoiding over-application. The difference is that in conventional systems the grower has the option of making up any nutrient shortfall in the organic materials with commercial fertilizer. Organic farmers will also occasionally use supplemental nutrients but from a more restrictive list of permitted substances.

Nutrients from land-applied materials

Similarities among materials

There is a wide range of organic materials that can be used as nutrient sources but they have some characteristics in common. They all contain a mix of mineral nutrient sources and organic materials, in various proportions that depend on livestock ration, feedstock, carbon sources, amount and type of bedding or dilution materials, as well as material storage and/or treatment.

The mineral forms of nutrients in an organic material are chemically identical to the nutrients in commercial fertilizer and are in the form that crops can take up immediately. However, nutrients in commercial fertilizers can be lost to the environment more easily than the same nutrients bound within an organic compound. In manure, for example, the nitrogen is split between organic compounds and ammonium. The ammonium nitrogen is the same chemical compound as aqua ammonia or as anhydrous ammonia that has dissolved in soil water. Ammonium is immediately available for plant uptake, but like aqua ammonia, if this material is left on the soil surface, it will vaporize into the air and be lost as ammonia. This results in a significant reduction in available nitrogen from manure that is not incorporated into the soil. The proportion of ammonium nitrogen in various organic materials is shown in Table 6–1.

Organic compounds are less subject to loss. They are not available to plants until they are mineralized (broken down to the mineral forms) by bacteria and other soil organisms or by chemical reduction. The speed at which mineralization happens depends on how easy or difficult the organic compounds are to break down, the soil conditions (temperature, moisture, aeration, pH, etc.) and the physical contact between the materials and the soil.

Whether the material is of human or animal origin matters less than how it has been managed. Each material will go through similar chemical and biological transformations in the soil.

Table 6–1. Proportion of total nitrogen present as ammonium*
(typical values expressed as % of total N, as applied to land)

Nutrient type	Ammonium-N
liquid hog	66%
liquid dairy	42%
liquid beef	43%
liquid poultry	67%
solid hog	26%
solid dairy	21%
solid beef (high bedding)	12%
solid horse	15%
solid poultry (broilers)	6%
solid poultry (layers)	46%
composted cattle manure	0.6%
municipal sewage biosolids:	
aerobic	1.6%
anaerobic	35%
dewatered	12%
lime stabilized	trace
paper mill biosolids	trace
spent mushroom compost	5%

* As the liquid concentration of the material increases, the ammonium content also increases. *Source:* NMAN3 manure database

Differences between materials

The fundamental difference between different types of manure and between manure and other organic amendments is the amount and type of dilution material added or removed and the treatment or processing of materials they are applied to land. On most livestock farms, the urine and feces are diluted with either bedding to form a solid manure or water to form a liquid. All of the resulting material is usually applied to land. Municipal sewage biosolids, on the other hand, are highly diluted when they enter the treatment plant.

The goal of sewage treatment is to remove and clean most of the water for release into the environment. The remaining portion (a by-product of this process) is either further processed for a specific market (e.g., N-Viro) or is applied to land.

Livestock type and diet

Manure will vary between farms in form and nutrient content. Livestock species vary in the type of ration they are normally fed, with ruminants generally receiving diets that are high in forages, while monogastric (hog or poultry) diets are more concentrated. This means that ruminant manure will contain more fibre and have a lower nutrient concentration than most hog or poultry manure. Rations for young livestock are normally higher in protein and minerals than the feed for mature animals, so the nutrient content of the manure will also be higher from these animals. Changes in the ration, such as the inclusion of the enzyme phytase in the diet or amino acid balancing to reduce protein requirements, will have significant effects on the nutrient content of the manure excreted by the animal. Average macronutrient and micronutrient contents for various manure types are shown in Table 6–2.

Some manures undergo further treatment for a variety of purposes. Liquid-solid separation, for example, can be used to separate manure solids for re-use as a thin layer of bedding. Composting is an aerobic process that greatly reduces manure volume and can improve spreadability. Carbon-to-nitrogen ratios and moisture content are extremely important in composting: if the material is properly managed and cured, N is incorporated into organic compounds and there is negligible nitrate or ammonium remaining. Anaerobic digestion is a process that converts part of the organic compounds in the manure into methane gas for heating or electrical generation and leaves much of the nitrogen in the ammonium form.

Options to Reduce the Nutrient Content of Manure

- **Balance the ration properly.** Nutrients in excess of livestock requirements will simply be excreted in the manure. Phase feeding and split-sex feeding will match nutrient needs at different stages in production. A manure analysis that includes micronutrients can be useful in comparing manure nutrients to average values for a specific livestock type.
- **Minimize feed wastage.** Inspecting, adjusting and cleaning feeders regularly and using feed equipment designs that minimize spillage will reduce feed nutrients in manure.
- **Add phytase enzyme to rations** for hogs or poultry and reduce supplemental phosphorus accordingly. This enables them to digest much of the phosphorus in grains that would be otherwise unavailable and therefore bypassed to the manure.
- **Balance the amino acids in the feed** so the livestock have enough to meet their needs without feeding excess protein. This will reduce the nitrogen content of the manure.

Table 6–2. Average nutrient analyses of liquid and solid livestock manures

Data from manure analysis provided from Ontario laboratories collected between 1992 and 2018. Micronutrient data is obtained from a smaller subset of data. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

LEGEND: — = data not available Aver. DM = average dry matter comp. = composite

Manure type	Manure sub-type	Aver. DM (%)	Total N[1] (%)	NH_4-N (ppm)	P (%)[2]	K (%)	Ca (ppm)	Mg (ppm)	S (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)
Liquid livestock manures												
Hogs	sows (SEW)	1.7	0.24	0.18	0.06	0.11	550	275	50	60	20	10
	weaners	2.3	0.28	0.19	0.09	0.15	775	400	150	75	25	15
	finishers	4.9	0.52	0.36	0.15	0.27	1,900	1,500	700	115	50	40
	farrow to finish	3.8	0.43	0.29	0.10	0.21	1,500	650	300	100	35	25
Dairy	comp.	8.6	0.39	0.16	0.09	0.25	3,500	1,100	350	35	15	30
	thick	14.1	0.53	0.18	0.14	0.31	4,250	3,350	500	115	35	95
	fluid	4.4	0.25	0.12	0.04	0.19	2,500	700	300	100	35	30
	watery	1.1	0.12	0.06	0.02	0.11	375	150	45	45	15	5
Beef	comp.	8.6	0.37	0.15	0.08	0.23	4,000	1,850	350	50	10	50
Runoff	comp.	0.6	0.05	0.03	0.01	0.08	250	110	50	5	3	2
Mink	comp.	3.6	0.45	0.26	0.12	0.10	1,000	285	450	80	5	10
Veal (milk-fed)	comp.	1.5	0.08	0.06	0.02	0.18	—	—	—	—	—	—
Chickens	layers	9.9	0.81	0.56	0.27	0.29	15,000	850	1,500	70	10	65
	pullets	15.3	1.04	0.62	0.40	0.34	22,000	1,000	—	80	10	85
Biosolids	aerobic	2.0	0.12	0.01	0.06	0.00	—	—	—	—	—	—
	anaerobic	4.4	0.28	0.08	0.14	0.00	—	—	—	—	—	—
Solid livestock manures												
Hogs	comp.	30.8	0.93	0.29	0.49	0.57	5,000	2,050	—	160	75	150
Dairy	light bedding	21.2	0.69	0.16	0.20	0.60	7,000	2,500	1,000	90	25	90
	heavy bedding	41.0	0.82	0.11	0.21	0.66	10,000	4,500	550	50	20	90
Beef	light bedding	24.1	0.70	0.14	0.22	0.55	8,500	3,500	—	100	30	100
	medium bedding	34.5	1.03	0.20	0.37	0.74	10,000	3,200	—	140	30	110
	heavy bedding	45.6	1.34	0.25	0.54	0.87	11,500	3,000	—	150	30	120
Sheep	comp.	32.2	0.87	0.28	0.34	0.76	14,000	3,800	—	240	20	140

[1] Total N = Ammonium-N + Organic-N

[2] % P = total phosphorus

Table 6–2. Average nutrient analyses of liquid and solid livestock manures

Data from manure analysis provided from Ontario laboratories collected between 1992 and 2018. Micronutrient data is obtained from a smaller subset of data. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

LEGEND: — = data not available   Aver. DM = average dry matter   comp. = composite

Manure type	Manure sub-type	Aver. DM (%)	Total N[1] (%)	NH_4-N (ppm)	P (%)[2]	K (%)	Ca (ppm)	Mg (ppm)	S (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)
Solid livestock manures (continued)												
Dairy goats	comp.	35.7	1.04	0.28	0.28	1.03	15,000	1,100	—	50	20	50
Compost	cured	45.7	0.84	0.00	0.26	0.45	21,000	4,000	1,350	80	40	110
	immature	47.2	1.32	0.12	0.41	1.05	25,000	3,600	1,350	85	40	110
Veal (grain fed)	comp.	30.5	0.79	0.14	0.19	0.51	7,000	3,000	—	75	10	65
Horses	comp.	37.4	0.50	0.07	0.15	0.43	9,000	2,500	—	70	25	110
Mink	comp.	45.8	3.28	1.42	1.82	0.79	20,500	2,000	6,800	800	30	140
Chickens	layers	37.3	2.07	0.81	1.00	0.98	48,000	600	3,000	230	30	220
	pullets	42.6	3.19	0.70	1.38	1.39	—	—	—	—	—	—
	broilers	66.1	3.12	0.66	1.41	1.79	21,571	800	3,500	380	50	350
	broiler-breeder growers	62.8	1.88	0.29	1.42	1.29	—	—	—	—	—	—
	broiler-breeder layers	65.1	2.21	0.32	1.58	1.56	—	—	—	—	—	—
Turkeys	toms	52.3	2.62	0.87	1.38	1.59	12,700	2,800	—	—	—	—
	poults	70.5	3.31	0.66	0.90	1.22	—	—	—	—	—	—
	breeders	54.8	2.16	0.86	1.30	1.35	23,000	7,000	—	—	—	—
	broilers	61.8	3.35	0.60	1.21	1.42	26,000	7,000	—	500	200	530
Biosolids	comp.	32.1	3.76	0.64	1.31	0.11	—	—	—	—	—	—

[1] Total N = Ammonium-N + Organic-N

[2] % P = total phosphorus

Manure handling and treatment

The manure handling and collection system in the barn will mix the manure with various dilution materials. In solid manure systems this is the straw or wood shavings used for bedding, while in liquid systems it is water spilled from drinkers or washwater. There is tremendous variability in the amount of dilution in various systems. Typical amounts of available nutrients for various manure types and organic amendments are shown in Tables 6–2 through 6–7.

Table 6–3. Approximate amounts of available nutrients from liquid manure types (as applied) — kg/m³

Type of manure	**Manure sub-type**	**Aver. dry matter (%)**	**Nitrogen[1] Fall applied[2]**	**Nitrogen[1] Spring applied**	**P_2O_5[3]**	**K_2O**	**Number of samples**
			kg/m³				
Hogs	sows (SEW)	1.7	0.8	1.6	0.6	1.2	327
	weaners	2.3	1.0	1.9	0.8	1.6	77
	finishers	4.9	1.8	3.3	1.4	2.9	458
	farrow to finish	3.8	1.5	2.8	0.9	2.3	119
Dairy	composite	8.6	1.2	1.8	0.8	2.7	2,449
	thick	14.1	1.6	2.1	1.3	3.3	724
	fluid	4.4	0.8	1.3	0.4	2.1	532
	watery	1.1	0.4	0.8	0.2	1.2	128
Beef	composite	8.6	1.1	1.6	0.7	2.5	154
Runoff	composite	0.7	0.2	0.3	0.1	1.0	49
Mink	composite	3.6	1.6	3.1	0.9	1.0	22
Veal (milk-fed)	composite	1.5	0.2	0.4	0.2	1.9	3
Chickens	layers	9.9	2.8	4.8	2.5	3.1	81
	pullets	15.3	3.6	5.8	3.7	3.7	11
Biosolids	aerobic	2.0	0.4	0.8	0.6	0.0	10
	anaerobic	4.4	1.0	1.7	1.3	0.0	39

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hr

[2] Assumes an application date of early October

[3] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining phosphorus becomes available by the following year.

Data from manure analysis performed at University of Guelph, Stratford Agri-Analysis, A&L Canada Labs and Agrifood Labs between 1991 and 2018. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

Available phosphate is calculated as 40% of total phosphate in the manure. Available K_2O is calculated as 90% of the total K_2O.

Table 6–4. Approximate amounts of available nutrients from liquid manure types (as applied) — lb/1,000 gal

Type of manure	Manure sub-type	Aver. dry matter (%)	Nitrogen[1] Fall applied[2]	Nitrogen[1] Spring applied	P_2O_5[3]	K_2O	Number of samples
			lb/1,000 gal				
Hogs	sows (SEW)	1.7	8.4	16.3	5.5	11.9	327
	weaners	2.3	9.8	18.9	8.3	16.2	77
	finishers	4.9	18.2	33.4	13.8	29.2	458
	farrow to finish	3.8	15.1	28.2	9.2	22.7	119
Dairy	composite	8.6	11.7	18.1	8.3	27.0	2,449
	thick	14.1	15.9	20.9	12.9	33.5	724
	fluid	4.4	7.5	13.4	3.7	20.5	532
	watery	1.1	3.6	8.4	1.8	11.9	128
Beef	composite	8.6	11.1	16.3	7.4	24.8	154
Runoff	composite	0.7	1.5	2.9	0.9	9.7	49
Mink	composite	3.6	15.8	31.4	9.2	9.7	22
Veal (milk-fed)	composite	1.5	2.4	3.7	1.8	19.4	3
Chickens	layers	9.9	28.4	47.6	24.8	31.3	81
	pullets	15.3	36.4	58.5	36.8	36.7	11
Biosolids	aerobic	2.0	4.2	7.8	5.5	0.0	10
	anaerobic	4.4	9.8	17.4	12.9	0.0	39

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hours

[2] Assumes an application date of early October

[3] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining phosphorus becomes available by the following year.

Data from manure analysis performed at University of Guelph, Stratford Agri-Analysis, A&L Canada Labs and Agrifood Labs between 1991 and 2018. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

Available phosphate is calculated as 40% of total phosphate in the manure. Available K_2O is calculated as 90% of the total K_2O.

Table 6–5. Approximate amounts of available nutrients from solid manure types (as applied) — kg/tonne

Type of manure	Manure sub-type	Aver. dry matter (%)	Nitrogen[1]		P_2O_5[3]	K_2O	Number of samples
			Fall applied[2]	Spring applied			
			kg/tonne				
Hogs	composite	30.8	3.7	3.6	4.5	6.2	80
Dairy	light bedding	21.2	2.1	3.0	1.8	6.5	86
	heavy bedding	41.0	2.5	1.3	1.9	7.1	278
Beef	light bedding	24.1	2.1	2.7	2.0	5.9	416
	medium bedding	34.5	3.1	4.2	3.4	8.0	203
	heavy bedding	45.6	4.0	5.3	5.0	9.4	157
Sheep	composite	32.2	2.6	2.8	3.1	8.2	73
Dairy goats	composite	35.7	3.1	3.9	2.6	11.1	45
Compost	cured	45.7	3.4	1.0	2.4	4.9	37
	immature	47.2	5.3	5.2	3.8	11.3	40
Veal (grain fed)	composite	30.5	2.4	2.6	1.7	5.5	16
Horses	composite	37.4	1.5	-1.3	1.4	4.6	41
Mink	composite	45.8	16.4	21.8	16.7	8.5	104
Chickens	layers	37.3	10.4	12.6	9.2	10.6	224
	pullets	42.6	16.0	23.2	12.7	15.0	78
	broilers	66.1	15.6	18.8	13.0	19.3	193
	broiler-breeder growers	62.8	9.4	7.8	13.1	13.9	26
	broiler-breeder layers	65.1	11.1	10.7	14.5	16.8	74
Turkeys	toms	52.3	13.1	15.5	12.7	17.2	33
	poults	70.5	16.6	20.0	8.3	13.2	2
	breeders	54.8	10.8	10.5	12.0	14.6	12
	broilers	61.8	16.8	21.9	11.1	15.3	6
Biosolids	composite	32.1	15.0	30.8	12.1	1.2	89

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hr

[2] Assumes an application date of early October

[3] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining phosphorus becomes available by the following year.

Data from manure analysis performed at University of Guelph, Stratford Agri-Analysis, A&L Canada Labs and Agrifood Labs between 1991 and 2018. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

Available phosphate is calculated as 40% of total phosphate in the manure. Available K_2O is calculated as 90% of the total K_2O.

Table 6–6. Approximate amounts of available nutrients from solid manure types (as applied) — lb/ton

Type of manure	Manure sub-type	Aver. dry matter (%)	Nitrogen[1] Fall applied[2] (lb/ton)	Nitrogen[1] Spring applied (lb/ton)	P_2O_5[3] (lb/ton)	K_2O (lb/ton)	Number of samples
Hogs	composite	30.8	7.4	7.1	9.0	12.3	80
Dairy	light bedding	21.2	4.1	6.1	3.7	13.0	86
	heavy bedding	41.0	4.9	2.5	3.9	14.3	278
Beef	light bedding	24.1	4.2	5.5	4.0	11.9	416
	medium bedding	34.5	6.2	8.4	6.8	16.0	203
	heavy bedding	45.6	8.0	10.7	9.9	18.8	157
Sheep	composite	32.2	5.2	5.5	6.3	16.4	73
Dairy goats	composite	35.7	6.2	7.8	5.2	22.2	45
Compost	cured	45.7	6.7	1.9	4.8	9.7	37
	immature	47.2	10.6	10.4	7.5	22.7	40
Veal (grain fed)	composite	30.5	4.7	5.2	3.5	11.0	16
Horses	composite	37.4	3.0	-2.5	2.8	9.3	41
Mink	composite	45.8	32.8	43.6	33.5	17.1	104
Chickens	layers	37.3	20.7	25.2	18.4	21.2	224
	pullets	42.6	31.9	46.4	25.4	30.0	78
	broilers	66.1	31.2	37.6	25.9	38.7	193
	broiler-breeder growers	62.8	18.8	15.7	26.1	27.9	26
	broiler-breeder layers	65.1	22.1	21.4	29.1	33.7	74
Turkeys	toms	52.3	26.2	31.0	25.4	34.3	33
	poults	70.5	33.1	40.0	16.6	26.4	2
	breeders	54.8	21.6	21.1	23.9	29.2	12
	broilers	61.8	33.5	43.9	22.3	30.7	6
Biosolids	composite	32.1	30.1	61.5	24.1	2.4	89

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hr

[2] Assumes an application date of early October

[3] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining phosphorus becomes available by the following year.

Data from manure analysis performed at University of Guelph, Stratford Agri-Analysis, A&L Canada Labs and Agrifood Labs between 1991 and 2018. Micronutrient concentration is highly dependent on animal diet, so will vary widely between farms. An actual analysis is the best source of information.

Available phosphate is calculated as 40% of total phosphate in the manure. Available K_2O is calculated as 90% of the total K_2O.

Table 6–7. Typical nutrient contents of municipal organic amendments (dry weight)

LEGEND: — = data not available

Type of amendment	Material	Aver. dry matter (%)	Dry matter basis: Total Nitrogen (%)	NH_4-N (%)	Usable N in year applied (%)	Available P_2O_5 (%)	Available K_2O (%)
Municipal sewage biosolids	aerobic	1.7	5.0	0.01–0.75	0.08	2.5	>0.01
	anaerobic	3.0	6.4	0.33–3.4	2.7	3.3	>0.01
	dewatered	26	3.6	0.35–0.65	1.0	2.5	>0.01
	pelletized	—	—	trace	0.8	4.5	>0.01
Paper mill biosolids	primary	50	0.3	trace	0.1	trace	trace
	primary + secondary	32.8	2.5	—	1.4	.08	0.02
Distillers grains	dried	90	5.0	0.5	3.0	1.5	1.2
Other organic amendments	anaerobic digestate	3	5–10	7.0	8.3	3.3	3.7
	leaf-yard waste compost	60	1.6	trace	0.5	0.6	1.0
	food-waste compost	70	3.3	0.1–0.4	1.1–1.4	1.5	1.9
	spent mushroom compost	35	2.1	trace	0.63	0.75	1.25
Processed biosolids	biosolids pellets	92	4.7	0.13	1.1–1.6	4.2	0.2
	LysteGro	12–15	5.6	2.9	0.35	5.25	2.25
	N-Viro	75	0.74	0.03	0.75	1.0	4.25

The quality and nutrient content of non-agricultural source materials is unique and must be determined on a case-by-case basis. Generators are required to sample and analyze these materials on a regular basis. This information should be used to determine accurate application rates for crop fertility requirements.

Biosolids

Sewage biosolids enter the treatment plant as an extremely dilute liquid material, since water is used as the carrier to transport these materials to the plant. Prior to nutrient management planning requirements for land application of biosolids, the sewage biosolids could contain significant quantities of contaminants if the system collected wastewater from industrial as well as domestic sources. Sewer use bylaws in most communities have now restricted these contaminants to very low concentrations so the biosolids produced by the plant meet the criteria for a non-agricultural source material (NASM) plan.

During the treatment process, the solids are concentrated and the phosphates are precipitated out of the water in insoluble forms, while most of the potassium remains in solution and is not retained. The biosolids at the end of the process contain both organic and ammonium nitrogen, plus a significant amount of phosphorus. The availability of this phosphorus to plants may vary depending on the specific treatment process used. These biosolids may undergo further treatment before land application, which can significantly alter the quantity and availability of the nutrients.

Additional non-agricultural source materials

Other materials from industrial or municipal sources may be suitable for land application. These can vary widely depending on the source of the material and the treatment to which it has been subject. Paper mill biosolids are primarily carbon compounds, with relatively low amounts of nutrients. Leaf-yard waste composts will vary widely in nitrogen, phosphorus and potassium contents, depending on the source of the feedstock material. These materials need to be assessed on a case-by-case basis if they are to be used as a nutrient source. Typical values for some non-agricultural source materials are shown in Table 6–7.

The physical and chemical characteristics of the various manure types and biosolids overlap. This means that the management to optimize the use of the nutrients from these materials will be the same and will depend more on the characteristic of the individual material rather than the source. However, non-agricultural source materials (NASM) are subject to additional rules intended to ensure that their application is done in a way that benefits crop production.

Factors affecting nutrient availability to the crop

Nitrogen

Crops take up nitrogen in its mineral forms, as either nitrate (NO_3^-) or ammonium (NH_4^+). This means the ammonium portion of the manure is immediately available to the crop while the organic nitrogen needs to be mineralized before it can be used. For optimum use of the nutrients in manure, they should be available where and when the crop can utilize them. It is not always easy — or even possible — to meet this goal, however, with current manure management options.

Ammonia volatilization

Ammonium nitrogen can easily convert to ammonia gas when manure is exposed to the air, resulting in the loss of a large part of the available N from the manure. Conditions that favour rapid loss of ammonium-N from the surface of the soil include: a high concentration of ammonium in the manure, a high pH in the manure, warm temperatures, dry soils and windy conditions. Crop canopy or residue has an inconsistent effect on ammonia volatilization. It can reduce the amount of loss from manure placed below the cover but can actually increase loss from manure spread on top of the canopy because of increased surface area. Incorporation of the manure effectively stops ammonia volatilization, since any ammonia that is released is quickly re-absorbed in the soil water and adsorbed on the surfaces of clay particles.

Mineralization

The organic nitrogen in manure needs to be converted to ammonium before it is available for plant uptake. This happens when microbes feed on the organic compounds and release ammonium as a waste product. The rate of mineralization increases when conditions are favourable for microbial activity. The nature of the organic materials in the manure will also affect the rate of mineralization. Solid manure applied in late summer or early fall will have a higher rate of mineralized nitrogen available for the following crop compared to the same manure applied in spring. With spring-applied manure, about 20% of the organic N from ruminant manure is considered to be available in the first cropping season after application, while up to 30% of the organic N from poultry manure is available.

Mineralization will be slow when soil conditions are cool. This can lead to temporary nitrogen deficiency during cool spring weather in crops that are planted on manured fields. A starter application of nitrogen can help to overcome this.

Immobilization

When materials high in carbon (such as manure with a high volume of straw, or primary papermill biosolids) are added to the soil, soil nitrogen can be immobilized by microbes while they break down the carbon compounds (see *Carbon-to-Nitrogen (C:N) Ratio*, below, and Table 6–8). This can reduce the nitrogen availability to crops if these materials are applied before planting. There is potential for using these materials to tie up soil nitrogen in the fall, to reduce leaching losses over winter, but the effectiveness has not been proven.

Carbon-to-Nitrogen (C:N) ratio

The C:N ratio is the balance between the amount of carbon in an organic material and the amount of nitrogen. The carbon is a constituent of organic compounds like cellulose, lignin and protein, which are food sources for soil micro-organisms. As the micro-organisms multiply to take advantage of increased food supply, they also need nitrogen. If there isn't enough N in the organic material, they will absorb nitrogen out of the soil to meet their needs. This immobilized N will be released after the extra carbon is used up and the microbial population starts to die off.

As a rule of thumb, mineralization occurs if the C:N ratio of the organic material is less than 25:1, while immobilization occurs if the C:N ratio is greater than 25:1. Additionally, the balance between mineralization and immobilization will depend on temperature and moisture conditions, as well as the nature of the organic material.

Table 6–8. Typical C:N ratios of some common materials

Material	C:N Ratio
soil micro-organisms	7–9:1
soil organic matter	10–12:1
alfalfa	13:1
fall rye:	
vegetative	14:1
flowering	20:1
mature	80:1
cereal straw	80:1
corn stalks	60:1
sawdust	200–400:1
paper mill biosolids:	
primary	80–100:1
secondary	7–10:1
distillers grains	9:1
solid cattle manure	15–30:1
solid poultry manure	5–10:1
composted manure	10–40:1
yard waste compost	15–40:1
spent mushroom compost	15–30:1

Phosphorus

Forms in manure

Most of the phosphorus in manure is associated with the solid portion and is found in either in the orthophosphate form (PO_4^{3-}) or in readily degraded organic compounds. This means that, chemically, the phosphorus in manure does not differ greatly from the phosphorus in fertilizer. The proportion of various forms of P are determined by livestock species, age, ration and bedding type and by manure storage method. In Ontario, the availability of manure P ranges from 40%–80% to that of fertilizer P. However, temperature, soil moisture and soil pH affect the P mineralization rate such that only 40% of the manure P is assumed to be available in the year of application.

A portion of the inorganic phosphorus in manure is water soluble, which makes it mobile and susceptible to runoff with surface water. This portion is measured as wet extractible phosphorus (WEP) and will vary with diet. It may also be related to the amount of phytase enzyme in the livestock digestive system. Cattle produce sufficient phytase naturally, while hogs and poultry produce very little and may have the enzyme added to the diet.

Greenhouse studies have shown that equal amounts of phosphorus from either liquid hog manure or fertilizer, when mixed evenly with the soil, result in equal plant uptake. The difference in apparent availability of the phosphorus could stem from the inability to place the manure in a band close to the seed for maximum availability and from uneven application rates across the field.

Contribution to soil test levels

Regular soil testing is the best method to track the buildup of soil phosphorus in individual fields. Nutrient management plans in Ontario credit 80% of the total P in the manure towards building soil fertility. The remaining 20% is assumed to be tied to soil particles or moved off the field with surface runoff or soil erosion.

Treatments to reduce phosphorus availability

Many municipal biosolids are treated with alum, iron sulphate or lime during the secondary treatment process to remove phosphate from the discharge water. A similar treatment is used in some poultry barns. This causes a high proportion of the P to be tied up in insoluble aluminum, iron or calcium phosphates, which can greatly reduce the nutrient availability from these materials in both the short and long term. Tissue analysis at plant pollination will indicate nutrient uptake in plants where these materials are utilized.

Potassium

Most of the potassium in manure is associated with the liquid portion, and essentially all of the potassium in manure is in soluble forms and available to crops. With solid manure, losses can occur from storage if runoff is not contained. In the past, high rates of manure application on dairy farms resulted in luxury consumption of K by alfalfa and mineral imbalances for dry cows in the dairy ration. In recent years, however, K levels in many forage fields have been declining to levels where winter survival could be impacted. Sewage biosolids contain very little potassium, since it is not retained with the solids during the treatment process.

Phosphorus and potassium content of manure varies significantly from farm to farm. The best estimates come from lab analysis.

Secondary and micronutrients

In addition to N, P, K and organic matter, manure contains significant quantities of calcium, magnesium, elemental sulphur and micronutrients. Deficiencies of these elements are uncommon on farms that regularly apply livestock manure.

Greenhouse nutrient feedwater and non-agricultural source materials (NASM), including sewage biosolids, also contain micronutrients. The levels will often depend on the type of facility and/or the mix of residential, institutional and industrial contributors to the system. Trace elements (heavy metals including arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium and zinc) and some of the micronutrients and sodium are regulated under the *Nutrient Management Act*. The levels of these elements are limited in biosolids, and if the guidelines are exceeded, the material cannot be used for land application. Most manure types are low in these elements, unless they have been added to feed to reduce antibiotic use (e.g., copper or zinc). The rate or frequency of manure application may need to be limited for these specific manures.

Predicting available nutrients from land applied materials

Optimizing the use of nutrients in organic materials depends on knowing how much nutrient is in the material being applied and what proportion of that will be available to the crop. Since most nutrient response calibrations have been done with mineral fertilizers, the availability of nutrients from organic sources is often expressed relative to fertilizer.

Tables that provide average nutrient values for various types of manure and biosolids, such as those in this chapter, are good planning tools. Given the variability among nutrient sources, however, analysis of the material will give better information if the sample collected is representative of the material to be land applied.

Interpreting manure analyses

Results from a manure analysis must be read carefully, since there can be wide variation in how the results are expressed. The analytical results may be expressed as a percentage of the dry matter in the manure or as a percentage of the fresh (wet) weight. Furthermore, the results may have been converted into a fertilizer replacement value, based on information provided when the sample was submitted.

The sidebar below gives the formulas for calculating the available phosphorus and potassium and the conversions from percentages to the commonly used units of weight.

Calculating available phosphorus and potassium from manure

Total P to available P_2O_5

% P x 2.29 = % total P_2O_5

% total P_2O_5 x 0.40 = % available P_2O_5 in application year

% total P_2O_5 x 0.80 = % available P_2O_5 for soil buildup

Total K to available K_2O

% K x 1.20 = % total K_2O

% total K_2O x 0.90 = % available K_2O

Most labs in Ontario report the amount of available P_2O_5 and K_2O from manure, but occasionally you see a sample reported as %P and %K. If this occurs, you will have to convert the figures to match the units of the fertilizer recommendation.

Conversion from per cent to units of weight

% available nutrient to unit of weight

% available nutrient x 10 = kg/t

% available nutrient x 20 = lb/ton

% available nutrient x 10 = kg/1,000 L = kg/m^3

% available nutrient x 100 = lb/1,000 gal (Imperial)

Total N vs. ammonium vs. organic N

In most organic materials, nitrogen exists in ammonium and organic forms, so the total N is the sum of these two quantities. Measurements made in the lab are actually of total N and ammonium N, and the organic N is determined by subtraction.

Greenhouse nutrient feedwater and some composted materials may contain a significant amount of nitrate-N. Check with the lab that the compost analysis package includes all aspects relevant to nitrogen availability: nitrate, ammonium and total N, as well as C:N ratio.

Estimates of available N from manure can be made as a proportion of the total N, which assumes that both the manure and the application management are “average.” This is a good general tool for planning the distribution of manure among different fields. More precise estimates of available N from manure can be made following application when the precise timing, weather conditions at and after application and the time before incorporation is known. Using the actual split between ammonium and organic N from the manure analysis can also make more precise estimates.

Impact of application timing and method

Application timing and method has the greatest impact on nitrogen availability, and much less on phosphorus or potassium. Manure sources should not provide more than two-thirds to three-quarters of the nitrogen needs for a corn crop in order to avoid over-application of phosphorus and to ensure N availability to the crop when mineralization is slow or delayed in cool conditions. Because there are varying proportions of mineral and organic N in organic materials, the impact of application timing and method is not the same for all materials. Figure 6–1 shows pathways and relative quantities of uptake and loss, depending on manure source and application timing and method.

Ammonia volatilization results in an immediate loss of available N. The amount lost varies with the time between application and incorporation and the conditions at the time of application. Ammonium N that is retained in the soil can still be lost following conversion to nitrate, either through leaching or denitrification. Organic materials that are high in ammonium nitrogen will provide the greatest amount of N to the crop when they are applied as close to the time of N uptake by the crop as possible.

N from manure is in both mineral and organic forms, in varying proportions. Some of the N is lost to the air or water, some remains in the organic form and the balance is available to be taken up by crops (see Figure 6–1). Organic N is not available to the crop until it has mineralized to ammonium. This process proceeds slowly when soils are cold. Materials that are predominantly organic N (e.g., solid beef or dairy manure) will show much less difference in N availability between spring and fall application, since the loss of the mineral N is balanced by greater availability of the organic portion. Where solid manure with high organic N and very low ammonium N are applied in late summer (e.g., after cereal grain harvest), the N available to the following crop is maximized. If the same materials are applied in early spring and incorporated, the ammonium N is retained and time is provided for mineralization to occur, but often not in time to meet the N needs of grain corn. A similar benefit could be gained from a late fall application of this material, as it is applied to soils that are already cold enough to inhibit nitrification. The difficulty with this approach is the variability of fall and winter weather conditions.

Due to the higher proportion of ammonium relative to organic N in liquid manure, fall application results in greater losses, including through leaching, than spring application. Surface application elevates the amount of ammonium N lost through volatilization. Spring injection of liquid manure maximizes the nitrogen available for plant uptake, as it more closely matches the period of crop demand and minimizes the risk of N loss to volatilization and leaching (Figure 6–1).

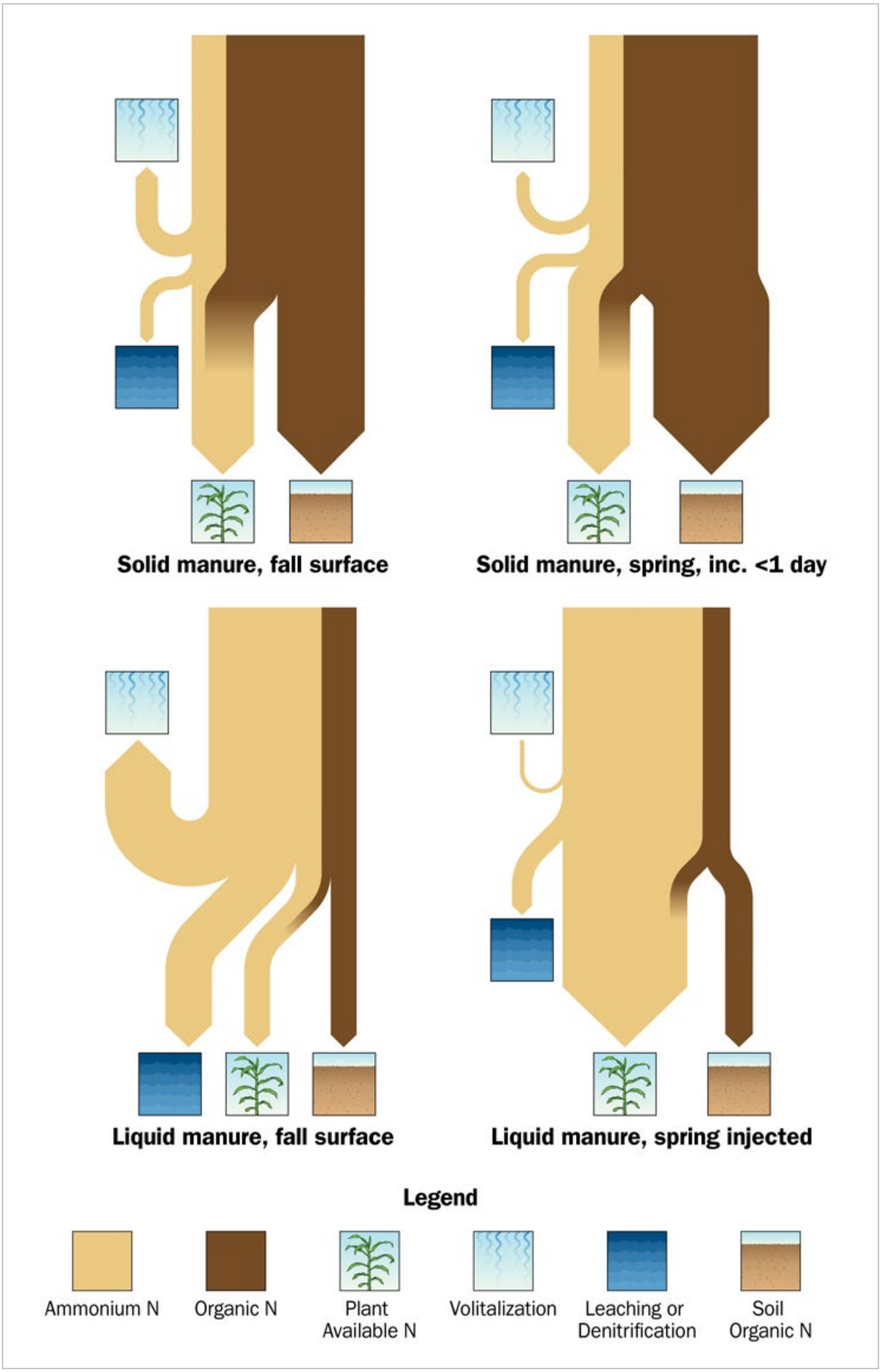

Figure 6–1. Impact of manure type and application method on fate of manure nitrogen

Impact of treatment systems — composting, anaerobic digestion, etc.

Treatment systems change the form of the nitrogen in the material and can also significantly reduce the nitrogen content of the material. Sampling and analysis are critical to knowing what value to place in a treated material and how best to manage it.

Composting is an aerobic process that seeks to convert most of the nitrogen in the material to an organic form. This is accomplished by adding materials with a high C:N ratio to manure or biosolids and then providing conditions that encourage microbial growth. In a properly managed composting system, most of the nitrogen is taken up by the microbes as they consume the high-carbon material. In improperly managed compost, up to half of the total N can be lost through volatilization. Not all of the nitrogen is bound in organic forms in finished compost. Because of the aerobic conditions, the mineral N that remains is primarily in the nitrate form. Composts can be surface applied with negligible loss of N through volatilization, but the availability of the organic N depends on conditions that favour mineralization.

Anaerobic digestion is used to reduce odours and pathogens in organic materials, as well as to produce methane gas that can be used for heating or electricity generation. The end product has lost much of the readily degraded organic material and has a greater proportion of the N in the ammonium form than the original material did. This increases the immediate availability of the N from the digested material, but it should be incorporated quickly. Volatilization losses from surface application of this material will generally be greater than from undigested materials.

Calculating plant-available nitrogen (PAN) from organic sources

For general planning, nitrogen availability from organic materials can be estimated from table values. For fine-tuning fertilizer application rates, however, a more precise estimate is desirable. This involves estimating the retention of ammonium N in the manure, mineralization from the organic N pool, and losses from the soil between manure application and crop uptake. See below for an example of how to calculate plant available nitrogen from an organic nutrient source.

Calculating total nitrogen (TN)

Total N	**= Organic N**	**+ Ammonium N (NH_4-N)**	**+ Nitrate-N (NO_3-N)**
	= (TN – NH_4 – NO_3)	+ NH_4-N	+ NO_3-N

Calculating plant-available nitrogen (PAN)

PAN	**= (TN – NH_4 – NO_3) × availability factor**	**+ NH_4-N × availability factor**	**+ NO_3-N x availability factor**
PAN spring	= (TN – NH_4 – NO_3) × Table A	+ NH_4-N × Table B	+ NO_3-N × Table C
PAN fall	= (TN – NO_3) × Table C		+ NO_3-N × Table D

Table A: Estimated percentage of organic nitrogen available in year of application (as applied)

% Organic N = % Total N - % NH_4-N
(ppm NH_4-N/10,000 = % NH_4-N)

Liquid	Solid
[% organic N – (% DM ÷ 50.93)]	[% organic N – (% DM ÷ 61.44)]
x 100 = lb/1,000 gal x 10 = kg/1,000 L or kg/m^3	x 20 = lb/ton x 10 = kg/tonne
Example: Liquid Dairy Manure (4.5% DM, 0.25% Total N, 0.12% NH_4-N, 0.04% P, 0.19% K) Available Organic N = [(0.25 – 0.12) – (4.5 ÷ 50.93)] = (0.13 – 0.09) = 0.04% 0.04% x 100 = 4 lb/1,000 gal 0.04% x 10 = 0.4 kg/m^3	**Example:** Solid Broiler Manure (70% DM, 3.12% Total N, 0.6% NH_4-N, 1.4% P, 1.8% K) Available Organic N = [(3.12 – 0.6) – (70 ÷ 61.44)] = (2.52 – 1.14) = 1.38% 1.38% x 20 = 27.6 lb/ton 1.38% x 10 = 13.8 kg/T

Adapted (K. Reid) from J. Lauzon & K. Janovicek, University of Guelph, 2013. The table is based on an evaluation of data from 180 field sites that measured crop yield response to manure.

Logic behind equations: Available manure organic N = organic N x (carbon content of manure x carbon retained by soil life x C:N ratio of soil life) x conversion factor (% to lb per ton or per 1,000 gal)

Assumptions:

- Organic N (%) = Total N (%) – Ammonium N (%)
- Average carbon content of manure is 42% of manure dry matter
- Retained carbon is 37.4% for liquid manure and 31% for solid manure
- The C:N ratio of soil life is 8:1

Table B: Estimated proportion of ammonium nitrogen from manure retained in year of application (spring applied)

		Incorporated					Not incorporated		
	Injected (covered)	1 day	2 days	3 days	4 days	5 days	Bare soil	Residue	Standing crop (below canopy)
average (factor)	1.00	0.75	0.60	0.50	0.45	0.40	0.35	0.50	0.66
cool (<10°C)	1.00	0.85	0.70	0.60	0.55	0.50	0.45	0.66	0.75
warm (>25°C)	1.00	0.65	0.50	0.40	0.35	0.30	0.20	0.35	0.55

Adapted from J. Lauzon & K. Janovicek, University of Guelph, 2013. The table is based on an evaluation of data from 180 field sites that measured crop yield response to manure.

Table C: Estimate of available nitrogen from manure applied in late summer or fall, as a proportion (factor) of total N applied

		Available nitrogen [1,2]				
		incorporated (<24 hr)			not incorporated	
Manure form	Type of manure	Late summer	Early fall	Late fall	Early fall	Late fall
solid	solid cattle/sheep/horse	0.21	0.31	0.34	0.21	0.21
	solid swine/compost[3]	0.30	0.40	0.45	0.40	0.45
	solid poultry/mink	0.41	0.53	0.61	0.37	0.32
liquid	liquid cattle	0.25	0.27	0.31	0.24	0.24
	liquid swine	0.22	0.38	0.47	0.25	0.25
	liquid poultry/mink[3]	0.26	0.33	0.51	0.26	0.39
	liquid biosolids	0.33	0.37	0.42	0.34	0.36

Available N in manure = Total N (from analysis) x available N (factor from Table)

[1] Assumes a spring-planted full-season crop (e.g., corn).

[2] Accounts for ammonia loss to atmosphere and mineralization of organic N.

[3] These coefficients are based on assumed N availability given the characteristics of each manure type, since there are no direct measurements of N availability for these materials.

Adapted from J. Lauzon & K. Janovicek, University of Guelph, 2013. The table is based on an evaluation of data from 180 field sites that measured crop yield response to manure.

Table D: Estimated percentage of nitrate-nitrogen available in year of application (all seasons)

LEGEND: Late summer = up to Sept 20, Early fall = Sept 21 to Nov 9, Late fall = Nov 10 to winter

	Incorporated (within 24 hr)					Not incorporated				
								Pre-plant[1]		
	Late summer	Early fall	Late fall	Pre-plant[1]	Side-dress[1]	Late summer/ early fall	Late fall	Bare soil	Residue	Side-dress
Nitrate-N retention	0.1	0.2	0.5	0.95	1.0	0.1	0.40	0.85	0.75	0.85

Source: Adapted from Barry, Beauchamp et. al., University of Guelph, 2000

[1] Assumes a spring-planted crop; side-dress refers to application to a growing crop.

Available nitrogen from previous manure applications

Most of the available (mineral) nitrogen in manure is used by the crop or is lost during the first season following application. The remaining organic nitrogen becomes available in small, diminishing quantities in the succeeding years. This availability is most often assumed to be 10% of the organic N applied 1 year ago, 5% from 2 years ago and 2% from 3 years ago. This is not normally enough to make a practical difference in nitrogen recommendations from a single application of manure. However, where solid manure is applied regularly to the same field, there can be significant residual nitrogen.

Calibrating application equipment

Calibrating manure application equipment is essential to ensure both the accuracy of the rate applied and uniformity of application. Several methods can be used to measure spreading rates.

For solid materials:

- Method A: Use a spreader with a load cell or weigh a load and measure the area it covers.
- Method B: Spread a metre-square plastic bag on the ground and spread solid manure on it as you would on the field. Weigh the manure (minus the weight of the plastic) and find the equivalent in Table 6–9.

To determine uniformity of application, weigh manure as described above in several areas of the field. Side-by-side application and beginning versus end of load applications often have different volumes, as do areas of overlapping application.

Table 6–9. Solid manure application calibration using 1 m x 1 m (40 in. x 40 in.) sheet

Weight/sheet		Application rate	
kg	lb	t/ha	tons/acre
0.5	1	3.6	1.6
1	2	7.2	3.2
1.5	3	10.8	4.8
2	4	14.3	6.4
2.5	5	17.9	8.0
3	7	25.1	11.2
5	10	35.8	16.0
7.5	15	53.8	24.0

Estimating the rate of solid manure applied by spreader volume is not recommended due to the variation in manure bulk density (see Table 6–10, *Densities of manure*) and in how high the spreader is heaped.

Table 6–10. Densities of manure

Type of Manure	kg/m^3	lb/ft^3	lb/bu
Liquid	1,000	62.4	80
Semi-solid	960	60	76
Thick solid	800	50	64
Light solid	560	35	45

For liquid materials:

The use of flow meters and GPS equipment aids in calibration and recordkeeping of manure application rates. Where this equipment is not available, the application rate can be determined from the volume of the tanker divided by the area covered by one tanker-load.

The area covered by a tanker-load of manure can be calculated two ways:

- Method A: from the width of spread, the speed of travel and the time it takes to empty the tanker.
- Method B: by placing a series of straight-walled containers (e.g., pails) on the ground you intend to cover. Spread the manure, and then measure the depth of manure in the container and determine the application rate from Table 6–11.

For both solid and liquid materials, take overlap into account, particularly for low dry matter material or greenhouse nutrient feed water irrigation systems.

Table 6–11. Liquid manure application calibration using a straight-walled pail

Depth of manure		Application rate	
mm	**in.**	**L/ha**	**gal/acre**
2.5	1⁄10	25,000	2,265
3.1	⅛	31,000	2,825
6.3	¼	63,000	5,650
9.4	⅜	94,000	8,500
12.5	½	125,000	11,325
15.6	⅝	156,000	14,150
18.8	¾	188,000	17,000
25	1	250,000	22,650

Nutrient management planning

Nutrient management planning is simply matching the needs of the crop and the nutrients already in the soil with the nutrients available from manure or other organic sources, and then balancing any deficits with mineral fertilizer. Many jurisdictions, including Ontario, have legal requirements for nutrient management planning. Although it is a regulatory requirement on some farms, in reality every farm can benefit from planning to optimize their nutrient use.

Whole-farm nutrient balances: Where does Ontario fit?

Some critics imply that intensification of agriculture will inevitably lead to excesses of nutrients and over-application of manure. For justification, they point to areas like North Carolina and Delaware, where regions within these states have expanded livestock and poultry production beyond the capacity of the land base to absorb nutrients. The result has been significant degradation of the surface and groundwater quality in these regions, as well as complaints about odour and poor air quality.

The situation in Ontario is much different. In 2002, the State of Delaware had almost 1 nutrient unit /ha, averaged over all the cropland in the state, while North Carolina had 1.25 nutrient units/ha. In contrast, in the 2001 Census of Agriculture, the province of Ontario had 0.65 nutrient units per hectare. (The figure for all of Canada was 0.43 nutrient units/ha.) A nutrient unit is the number of livestock that produce the lesser of 43 kg of nitrogen or 55 kg of phosphate (fertilizer replacement value), and it is used to compare different livestock on an equal nutrient basis.

It is certain that there are some small areas of nutrient excess, but the problem is one of distribution rather than over-supply.

Challenges with different livestock intensities

Livestock farms can be roughly divided into three classes, based on the intensity of their production. Each class has very different challenges in nutrient management.

The members of the first group are highly intensive, with a significant portion of the livestock diet coming from feed purchased rather than grown on-farm. This results in a surplus of nutrients coming onto the farm over what is sold as meat, eggs and milk. These farms are faced with the challenge of exporting manure to other farms or having a buildup of nutrients in their soils from over-application of manure.

The second group represents farms where the nutrient inputs to the farm in feed and fertilizer are close to balanced with the exports in meat, eggs and milk. Most of the feed is grown on-farm, and the manure is returned back to that land base. The challenge on this farm is distributing the manure properly among the available fields. Mineral fertilizers will still need to be used on most of these farms to balance the nutrients supplied by manure.

The third group has very low livestock intensities and does not generate nearly enough manure to meet the requirements for crop production. If these farms do not apply nutrients in the form of mineral fertilizers or import organic nutrient sources such as compost or biosolids, productivity will gradually decline as nutrients are exported off the farm.

Optimizing manure as a nutrient source

The value of manure as a fertilizer has been limited by uncertainty about the quantity of nutrients in the manure, the availability of these nutrients and the amount that is actually applied to the field. Following a systems approach to manure utilization can remove much of this uncertainty.

Manure application should aim to supply up to about three-quarters of the nitrogen requirements of the crop. During application, samples should be collected for analysis, and records should be kept of actual application rates, time to incorporation and weather conditions at application. This will allow a more accurate estimate of the nutrients available from the manure, and any deficits can be supplied with an application of mineral fertilizer.

Crops that benefit

Grain corn is a common recipient of manure because it has a high demand for nitrogen and is often grown as a feed crop on livestock farms. Using manure to supply all the nitrogen required by a corn crop, however, provides more phosphorus and potassium than the crop removes from the soil. Over the years, the concentrations of these two nutrients in the soil can become excessively high.

This buildup can be alleviated. Grain corn can be rotated with other crops that use large quantities of phosphorus and potassium, such as alfalfa. Or, the manure application rates can be reduced to two-thirds or three-quarters of the nitrogen requirements and the balance supplied as nitrogen fertilizer. This brings the additions of phosphorus and potassium more into line with the amount removed by the crop.

For summer application to standing crops such as corn or forages, rates should be kept below 40 m^3/ha (4,000 gal/acre) and less for highly concentrated manures. Application to forages should be done as soon as possible after harvest to avoid tire tramping damage and nitrogen burn (from ammonia) to new leaf growth.

Older forage stands with higher grass content benefit most from the manure nitrogen.

Manure applications to cereal crops, spring grains or soybeans should be done with caution, since too high a rate will increase the incidence of lodging.

No-till and manure

Manure is still one of the factors that makes livestock farmers think twice about no-till. Farmers who have to deal with manure but also engage in a no-till cropping system have to compromise — some tillage or some loss of nutrients from manure.

Crop rotation is important in no-till and reduced tillage systems. The most popular options are as follows:

- **Apply manure to wheat fields after harvest and follow with shallow tillage.** This allows faster breakdown of the wheat residue and alleviates risk of allelopathic interference for the planned corn crop while minimizing soil disturbance and reducing risk of compaction. This system also makes good use of manure nutrients, especially if combined with a fall cover crop. On sandy soils prone to leaching, application rates should reflect the quantity and type of nitrogen being applied. In most cases, solid manure containing a higher percentage of organic nitrogen will have less risk of loss through leaching.
- **Use manure on forages.** Although not the most economic use of manure nitrogen, legume forages require the phosphorus and potassium. Grassy forages will make more efficient use of nitrogen and also benefit from the P and K.
- **Use a strip-till system** where manure can be applied and incorporated into 15–20 cm (6–8 in.) deep strips during fall or spring. Using a guidance system, a crop can be planted into the same strip. Nutrients are placed near where the crop can utilize them, and the area between the strips remains un-tilled with full residue cover.
- **Side-dress liquid manure into a standing corn crop by injection.** The manure reaches the crop when the nutrients are most needed, and the risk of compaction is often lower. The biggest drawback is the time requirement. Injector design must be considered to minimize the risk of plant damage and reduced plant populations.

Environmental concerns

Using manure or other organic nutrient sources for crop nutrient needs is better for the environment. As with any nutrient source, however, using too much or not applying it carefully can cause harm from contaminated streams, runoff and leaching.

Avoid spreading manure in winter on frozen or snow-covered soils or in early spring when soils are saturated, due to the potential for runoff to surface water. Frozen soils cannot absorb the nutrients that are applied, and there are no growing crops to utilize them. Apply manure during dry, mild periods when applied manure can be immediately incorporated. Application on fields with growing crops or high residue that are far from surface water are also options for the situations where winter spreading may be necessary. Manure should not be spread adjacent to surface water. A vegetated buffer will help to trap material that runs off the field and help keep it out of streams and lakes.

Rain can cause organic nitrogen to wash into streams if manure has been applied to unprotected cropland. Phosphorus can be carried to streams either as dissolved reactive phosphorus carried in surface water or phosphorus attached to soil particles. Minimizing runoff from fields that receive manure will reduce the risk of nutrients and harmful pathogens reaching streams and waterways.

Flow into tile drains can become contaminated if manure enters a catch basin. With liquid manure, a 9-m (30-ft) buffer should be maintained around a catch basin or surface inlet while a 4.5-m (15-ft) buffer is suggested with solid manure. Another option is to block the tile run during and after spreading. All tile inlets should be regarded as direct connections to surface water and managed accordingly.

Flow can also become contaminated if manure travels through soil cracks and macropores to the tiles (see Chapter 2, Figure 2–12). This problem is most likely to occur in clay or clay loam soils where there is shrinking and swelling of the soil. A light tillage pass before spreading will disrupt the channels and significantly minimize the risk of movement. Blocking the tile run during and after spreading may also work.

Safe utilization of manure above crop requirements

Large livestock operations on a small land base have special challenges. To avoid over-application of nutrients, exporting manure to non-livestock farms or composting operations may be needed. If this is not possible, limit manure applications to the phosphorus requirements of the crop. Although the risk from excess nitrogen leaching is minimal on heavy-textured soils, losses through denitrification can be substantial, and this leads to greenhouse gas emissions. Nitrogen-based application rates can also result in over-supply of P and K. Excess P is a concern if it can reach surface water, leading to algae blooms. High rates should not be applied in areas where there is the potential for surface runoff or erosion. Incorporating the manure may also help to reduce the concentration of P in runoff water.

Long-term value of manure

The benefits of manure application on-farm extend beyond the year of application. Here is a summary of the benefits:

- Manure helps replenish available phosphorus and potassium in soils. Soil testing is the best way to estimate the long-term availability.
- Manure adds secondary nutrients, micronutrients and organic matter to soil.
- It adds organic nitrogen, which becomes available (in diminishing quantities) in the years following application.
- Added organic matter will improve soil structure and moisture-holding capacity.
- Added organic matter also increases the capacity of the soil to hold nutrients.
- Fields that receive regular applications of manure have fewer problems with soil crusting.
- Manure application adds microbial diversity and provides a food source for soil micro-organisms, which in turn promote larger root systems and better tolerance to dry weather.

Regulatory requirements

Every province and state has some type of regulatory control on the application of manure and biosolids, greenhouse nutrient feedwater and other organic amendments. This ranges from environmental protection laws that apply to everyone to specific regulations that dictate when and where a particular material can be applied. In Ontario, the first category is represented by the *Environmental Protection Act (1990)* and the *Ontario Water Resources Act (1990)*, which lay out penalties for anyone who pollutes surface water or groundwater or causes an adverse effect. The federal *Fisheries Act* also mandates that no deleterious substance can be allowed to enter surface water. In the second category, the *Nutrient Management Act (2002)* gives force to regulations on the storage, handling and land application of materials containing nutrients.

It is important to be aware of the most recent versions of any specific laws and regulations that apply in the jurisdiction where application of organic materials is planned.

Manure

Manure applications on livestock farms in Ontario are regulated under the *Nutrient Management Act (2002)*, which gives force to Ontario Regulation 267/03 (as amended). Phased-in farms are required to complete a nutrient management strategy. Farms with over 300 nutrient units or within 100 m of a municipal well are required to complete a nutrient management plan (NMP) and to follow it for any nutrient applications. Growers and advisors should refer to the regulation for details. The most current version of the regulation can be found at ontario.ca/laws.

Non-agricultural source materials (NASM)

Non-agricultural source materials, or NASM, include treated and recycled material from non-agricultural sources, like leaf and yard waste, fruit and vegetable peels, food processing waste, pulp and paper biosolids and sewage biosolids, that are applied to agricultural land to provide a beneficial use. These materials are placed into categories based on environmental risk (metals, odour, pathogens). In Ontario, NASM are regulated under the *Nutrient Management Act*, where materials such as sewage biosolids must meet quality criteria for pathogens and metals before they are approved for land application. Biosolids must be applied according to the criteria set out in a NASM plan.

A NASM plan is similar to an NMP because both documents deal with the land application of nutrients and both documents address sensitive features such as watercourses and wells. The NASM plan, however, is done on a field-by-field, where-applied basis and includes testing of the materials and the soils for 11 metals. It can include other requirements such as limits on fats, oil and grease, boron or sodium.

NASM plans include restrictions on setbacks from surface water and limits on the application to fields with pH under 6.0 and/or fields with phosphorus soil test levels over 60 ppm, as well as time between application and the harvest of various crops.

Detailed requirements for non-agricultural source material application can be found in the most recent version of the *Nutrient Management Act*, Ontario Regulation 267/03 at ontario.ca/laws.

Greenhouse nutrient feedwater (GNF)

Many greenhouse operations use circulation systems to deliver water and fertilizer to greenhouse crops that are grown without the use of soil. There are times when the nutrient solution is no longer suitable for growing greenhouse crops, at which point the nutrient solution can be used to fertilize other agricultural crops. Greenhouse nutrient feedwater (GNF) is the nutrient solution removed from a closed circulation system at a greenhouse operation that is registered under the Greenhouse Nutrient Feedwater Regulation, O. Reg 300/14.

Similar to other nutrients regulated under the *Nutrient Management Act*, there are restrictions on rate of nutrients applied, timing of application and setbacks from sensitive features. Full details of requirements can be found at ontario.ca/laws.

Nutrients from crop residues

Cover crops and crop residues provide many benefits in a cropping system, including nutrient sequestration, soil erosion control and improved nutrient cycling. As crop residues break down, they can provide significant quantities of nitrogen to succeeding crops. The value of legumes is well established in this regard, but there is also potential for nitrogen mineralization from the residues of non-legume crops. Conditions where this can be significant are where large quantities of residue are left following harvest (as in some horticultural crops) and the residue is relatively immature. This is a source of nitrogen that has been under-utilized.

Legumes are unique among crops because they form symbiotic relationships with bacteria (Rhizobia) that convert nitrogen from the air into ammonium, which is then available to plants. The legumes grown primarily for seed production, such as soybeans, use all of this nitrogen for crop growth and yield and leave little or none in the soil for the next crop.

Perennial forage legumes, on the other hand, are a source of additional nitrogen because they tend to fix more nitrogen than is needed for the current crop. The nitrogen from legumes is held almost completely in the organic form and is not available until the residues are broken down. This residual nitrogen must be considered when planning a fertilizer program for the succeeding crop. Cool spring weather may delay this process.

When considering the effects of legumes on the growth of succeeding crops, it is important to separate the effect of physical properties, such as improved soil structure and tilth, from the effect of residual nitrogen. The effect of a red clover cover crop on such properties has been shown to benefit the yield of the following corn crop in Ontario, even with the application of sufficient fertilizer nitrogen (Table 6–12).

Table 6–12. Grain corn yields with or without underseeded red clover

Year	Corn yield without red clover kg/ha (bu/acre)	Corn yield with red clover kg/ha (bu/acre)
2010	11,675 (186)	12,428 (198)
2011	9,855 (157)	10,169 (162)
2012	10,985 (175)	11,550 (184)
2013	13,621 (217)	13,433 (214)
2014	11,926 (202)	14,312 (228)
2015	13,621 (217)	14,123 (225)
2016	11,926 (190)	12,554 (200)
Average (2010–2016)*	11,989 (191)	12,554 (200)

* indicates statistically significant difference at P = 0.05.

Note: Grain corn yields from a corn-soybean-wheat rotation with or without underseeded red clover (red clover first seeded in 2009) from the long-term rotation tillage system trial at the University of Guelph, Ridgetown. Fertilizer nitrogen applied to corn at 202–269 kg/ha (180–240 lb/acre).

Source: Dr. Dave Hooker, University of Guelph. 2010–16.

Legumes in a cropping system

The predominant forage legumes included in Ontario crop rotations are alfalfa, red clover and trefoil. Alfalfa and trefoil are usually harvested as hay and maintained for at least 2 years. Red clover is usually included as a cover crop following small grains, with growth terminated at the end of the first year or early during the next growing season, just before corn planting.

The greatest benefits of forage legumes occur during the first year after plowdown. However, there may be residual benefits during subsequent years. Late May soil nitrate-nitrogen concentrations and indexed yields presented in Table 6–13 show that potential nitrogen availability and yield increases following forage legumes can be greater in the first year of corn and beyond.

Total nitrogen accumulation

Plowdown red clover, established as a cover crop following cereals, can also accumulate a substantial amount of nitrogen — about 40 kg/ha (35 lb/acre) for every tonne per hectare of top growth. A relatively thick 30 cm (1 ft) tall stand of plowdown red clover produces about 4 t/ha (2 tons/acre) of top growth containing about 160 kg N/ha (140 lb/acre). However, more typical plowdown red clover yields when established as a cover crop following cereals range from 1–3 t/ha (0.5–1.5 tons/acre). Nitrogen and biomass contribution does not come only from the top growth. Red clover root growth will increase 4 to 6 times if plowdown in the fall is delayed from September 1 to October 15. Most of the roots — up to 75% — are located in the top 15 cm (6 in.) of the soil.

Table 6–13. Effects of crop rotation on post-planting soil nitrate-N concentration and corn yields

Rotation	First-year corn		Second-year corn	
	Soil NO_3-N kg/ha	Yield %	Soil NO_3-N kg/ha	Yield %
continuous corn	9.1	100	9.5	100
soy–soy–corn–corn	12.6	104	10.6	97
soy–wheat–corn–corn	10.9	104	12.0	98
soy–wheat + clover–corn–corn	16.7	107	12.7	99
alfalfa–alfalfa–corn–corn	17.8	108	14.7	102

Effects of crop rotation on soil nitrate-N concentration 2 weeks after planting and on corn yields. Amounts are indexed relative to continuous corn for the first and second year of production. From a long-term rotation experiment.

Source: T. Vyn, Crop Science Department, University of Guelph.

Available nitrogen from legumes

Not all the nitrogen produced by a legume crop is available. The rate of mineralization may limit the availability of the nitrogen during the time when the subsequent crop needs it. Some of the nitrogen may be incorporated into soil organic matter or lost through volatilization or leaching. Despite this, the amount of nitrogen available from forage legumes can be considerable, often totally fulfilling the nitrogen requirement of a succeeding corn crop.

Accurately predicting the nitrogen available from forage legumes is difficult and depends on a number of factors, including the amount of legume growth, spring temperatures and soil moisture conditions, the tillage system and the timing of legume kill.

Obviously not all the recommended nitrogen credits should be applied if legume growth is poor or if the stand is variable across the field. However, when excellent legume (alfalfa, trefoil or red clover) growth has occurred, the recommended credits (Table 6–14) are quite conservative. Several Ontario studies indicate that fertilizer nitrogen is not required when corn is planted following excellent perennial forage legume stands.

The potential nitrogen availability from forage legumes to corn can be reduced if May and June weather conditions are extremely dry or wet. Excessive rainfall can result in denitrification or leaching losses. If soil conditions are extremely dry, especially during May or June, mineralization rates of legume-nitrogen can be decreased, thereby decreasing the amount available to corn.

How much is a full stand?

A full stand of clover, alfalfa or trefoil is anything greater than 120 plants per m^2 (12 plants per ft^2). Therefore, a 50% stand is 60 plants per m^2 (6 plants per ft^2), and a 33% stand is 4 plants. The nitrogen credit is the same whether the space between plants is empty or filled with grass and weeds.

Table 6–14. Adjustment of nitrogen requirement (i.e., N credit) following legumes

Type of crop	kg/ha	lb/acre
established forages — less than ⅓ legume	0	0
established forages — ⅓–½ legume	55	50
established forages — ½ or more legume	110	100
perennial legumes seeded and plowed in same year	78 (for field corn) 45 (all other crops)	70 (for field corn) 40 (all other crops)
soybean and field bean residue	30 (for field corn) 0 (all other crops)	27 (for field corn) 0 (all other crops)

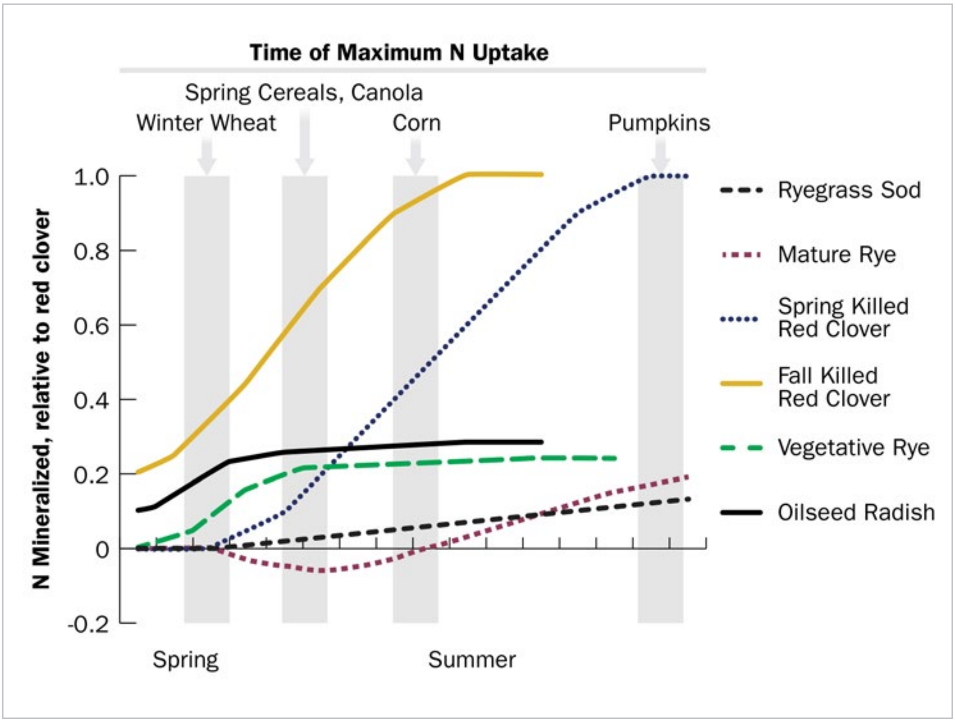

Figure 6–2. N mineralization from cover crop residues — relative time and amount

Optimizing nitrogen recovery

To be useful, the nitrogen from manure or crop residues must be released when the crop needs it. If the nitrogen is mineralized too soon, it can move deeper in the soil profile where it may be beyond the reach of roots. If it is released too late, the crop suffers from a shortage. This is illustrated in Figure 6–2.

Tillage systems that mix the legume top growth into the soil (mouldboard plow, chisel plow, disc) release the nitrogen from the crop residues faster than in a no-till system. Analysis of N response data in corn shows about 10% less nitrogen availability from a red clover cover crop in no-till than tilled systems.

Also, studies in no-till systems using red clover indicate that even though spring-killed red clover accumulated more nitrogen, fall-killed red clover produced greater corn yields in the absence of fertilizer nitrogen and required less fertilizer nitrogen to optimize yields. This suggests that nitrogen mineralization from fall-killed red clover is more available when the corn plant needs it than spring-killed red clover in no-till systems (Figure 6–2). A simple credit system can provide a general idea of nitrogen availability (see Table 6–14). The variability in the growth of the crop (and hence, the amount of nitrogen in the residue), together with the variability in the soil and weather conditions that control mineralization, mean that the precise N availability will vary from year to year. However, soil nitrate tests can help to predict the need for supplemental nitrogen.

Nitrogen availability from non-legume residues

Many horticultural crops are harvested before the plants reach physiological maturity, and a relatively small part of the plant is removed from the field. This leaves a large quantity of green, succulent material in the field, which can rapidly break down to release mineral N into the soil. In cases where multiple crops are grown in the same field, this nitrogen can reduce the fertilizer requirement of the succeeding crops.

Cover crops for nitrogen management

Relatively good stands of actively growing cover crops, including legumes such as red clover, will take up (i.e., sequester) significant amounts of nutrients, including soil mineral nitrogen. Cover crops following winter wheat in Ontario have reduced the level of nitrate left in the soil in October and November by 50% compared to where no cover crop was planted. Figure 6–3 shows how much residual soil nitrate cover crops remove from the soil following a vegetable crop. This results in less nitrate-N available to be lost over winter.

Under optimal growing conditions, non-legume cover crops (ryegrass, cereal grains) can take up substantial amounts of soil mineral nitrogen. Oilseed radish has been reported to contain up to 100 kg/ha of nitrogen in above-ground growth under optimal growing conditions.

Although non-legume cover crops can sequester a significant amount of nitrogen, subsequent crop (i.e., corn) yields may not be increased to the same extent as following legume cover crops. To date, it has been difficult to show a consistent reduction in N fertilizer requirement for crops grown following a non-legume cover crop. The amount of growth, C:N ratio and spring weather conditions will impact nutrient cycling and nitrogen mineralization.

Cover crops vary widely in the timing of nitrogen mineralization (See Figure 6–2). Oilseed radish (OSR) and spring cereals tend to start to release nitrogen early in the spring, when it may be subject to losses.

Some cover crops, like ryegrass, are extremely resistant to breakdown. Although they absorb significant quantities of nitrogen, little is released to the next crop during the growing season.

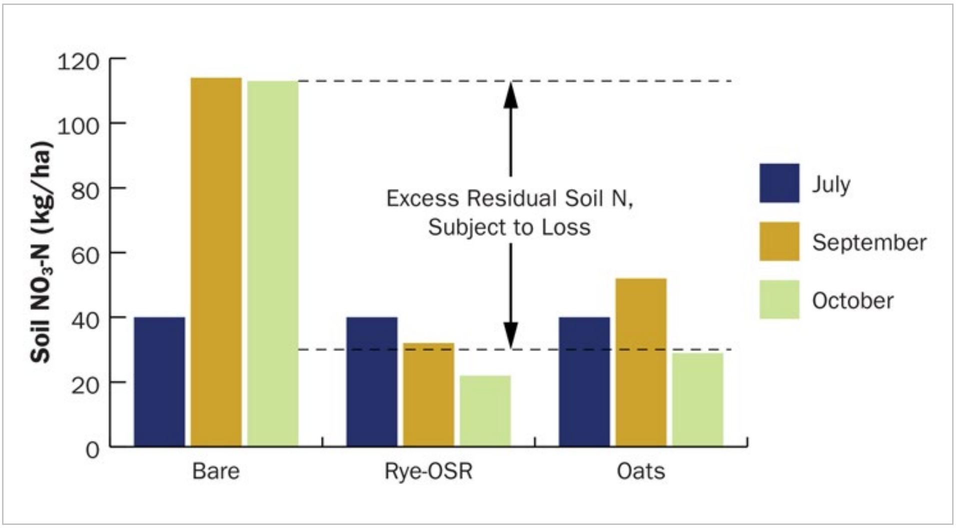

Figure 6–3. Nitrogen immobilization by various cover crops following cucumbers.
Source: Dr. Laura Van Eerd, University of Guelph, Ridgetown. 2004.

There are circumstances where cover crops can inhibit the growth of the following crop. A heavy layer of crop residue can keep the soil cool and wet in the spring, slowing crop germination and development as well as slowing nutrient mineralization. It may physically impede the operation of planting equipment, reducing the stand. It may also harbour pests like slugs or nematodes, which can harm the crop. Cover crops are one part of a cropping system, and their integration often requires adjustments in other parts of the system to maximize benefits and minimize crop production risks.

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