Organic Agronomy Training

Dr. Martin Entz – University of Manitoba

Lesson 1

Designing Cropping Systems with a Focus on Nutrient Management

Organic Agronomy Training

This training was developed and delivered by Martin Entz, PhD, Department of Plant Science, University of Manitoba. It is intended for private and public sector agronomists who want to respond to the growing demand from producers for more information about organic grain production. Grain farmers considering a transition to organic or current organic practitioners who want to learn the theory and latest science will also find the course valuable. The course was designed with the Prairies in mind, however agronomists in other ecoregions will learn universal principles of organic production.

The training consisted of five 75 minute live online sessions over two weeks in January 2023:

- January 5: Designing Cropping Systems with a Focus on Nutrient Management
- January 6: Crop Establishment and Seeding Systems, Tillage and Weed Control
- January 10: Pest Management with a Focus on Disease, Insects (and Weeds)
- January 12: Soil Management for Organic Production: Putting Theory into Practice
- January 13: Question & Answers

All course content (lesson recordings, presentations and notes) can be accessed on pivotandgrow.com.

The Organic Agronomy Training was developed as part of the Prairie Organic Development Fund's Canadian Organic Ingredient Strategy.

The Canadian Organic Ingredient Strategy was funded by:

CANADIAN AGRICULTURAL PARTNERSHIP

PODF PRAIRIE ORGANIC DEVELOPMENT FUND

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Lesson One: Nutrient Management in Organic Crop Rotations

Supplying nitrogen (N) to organic crops can be a challenge, particularly in large-scale grain operations. However, incorporating legumes into the crop rotation can address this challenge. On the vast majority of Prairie organic farms, legumes are the main source of N. Nitrogen can also be supplied by manure and other amendments, but these N sources are mostly used in areas with intensive livestock farming or in small-scale organic production, such as market gardens.

Learn more about bringing nutrients into organic crop production in this 30-minute video by Dr. Martin Entz: Nutrient management in organic grain production.

Different grain legume crops add different amounts of N to following crop

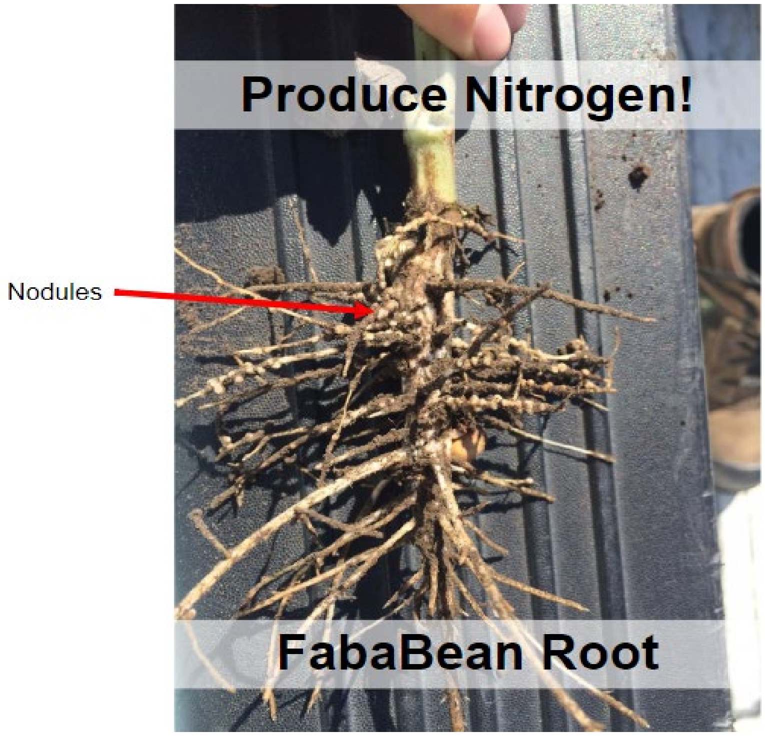
Estimates of N contribution to the following crop from having grain legumes crops in rotation

Grain Legume	N addition to following crop
Pea, lentil, fababean	10-15 kg N/1000 kg of seed harvested
Chickpea	3 kg N/1000 kg of seed harvested
Dry bean	1 kg N/1000 kg of seed harvested
Soybean	1 kg N/1000 kg of seed harvested

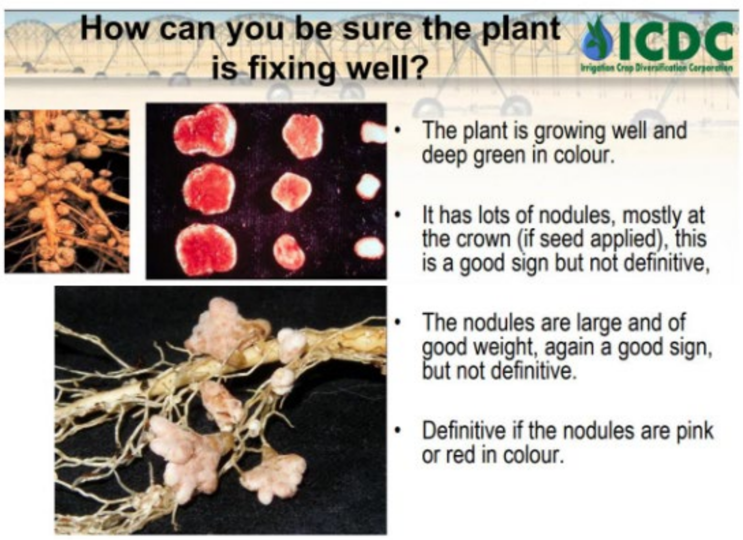
Nitrogen fixation

Nitrogen fixation is the process in which certain soil bacteria, *Rhizobia*, convert N from the air to a form of N that plants can use. This process takes place in nodules–round or oblong - growths on the roots of legumes. Rhizobia can be found naturally in the soil or can be introduced as a commercial inoculant. Each legume species is inoculated by a specific species of Rhizobia, however commercial inoculants contain a range of species that can inoculate various legumes (this is covered in Lesson 2).

Nitrogen fixation peaks around flowering. To maximize the N contribution of a legume, terminate it at full flower. As legumes mature, much of the N moves aboveground into the leaves and particularly into the seed. If the seed is harvested or the legume is cut as hay, much of the N will be removed from the field.



Ways to include legumes in crop rotation



- Grain legumes (e.g., peas, lentils, soybeans, faba beans, lupin)
- Perennial alfalfa or clover
- Cover crop: Single-year green manure cover crop (e.g., fababean+oat intercrop)
- Cover crop: Late-season legume cover crop (e.g., seed peas after a grain crop or overseed red clover into a mature grain crop)

Voices from the Field: MacKay Ross

In midsummer of the first year of the crop rotation, MacKay Ross typically incorporates pasture and seeds cover crops "to cover the land and to build some soil over the remainder of the current year." The following spring, he will no-till seed a cash crop, often peas.

"In the case of something like peas, where you just end up with just dust off the back of the combine," MacKay explains, he will underseed the crop to subterranean clover to make up for the lack of biomass.

Subterranean clover doesn't compete with the peas, he explains. "Yet it's a solid cover. First thing in the spring, the subterranean clover is laying there covering up the soil." He then seeds oats. After the oat harvest, there's enough stubble to protect the soil over the winter.

MacKay is using what some might see as a climatic constraint to his advantage. Being in Zone 2b, most cover crops can't overwinter. Using cover crops that winterkill, such as subterranean and crimson clover, makes it possible for MacKay to seed earlier in the spring while still protecting the soil over the winter. However, having only about 80 frost-free days limits MacKay's choice of cash crops and cover crops.

He is considering underseeding oats with annual legumes such as crimson clover. Or if he feels it's time for pasture, he'll underseed oats with a perennial hay mix.

Grain legumes (pulses)

Important organic grain legumes in the Prairie region include peas, lentils, soybeans, dry beans, faba beans, chickpeas and lupins. Even though these crops all fix a considerable amount of N while they grow, much of the N is removed when the crop is harvested.

How much N is left after growing grain legumes? Researchers have tried to estimate how much N grain legumes leave for the following crop. Results from Manitoba show that peas, lentil and fababeans provide 10-15 kg N for every 1000 kg of seed harvested. In terms of bushels, these crops will provide 8.9-13 lb N for every 15 bushels of crop harvested (0.6-0.88 lb N/bushel of pea, lentil or fababean harvested). Dry bean and soybean leave only 1 kg N per 1000 kg seed harvested, while chickpea provides 3 kg N per 1000 kg seed harvested.[1]

[1] Przednowek, D.W.A., Entz, M.H., Irvine, B., Flaten, D.N. and Thiessen Martens, J.R., 2004. Rotational yield and apparent N benefits of grain legumes in southern Manitoba. *Canadian Journal of Plant Science*, *84*(4), pp.1093-1096.

Voices from the Field: Penny Lane Organic Farms

In terms of cash crops grown on Penny Lane Organic Farms in Saskatchewan, lentils are the most successful. This came as a surprise to Stewart Wells during the farm's transition. They had grown lentils using herbicides but he was skeptical about how well they would work in organic production because "lentils are not very competitive. They don't grow very tall, don't shade out any weeds or actively compete with weeds."

They are one of Penny Lane's best crops financially, "pretty much every year with the exception of grasshoppers." Grasshoppers are particularly damaging to lentils because they focus on the flowers and pods. The plants may look healthy but you might not get a crop.

They have switched from large green to small green lentils before settling on CDC Peridot French green (du Puy) lentils. The French green lentils garner a higher price and have agronomic benefits. They store better than the large greens, which can oxidize and change colour during storage, causing their value to drop. In contrast, Stewart says he's found that buyers can be happy with three-year-old French lentils. Also, small and French green lentils are less susceptible to root rot compared to large ones.

"With lentils and peas, I worried about getting too many different varieties." Stewart recalls cleaning up sloughs one year when they had grown both green and yellow peas on the farm. He looked back and saw a yellow-green mix in the hopper that "looked attractive but would be pretty tough to sell."

Perennial forage legumes

Perennial forages, such as alfalfa **and red clover**, can provide large amounts of N to following crops. For example, in Portage la Prairie, MB, a 3rd-year alfalfa crop left 127 lb/acre (149 kg/ha) of N in the soil even after taking two hay harvests that year. This means 127 lb/acre of N would be available to the following crops.[2]

Total N fixed: 155-415 lb/acre
Net N contributed to soil:

- Year 1 – 75 lb/acre
- Year 2 – 132 lb/acre

[2] Kelner, D.J., Vessey, J.K. and Entz, M.H., 1997. The nitrogen dynamics of 1-, 2-and 3-year stands of alfalfa in a cropping system. *Agriculture, ecosystems & environment*, *64*(1), pp.1-10.

- Year 3 – 127 lb/acre

Grass-legume vs pure legume? What's the N contribution from forages that contain a combination of grasses and legumes (e.g., alfalfa/timothy)? The answer: as long as the legume makes up at least 50% of dry matter, the N contribution of the mix will be equal to that of a pure legume stand.

Grazed vs hayed? What if the perennial legume is grazed? The researchers estimate that a grazed system would leave about 15% more N than a hayed system.

Voices from the Field: Haywire Farms

Using a cut of cover crops as silage is a way of finding a balance on Haywire Farms outside of Edmonton. Taking that first cut contributes to the farm's cash flow, in a sense, by feeding the silage to livestock. And the growth that could otherwise be a second cut is left for the soil. "We're sharing between the needs of revenue generation versus the needs of the soil," says Trevor Riehl. "I get that a full year of green cover is banking revenue for the future but there's the matter of what makes sense with your overhead."

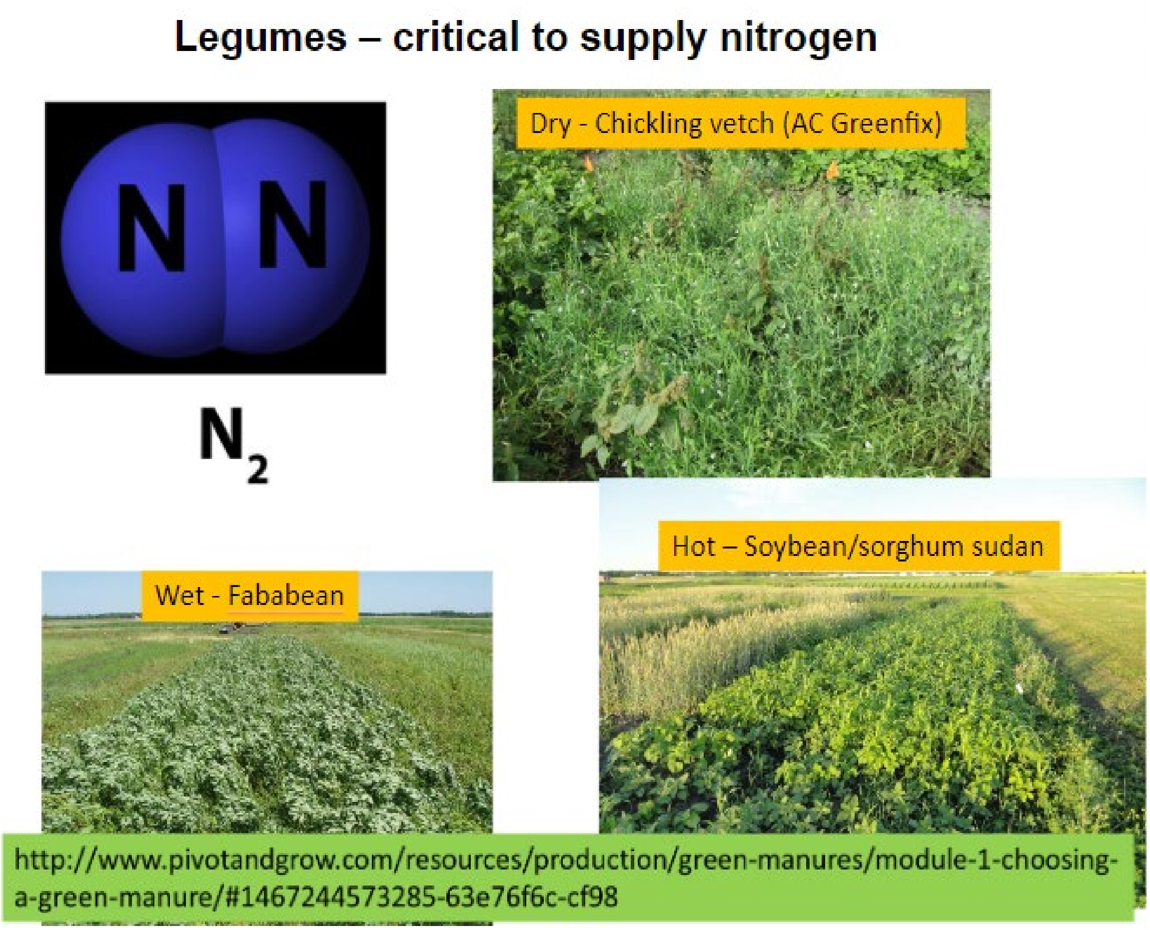
Voices from the Field: Marshall Farms

To provide nitrogen in the rotation, the Marshalls intercrop alfalfa with hemp. In the same seeding pass, they seed 10 pounds/acre of alfalfa in the same row as 30 pounds of hemp. If there's a problem with a hardpan, they might add chicory to the mix.
"In the fall, when the hemp comes off, those little young alfalfa plants get sun and keep growing," Larry Marshall says. If they want a green manure, they incorporate the alfalfa in late July the following year and get 100 pounds of nitrogen per acre.

Cover crop: Full season green manure

Many organic farmers on the Prairies dedicate a full growing season to a legume-based **green manure**. A **green manure** is a cover crop, sometimes called a plowdown crop, that is not harvested but grown to improve the soil.

The Green Manure Tool Kit | Pivot and Grow contains detailed information on how to select, seed, manage and terminate green manures, with a focus on the Canadian prairie organic farms. Another great resource is the free, downloadable book, Managing Cover Crops Profitably, 3rd Edition - SARE.



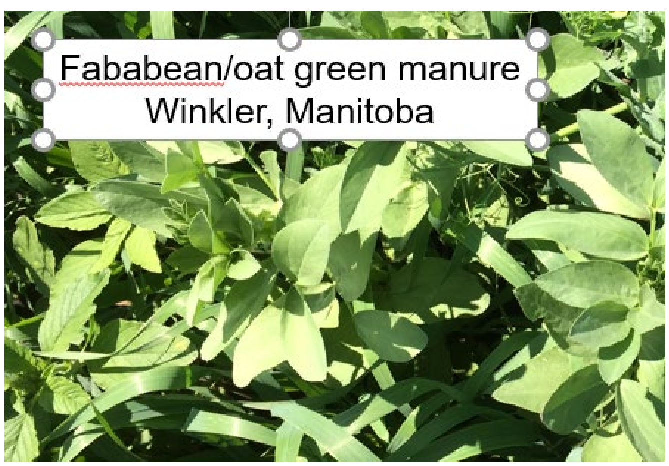
Green manure yield and %N data from U of M Carman, 2006 and 2007

Table 1. Green manure crop data for 2006

Green manure	Nitrogen	Dry matter Production	Dry matter Nitrogen
	%	kg/ha	
Pea	2.52	4138	111
Hairy vetch	2.43	4159	101
Pea-oat	2.21	4348	97
Chickling vetch	3.50	2518	88
Fababean	2.75	2049	61
Lentil	1.80	2075	38
Flax	1.31	2305	31
LSD (p=0.05)	0.63	1369	50

Table 2. Green manure crop data for 2007

Green manure	Nitrogen	Dry matter Production	Dry matter Nitrogen
	%	kg/ha	
Hairy vetch	3.49	5561	194
Pea	3.18	5667	180
Chickling vetch	3.50	4507	157
Lentil	3.20	3833	122
Pea-oat	1.69	7030	119
Flax	1.63	4449	73
Fababean	2.75	3579	98
LSD (p=0.05)	0.34	895	27



When selecting and managing a full-season green manure, consider:

- Selecting a legume that is not typically grown on the farm for grain (e.g., if you're growing peas as a cash crop, avoid using peas as a green manure).
- Growing mixtures of cover crop species instead of a monoculture.
- Rotating green manures – don't rely on the same green manure species all the time.
- Using high seeding rates so that the green manure will compete better with weeds.

- Reducing tillage during the termination process to maintain soil cover. Using a legume that will winterkill is one way to minimize tillage.
- Using rotational grazing if the cover crop is grazed so that the nutrients are spread evenly across the field.
- Planting a late-season catch crop to reduce N losses, especially if the green manure is terminated early.

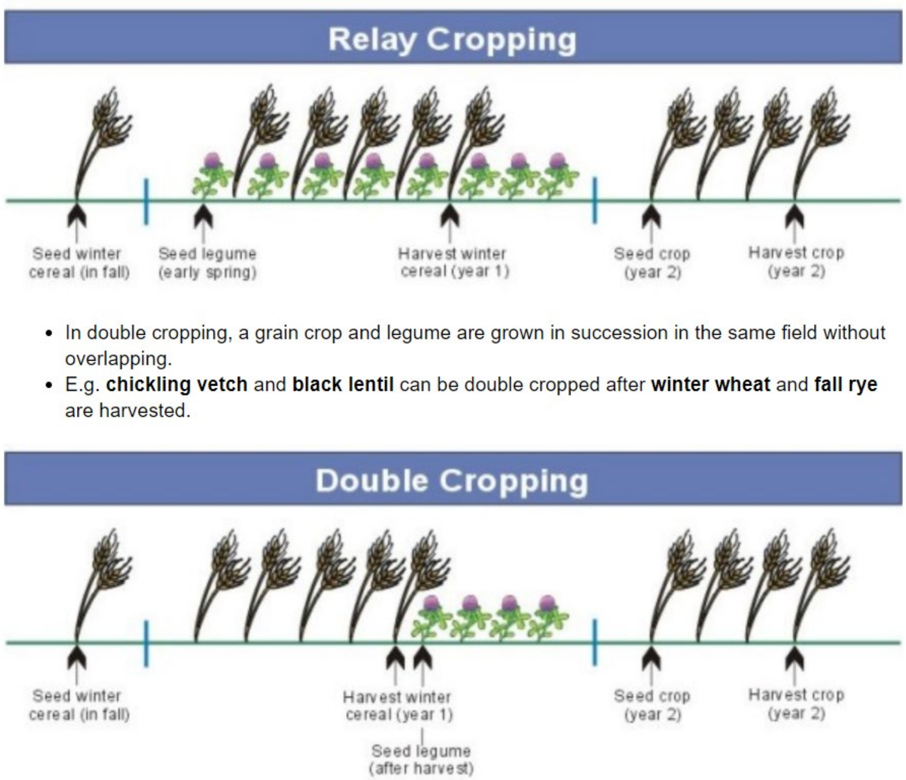
A catch crop is a cover crop planted to take up excess nutrients. This way, rather than leaching out of the soil, the nutrients will be released when the catch crop is incorporated into the soil. Catch crops are often heavy-feeding cereals, grasses or brassicas, such as fall rye, annual ryegrass and tillage radish.

To learn more about using cover crops on the prairies, check out [the hour-long podcast from Manitoba Organic Alliance].

Cover crops: Intercropping, relay cropping and double cropping

Another way to bring N into the crop rotation is to use a late-season legume cover crop. There are many different ways of doing this, particularly in areas with a long growing season. Examples:

- Seed peas, chickling vetch or lentils after harvesting a cereal crop. This is referred to as double cropping since the cover crop is the second crop seeded that year with no overlap.
- Underseed alfalfa or sweetclover to winter wheat or fall rye in the spring and leave the legume to grow in autumn. This is referred to as relay cropping since the second crop is seeded after the first crop has matured. Another option is to seed alfalfa or clover into spring cereals.
- Seed fall rye after harvesting a grain legume cash crop. The rye will work as a catch crop. It will take up the extra N in the soil and hold it in its tissue over the winter. After the rye is incorporated the following year, the N will be released but more slowly because it will be combined with the **carbonaceous** rye residue (i.e., has a high **C:N**).



This image shows examples of relay and double cropping systems in winter cereal production.

Learn more about relay cropping and double cropping with cover crops in Section 1.2. Reducing Green Manure Commitment in The Rotation and Finding Synergies: Relay and Double Cropping - Green Manure Tool Kit Module 3.

Catch crops vs late-season legume green manures - what's the difference?

Late-season green manures and catch crops are often exactly the same thing. A catch crop is seeded with the purpose of "catching" nitrogen so that it is not lost before next year's crop can use it. One difference is that catch crops are not legumes - catch crops take up, not fix, N. The image below shows two catch crops (barley and tillage radish) planted after a legume green manure was grazed. Both cover crops were equally effective in "catching" the N produced by the green manure. However, tillage radish was better at releasing the N in the following year[3].

[3]Cicek, H., Martens, J.R.T., Bamford, K.C. and Entz, M.H., 2015. Late-season catch crops reduce nitrate leaching risk after grazed green manures but release N slower than wheat demand. *Agriculture, ecosystems & environment*, *202*, pp.31-41.

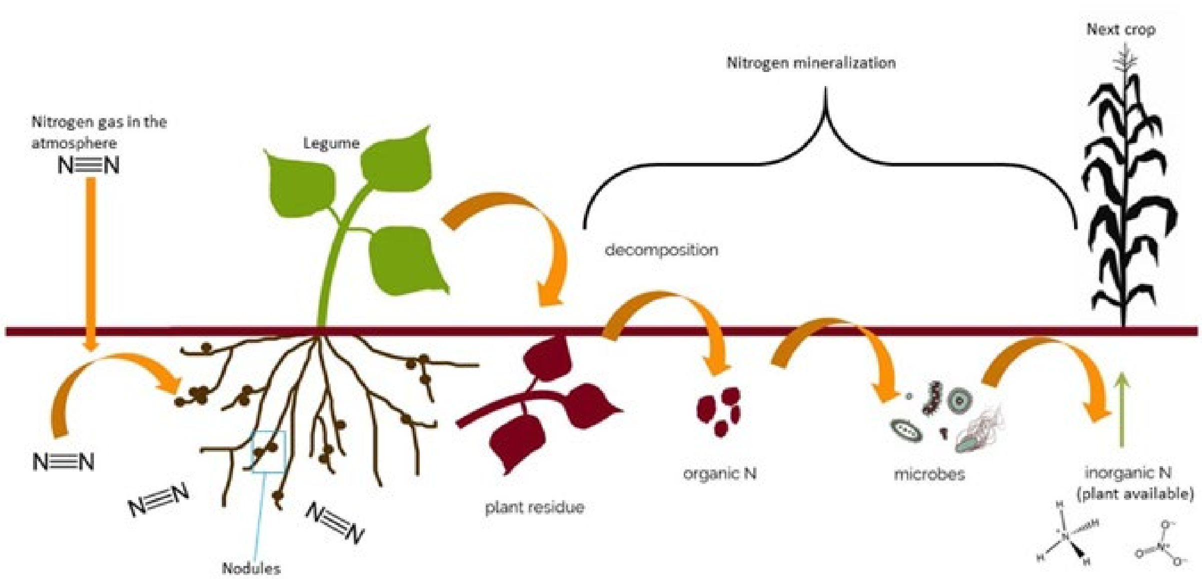
Getting the N out of the legume

Even if there is lots of N in the soil, crops can suffer from a N deficiency because plants can only take up certain forms of N. In the process of **N mineralization**, soil organisms convert the N that is contained in soil organic matter, crop residues, manure or other organic amendments into ammonium and nitrate. These are inorganic (mineral) forms of N that plants can take up. Because soil microbes are responsible for N mineralization, the process is highly dependent on weather and the health of the soil microbial communities.

Factors that increase the speed of N mineralization from legume plant material include:

- Adequate soil moisture and temperature
- A **C:N ratio** of the legume material below 20:1
- Healthy soil biological community

In terms of N mineralization, there can be too much of a good thing because plant-available N is also water-soluble. This can leach out of the soil and possibly contaminate water bodies or groundwater. Ideally, the rate of N mineralization is roughly the same as the rate as N uptake by plants. If N mineralization is expected to be rapid, farmers can use a catch crop or a heavy-feeding cash crop to take up the extra N. Another way to avoid N loss from rapid mineralization is to incorporate material with a high C:N, such as straw, mature grasses or cereals, with legumes, particularly if the legume has lush, succulent growth (and a low **C:N**).



Nitrogen cycling with a legume green manure. Figure modified slightly from that kindly provided by Dr. Julie Grosman and Sharon Perrone, University of Minnesota.

Want to learn more about designing a crop rotation? Check out the Rotation Fact Sheet.

To learn even more, explore these links.

NITROGEN FIXATION is the conversion of atmospheric nitrogen into plant-available nitrogen. Nitrogen fixation occurs naturally when lightning strikes and through the action of Rhizobia. The Haber-Bosch industrial process uses fossil fuel energy to fix nitrogen to make synthetic nitrogen fertilizers.

NITROGEN MINERALIZATION is the process of converting organic nitrogen into plant-available, inorganic nitrogen. This process occurs during decomposition with the activity of soil microorganisms.

ORGANIC NITROGEN is nitrogen that is bound into the tissues of organisms, where nitrogen is used to form proteins and DNA. Organic nitrogen is strongly bound into these structures and is not readily available for plants to use.

INORGANIC NITROGEN is also referred to as plant-available nitrogen. Inorganic nitrogen is not bound in tissues, but is rather bound to hydrogen or oxygen to form NH4+ or NO3–. Inorganic nitrogen can be taken up by plants for growth, and can also be leached or released to the atmosphere.

Nutrient management: P, K, S and micronutrients

This lesson explores how to supply organic cropping systems with nutrients other than nitrogen. These include phosphorus (P), potassium (K), sulfur (S) and micronutrients.

The status of available nutrients on organic farms has been studied in many parts of the world. Results from Manitoba and Australia show that the greatest difference between organic and conventional fields was in terms of P, with P levels being lower in organic than conventional systems.

	Manitoba (kg/ha)[4]		South Australia (kg/ha)[5]	
Nutrient	**Organic**	**Conventional**	**Organic**	**Conventional**
Nitrogen	92.5	70		
Phosphorus	15.5	30	14.2	27.2
Potassium	654	700	1.58 meq/kg	1.69 meq/kg
Sulfur	101	60	16.4	26.9
Copper			0.70	0.57
Zinc			0.85	0.56
Iron			14	15

The image below shows a dramatic example of a P deficiency. The alfalfa in the back half of the plot is growing where available P is less than 4 ppm (about 8 kg/ha), while the foreground has soil P of 18 ppm. This example is from the University of Manitoba long-term study at Glenlea (20 km south of Winnipeg). In other cases, for example on Ontario dairy farms, low soil P did not always result in such a dramatic decline in alfalfa production.[6] Nevertheless, soil P remains a significant challenge for organic production on the Prairies and P deficiency on organic farms can lead to unproductive crops. See Nutrient management in organic grain production for an example from Manitoba.

[4] Entz, M.H., Guilford, R. and Gulden, R., 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. *Canadian Journal of Plant Science*, *81*(2), pp.351-354.
[5] University of Adelaide, S. Australia.
[6] Schneider, K.D., Cade-Menun, B.J., Lynch, D.H. and Voroney, R.P., 2016. Soil phosphorus forms from organic and conventional forage fields. *Soil Science Society of America Journal*, *80*(2), pp.328-340.

How long does it take for a P deficiency to occur in organic production?

The P deficiency in the forage-grain rotation (two years of alfalfa hay followed by wheat and flax) at Glenlea took about 15 years to become a noticeable problem.

Similar results were observed in a long-term study in Saskatchewan at Agriculture and AgriFood Canada's Indian Head Research Farm. The Indian Head rotation (which is still running) started in 1958 and compared fallow-based grain systems, continuous grain systems, green manure-grain systems and alfalfa hay-grain systems. The green manure grain and forage grain systems do not receive synthetic fertilizer so this provides an excellent opportunity to look at the effect of changes in P in a system similar to organic production.[7] However in the grain-only organic rotation at Glenlea, P deficiencies have not yet been observed after 25 years of organic production. ***Therefore: P deficiencies are most common when hay is exported (removed from the field).***

Assessing nutrient deficiencies

Nutrient deficiencies in organic production can be assessed using

- Soil tests
- Plant tissue tests
- Nutrient budgets

Soil tests

How do farmers and agronomists know whether the P deficiency is as dramatic as the image above? Soil tests are especially useful for determining K, S and micronutrient deficiencies. For P, soil tests have been shown to be useful when available soil P levels are either less than 5 ppm, or above 10 ppm.

Voices from the Field: Mill Creek Organics

The Boersches want to fine-tune the nutrient levels of the soil, and ultimately of the crops. They constantly want to identify their limiting factors and address these through soil amendments or crop rotation. They perform a series of tests including:

Brix tests. These provide a rough estimate of the sugar content of plant sap. High Brix numbers are often associated with greater flavour, improved storage qualities of a crop

[7] Lafond, G.P., Campbell, C.A., Lemke, R., May, W.E. and Holzapfel, C.B., 2012. Indian Head Long Term Crop Rotations: Indian Head Saskatchewan. Prairie Soils Crops, 5, pp.42-50.

and the ability of a plant to resist pest pressure. Alex Boersch says their Brix numbers have improved over the last several years from 8-9 to 12-14.

Tissue and sap analyses. The Boersches now do more of these lab tests than Brix tests to better quantify the sugar content and to see how the nutrient balance in the plants compares to the nutrient levels of the soil.

Soil nutrient tests. Alex aims for the Albrecht-recommended ratio of 13 parts calcium to 2 parts magnesium to 1 part potassium, however he finds it a challenge to achieve this due to their soil's very high cation exchange capacity (40-50). On the conventional fields, they have been encouraged by seeing a dramatic drop in the level of nitrates. Alex feels that nitrates are directly correlated to Brix - with high nitrates leading to a drop in Brix. (The nitrate levels on the organic fields have never been excessive.)

Soil micronutrient tests. At times, their organic fields have "been a bit short on boron, zinc and molybdenum." They address these deficiencies partially through fish emulsion but also through application of specific micronutrient amendments as allowed by the Canadian Organic Standards.

Soil biological assays. Alex uses the Haney[8] *soil tests to measure macro- and micro-nutrient levels, carbon-to-nitrogen ratios and various biological parameters, such as biologically active carbon and carbon respiration. Essentially, the test evaluates the level of nutrients available for soil microorganisms and describes the soil biota.*

Alex aims to increase the level of biologically available carbon to better support soil life, and also to change the bacteria-to-fungi ratio. When they started testing about four years ago, the bacteria-to-fungi ratio was about ten-to-one, which Alex considers is likely similar or better than most farms that only grow annual crops. He is aiming for less bacterial dominance, perhaps even getting to the one-to-one ratio promoted by Dr. Elaine Ingham[9]*.*

Plant tissue tests

Research in Manitoba and Saskatchewan has shown that when soil test P levels are between 5 and 10 ppm, it is hard to know if a serious P deficiency will be observable in crops. When soil tests show P levels between 5 and 10 ppm, farmers can use a plant tissue test to determine whether a serious P-supply problem exists. This test is referred

[8] https://www.covercropstrategies.com/articles/1550-understanding-the-haney-soil-test
[9] https://www.soilfoodweb.com/

to as the "green manure bioassay" and involves sampling a green manure crop just before it is terminated. Farmers or agronomists should take all above-ground plant material (weeds and green manures) from several areas of each field (each sample from ¼ m^2). These samples should be dried, weighed and sent to a lab for testing. Ask the lab for a "forage or feed test" as this test will provide information on all the macronutrients and micronutrients.

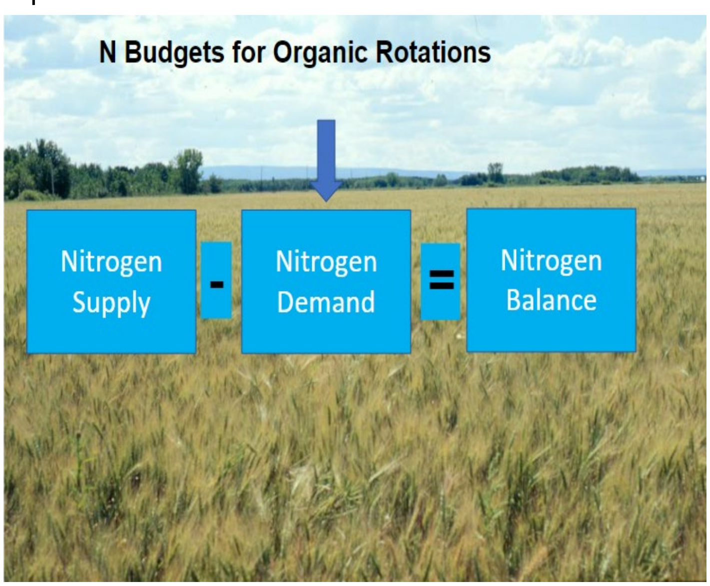
How to Take Soil and Plant Tissue Samples with Joanne Thiessen Martens and Scott Beaton. *Pivot and Grow – Grain on the Brain (SEASON 1, EPISODE 3).*

Voices from the Field: Upland Organics

At Upland Organics in Southern Saskatchewan, Allison Squires and Cody Straza keep detailed records of soil health tests and experiments, thanks to Allison's scientific background. (She holds a PhD in environmental toxicology.) In addition to sending soil samples to a lab for physical and chemical analyses, Allison conducts on-farm soil tests on each parcel at least every five years, including measures of soil aggregation, compaction (using a penetrometer) and infiltration rates. She samples the Brix levels of plant tissues to assess the health, sugar levels and nutrient content of the crops (including forage).

Nutrient budgets

A nutrient budget estimates the nutrients added to the field (e.g., in fertilizer, manure or N-fixation), the amount of nutrients removed by the crops, and the nutrients left after harvest for future crops.



Crop demand

Crop	N	P_2O_5	K_2O	S
Crop nutrient removal (lb/bushel)				
Wheat 10% protein	1.2	0.5	0.35	0.1
12%	1.5	0.5	0.35	0.1
14%	1.9	0.5	0.35	0.1
Barley	1.1	0.36	0.35	0.07
Oat	.96	0.25	0.18	0.06
Corn	0.75	0.37	0.27	
Pea	2.3	0.7	0.7	0.14
Flax	2.12	0.6	0.6	0.2
Sunflower (lb/lb)	0.026	0.008	0.006	0.002
Alfalfa (lb/ton)	56	15	60	5
Bromegrass (lb/t)	36	13	59	3

A **bushel of corn removes** about 0.75 **lb nitrogen**, 0.37 **lb** P2O5, and 0.27 **lb** K2O from the soil. A **bushel** of soybeans will **remove** 4 **lbs nitrogen**, 0.8 **lb** P2O5, 1.4 **lbs** K2O (Figure 1).

Crop nutrient removal: Wheat grain example

30 bushels per acre x *1.9 lb N/bu = 57 lb N removed

48 bushels per acre x **1.5 lbN/bu = 72 lb N removed

*14% protein
**12% protein

An example of a nutrient budget is below. This is for a multi-year rotation which begins with an alfalfa hay crop. The N balance of the whole seven-year is close to zero (-9.5 kg/ha), which is good news because this means that cash crops can be harvested without the use of synthetic fertilizers or a net loss of N. But using "book values" for the average amount of P, K and S removed through crop harvest indicates that the rotation has removed significant amounts of these nutrients. This example clearly shows that supplying N through legumes is entirely possible using the rotation. However, other strategies are required to replenish P, K and S.

Crop	N	P_2O_5	K_2O	S
Nutrient balance (lb/ac)				
Alfalfa hay (4 ton/acre)	+130 104 available over 3 years 26 to soil organic matter	-144	-540	-60
Wheat (34 bu/ac)	-64.5	-19	-14.2	-3
Flax (15 bu/ac)	-30	-16.5	-9	-3
Oat (50 bu/ac)	-45	-12.5	-9	-3
Balance	-9.5	-96	-572	-69

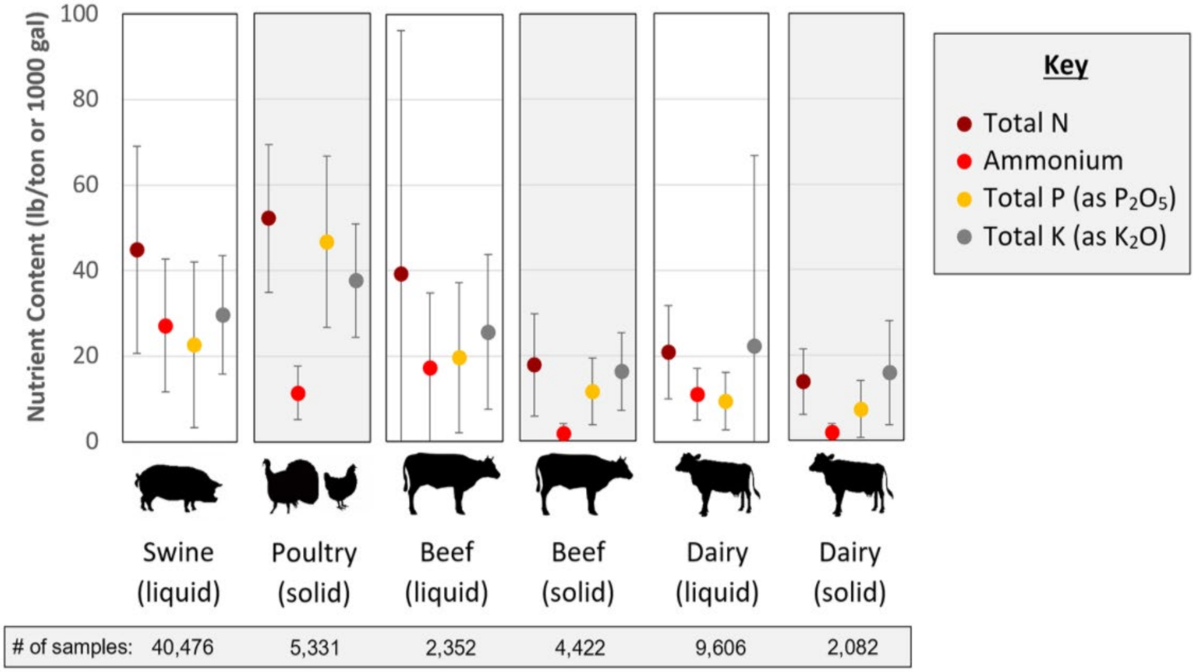
Nutrient sources

Animal manure

Animal manure is the most common source of external, non-N nutrients for organic production. A Canadian survey found that approximately 40% of Canadian organic farmers add animal manure to their fields.[10]

Different sources of manure vary greatly in terms of their nutrient content. In general, solid poultry manure has the highest N and P concentrations, while beef and dairy manure have the lowest. However, in order to know exactly what nutrients are contained in manure, manure should be tested before use. Only a lab test will provide farmers and agronomists with the necessary information to make an informed decision about application rate. All major soil testing labs provide manure analysis services.

[10] Nelson, A.G., Froese, J.C. and Entz, M.H., 2010. Organic and conventional field crop soil and land management practices in Canada. *Canadian Journal of Plant Science*, *90*(3), pp.339-343.



The dots represent the mean (average) concentration of the nutrients and the lines show the range of concentrations. If you focus on the dots, you will see that poultry manure, for example, has higher rates of total P than other manure. Source: https://extension.umn.edu/manure-management/manure-characteristics

The effectiveness of animal manures to provide many different nutrients is given in the following example.

	Nutrients										
	N	**P**	**K**	**S**	**Mg**	**Ca**	**Fe**	**Zn**	**B**	**Mn**	**Cu**
Poultry Manure (Rate of 5.6 tonne/ha)	200	100	106	42	23	115	3.7	1.8	0.2	1.9	1.3
Corn Grain Harvest (160 bu/acre)	-120.8	-36.7	-44.7	-9.9	-14.4	-2.6	-0.33	-0.25	-0.05	-0.05	-0.03
Net Change	79.2	63.3	61.3	32.1	8.6	112.4	3.37	1.55	0.15	1.85	1.27

This means that just four corn harvests would remove all of the boron (B) added by the manure, but it would take 40 corn harvests to use up all the copper (Cu).[11]

Availability of nutrients from manure_varies depending on the nutrient. Phosphorus is 80% available in the year of application while 90% of the K is available. N is less available in the first year after application. In the case of beef manure, 25-60% of N in the manure will be available in the first year. For swine manure, 35-80% of N is available in year 1 while for poultry manure, 45-70% of N is available.

Rules for manure application must be studied before embarking on a manure-spreading program. Each Canadian province has its own set of rules for manure application. The rules for Manitoba, Saskatchewan and Alberta are available at: Manure Management - Agriculture, Managing Manure as a Fertilizer | Soils, Fertility and Nutrients | Government of Saskatchewan, and Manure management guidelines and legislation | Alberta.ca respectively.

There are also strict requirements to follow when using manure in organic production. Check out "animal manure," "compost" and "manure" in Table 4.2 of the Permitted Substances Lists and also Clause 5.5.2.5 of the Canadian Organic Standards.

Compost

Solid manure is often composted before using. Composting kills some pathogens and weed seeds. Also, composting greatly reduces transport and spreading costs. A Canadian prairie study found that composting resulted in an average 40% loss of dry matter and 80% loss of water - with an average loss of 66% of the total mass.[12]

Nutrient availability varies significantly depending on what the compost is made from. Compost derived from high-nutrient materials, such as municipal biosolids or animal wastes, is likely to have relatively high nutrient availability, compared to compost containing more straw, stover or forestry waste. The availability of P and K from compost is similar to that of manure. Release of N from compost will depend on the C:N ratio of the manure. It is generally accepted that below a C:N ratio of 20:1, available N will be released, and above 30:1, available N will be immobilized (tied up) by soil microbes. Thus, if the C:N ratio of the compost is greater than 20:1, 20:1, a legume can be grown before or after the compost application to supplement nitrogen.

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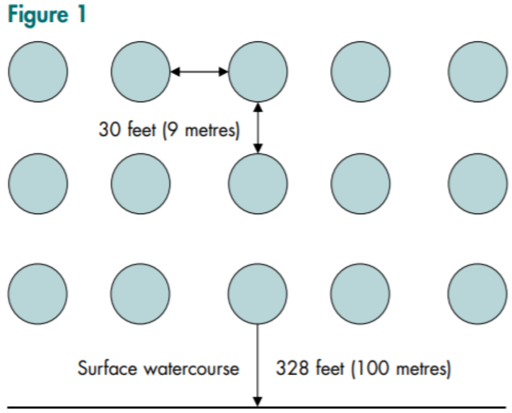
[11] Heckman, J.R., Weil, R. and Magdoff, F., 2009. Practical steps to soil fertility for organic agriculture. *Organic farming: the ecological system*, *54*, pp.137-172.

[12] Larney, F.J., K.E. Buckley, X. Hao and W.P McCaughey. 2006 Fresh, Stockpiled, and Composted Beef Cattle Feedlot Manure: Nutrient Levels and Mass Balance Estimates in Alberta and Manitoba. Technical Reports: Waste Management. J. Environ. Qual. 35:1844-1854.

Bale grazing – a strategy to enrich soils with P

Bale grazing provides an opportunity to move large quantities of nutrients from one area of the farm to another. Each hay bale weighing 1000 lb (400 kg) contains approximately 15 lb of P_20_5; this is true for both alfalfa and pure grass bales. For severely P-deficient soils, winter grazing bales for one season can add enough P to replenish soils for a decade. The basics of bale grazing are available from the Manitoba Agriculture website and an example of bale grazing can be seen at Soil Health, A Montana Perspective - Bale Grazing

Figure 1



Source of picture: Hay and forage grower; Source of diagram: Manitoba Agriculture

Other organic nutrient sources

Information on other nutrient sources for organic production are readily available online. An example from the United States Department of Agriculture is shown below. **Note that not all of these substances are permitted in organic production in Canada.** For example, Chilean nitrate is not permitted. Before using an input , check with your certification body and refer to the Permitted Substances Lists.

Table 4. Nutrient analysis (percent by weight) of common organic fertilizer materials (Gaskell et al., 2007)

Material	Nitrogen (% N)	Phosphorus (% P_2O_5)	Potassium (% K_2O)
Chilean nitrate	16	0	0
Blood meal	12	0	0
Feather meal	12	0	0
Fish meal/powder	10-11	6	2
Seabird & bat guano	9-12	3-8	1-2
Meat and bone meal	8	5	1
Soybean meal	7	2	1
Processed liquid fish residues*	4	2	2
Alfalfa meal	4	1	1
Pelleted chicken manure	2-4	1.5	1.5
Bone meal	2	15	0
Kelp	<1	0	4
Soft rock phosphate	0	15-30**	0
Potassium-magnesium sulfate	0	0	22
Cocoa shells	1	1	3
Cottonseed meal	6	2	2
Granite dust	0	0	5
Hoof & horn meal	11	2	0
Seaweed, ground	1	0.2	2
Muriate of potash (KCl)	0	0	60

* Note: all analyses are % by weight, as specified in state fertilizer laws. For liquids, product density (weight per gallon) should be used to calculate nutrient application rate: (g/ac)*(lb nutrient/g)=(lb nutrient/ac)

* *Soft rock phosphate provides only 1-3% of its P in acid soils, and little or no P in soils with pH over 7.

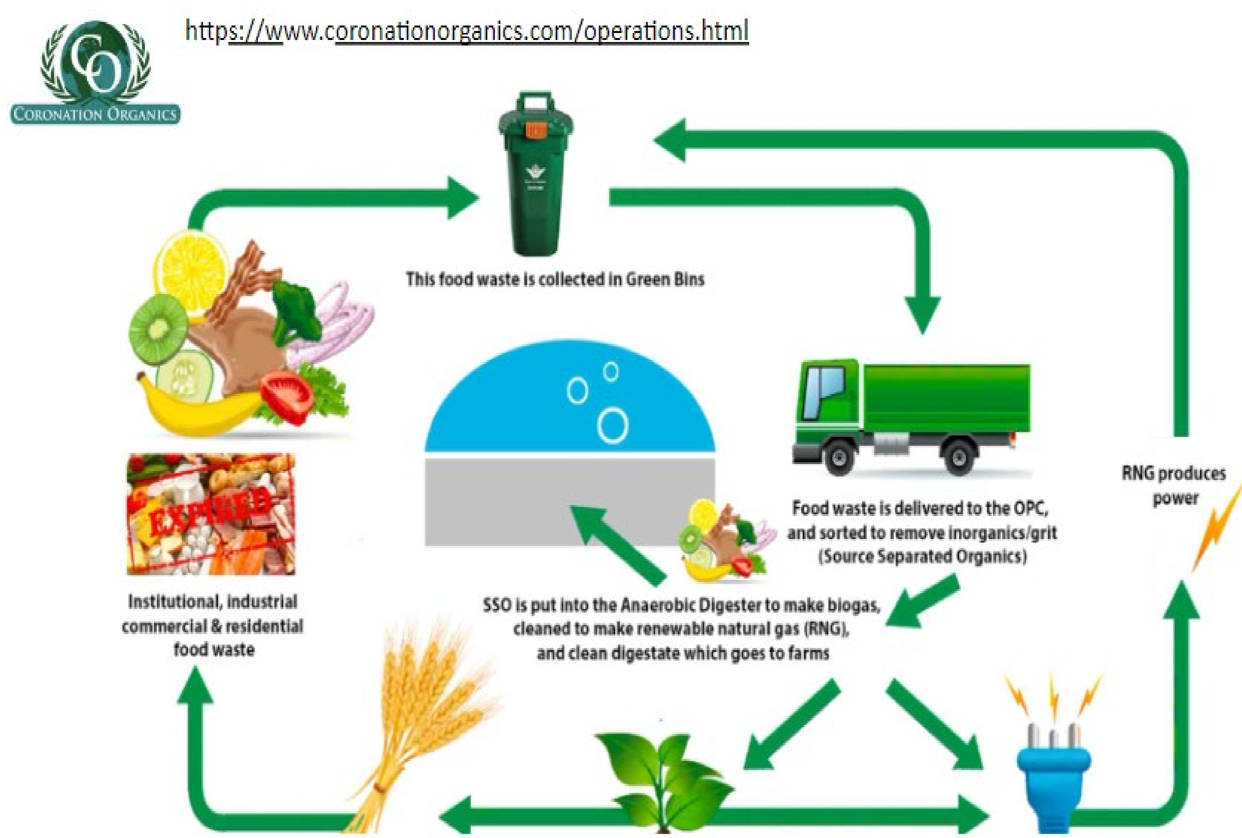
Sources of P

- Manure and compost – P from these sources is readily available to crops
- Feed and hay (mixed farm) – for example, bale grazing can provide P
- Mineral sources – rock phosphate contains P but does not release it well in neutral to alkaline pH soils)
- Organic fertilizers – includes bone meal and other biological sources
- Nutrients from the 'circular economy' - includes digestate, insect 'frass' and struvite as described below

Questions about rock phosphate: It is difficult to make universally applicable recommendations for rock phosphate applications because so many factors affect its dissolution (the process by which the minerals become dissolved in soil water) and subsequent availability to plants. Soil pH is important in the dissolution of the rock P. Rock P is much more soluble in acidic soils (soil pH < 5.5). In neutral pH and alkaline soils, rock P provides little benefit for plant nutrition. Extensive research in Canada has shown that even very high application rates of rock P don't necessarily increase P supply to crops.[13] For this reason, rock P is not recommended in most Prairie organic production in Canada, except on soils with a pH < 5.5.

Nutrients from the Circular Economy

The importance of recycled nutrients was recognized in the European Union's action plan for a "Circular Economy."[14] Recycled nutrients may be especially important on Canadian organic farms, which often suffer from phosphorus depletion because more P is exported from the farm than is added.[15]

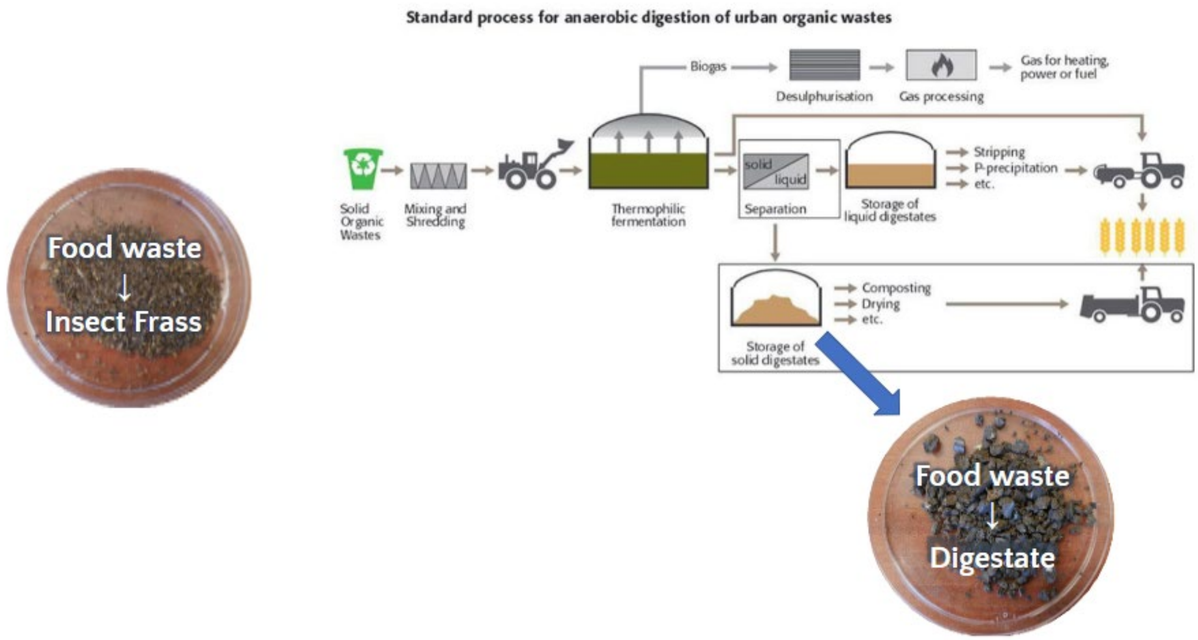


[13] Arcand, M.M., Lynch, D.H., Voroney, R.P. and van Straaten, P., 2010. Residues from a buckwheat (Fagopyrum esculentum) green manure crop grown with phosphate rock influence bioavailability of soil phosphorus. *Canadian Journal of Soil Science*, *90*(2), pp.257-266.

[14] https://www.eea.europa.eu/policy-documents/com-2015-0614-final

[15] Entz, M.H., Guilford, R. and Gulden, R., 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. *Canadian Journal of Plant Science*, *81*(2), pp.351-354; Schneider, K.D., Cade-Menun, B.J., Lynch, D.H. and Voroney, R.P., 2016. Soil phosphorus forms from organic and conventional forage fields. *Soil Science Society of America Journal*, *80*(2), pp.328-340.

http://www.fertilizer-machines.com/solution/fertilizer-technology/biogas-digestate-compost-fertilizer-produ.html



Examples of recycled nutrients

Digestate is what is left over from anaerobically digesting household compost. An example of a company producing digestate fertilizer is shown here.

Frass is the word to describe insect droppings. Commercial frass production exists in Canada, where Black soldier fly larvae are fed food waste. The larvae become a high protein livestock feed, while their manure (droppings) becomes an organic fertilizer.

Struvite is a mineral consisting of magnesium, phosphate, ammonium, and water, held together in a crystalline structure that precipitates naturally under the right conditions. Struvite can be recycled from urine. The 2020 COS permits the use of struvite from livestock urine as a soil amendment. Struvite is a 'slow-release' fertilizer that is more soluble in soil than rock phosphate, especially in alkaline soils. It has an N-P-K content of 5-28-0. To learn more, listen to the podcast or read the transcript here.

Learning from historical research on the Prairies

The Canadian government, through Agriculture and AgriFood Canada, has conducted many long-term studies and these studies are proving invaluable for informing organic crop production methods. At Indian Head, Saskatchewan, researchers compared fertilizer P sources with manure sources from 1947 to 1977.[16] Here is some of what they learned:

- Long-term wheat yields were increased when manure was used to add P compared with where fertilizer was used. The barnyard manure had a P level of 19 kg P/ha. The effect of manure on wheat yields was stronger than that of fertilizer P.
- The effect of manure was slower than the effect of fertilizer P.
- After 30 years, available P levels in the soil were higher where manure had been applied repeatedly compared with soil where an equivalent amount of fertilizer P was added.
- Levels of sulphur (S) and zinc (Zn) have also been increased by manure. In a separate study with flax, S deficiencies were shown on soil that received synthetic fertilizer but not on soil that received barnyard manure applications.
- Soils that receive P (and other nutrients) through manure or composts have better physical condition than soils that receive their nutrients as fertilizer.

Why do soil amendments often improve soil fertility and health?

Soil amendments, such as compost, often do more than just add nutrients. Soil amendments can:

- stimulate soil life, including the organisms responsible for nutrient cycling,
- improve soil structure,
- convert nutrients into plant-available forms by decomposing plant and animal material,
- suppress diseases, particularly soilborne pathogens, such as root rot and damping off.

Examples of organic crop rotations

Throughout this course, the benefits of crop rotation and factors to consider when designing a crop rotation will be examined. For example, a well-designed crop rotation can help control weeds and reduce pest problems.

To learn more about organic crop rotations, see the free, downloadable book Crop Rotation on Organic Farms - SARE, as well as the *Organic Field Crop Handbook* available from Canadian Organic Growers. You can also check out Manitoba Organic Alliance's 32-minute podcast with a discussion of strategies for designing organic crop rotations that build soil fertility, manage weeds and prevent disease and pests.

[16] Spratt, E.D. and McIver, R.N., 1979. The effect of continual use of phosphate fertilizer and barnyard manure on yield of wheat and the fertility status of a clay chernozem soil. *Canadian Journal of Soil Science*, *59*(4), pp.451-454.

Sample organic crop rotations

Year	Manitoba	SE Saskatchewan	Manitoba	PEI	Manitoba
1	Alfalfa seed	Alfalfa hay	Green manur e	Red clover green manure	Alfalfa/grass grazed
2	Alfalfa seed	Alfalfa hay	Wheat or flax	Spring wheat	Alfalfa/grass grazed
3	Alfalfa seed	Alfalfa hay	Lentil or pea	Soybeans	S. Wheat
4	S. Wheat or Hemp	Oilseed (flax, hemp or sunflower)	Alfalfa hay	Pea/barley intercrop	Soybean
5	Lentils or peas	Winter wheat and red clover or oats and sweetclover	Alfalfa hay	Oats underseeded to red clover	Barley/hairy vetch green manure
6	Hemp or S. wheat	Sweet clover or red clover grazed	Wheat or flax		Flax
7	Flax underseede d to alfalfa	Spring wheat	Oats		Oats or Fall Rye

Voices from the Field: Upland Organics

When Cody Straza and Allison Squires began farming, they started with a simple four-year organic crop rotation: cereal, pulse, oilseed and green manure. Over the course of four to five years, Allison and Cody noticed improvements in the soil and better weed control. Yields were good, although getting high levels of protein in the cereals was sometimes challenging. Soil organic matter was low - less than 2%. They began following the five principles of soil health (see below) about five years after starting farming. In 2021, the farm became certified as Regenerative Organic. The regenerative soil practices improve soil health and the ability of the soil to capture and retain moisture and nutrients.

Five soil health principles:

1. Minimize soil disturbance
2. Keep the soil covered
3. Increase diversity
4. Keep a living root in the soil as much as possible
5. Integrate livestock

…"Once we learned about the five soil principles," explains Cody, "our goal became to implement as many of these as possible."

Cody and Allison started with the "low-hanging fruit" and identified diversity as an easy first step. The more diversity above ground, they explain, the greater the diversity and health of the microorganisms below ground. Abundant, diverse soil life is key to good soil structure, retention of nutrients and water, and long-term fertility.

A simple step was expanding their cover crop by adding oats to the field peas they had been using as a green manure. Over the years, they kept adding more species and are now using cocktail mixes with up to 10 species. They also intercrop. For example, they underseed yellow sweetclover into annual crops. After the cash crop is harvested, the sweetclover will continue to grow, fix nitrogen and protect the soil from erosion.

Meanwhile, they increased the number of cash crops. Initially they grew French green lentils, flax and durum, but have since added sunflowers, camelina and various cereals including spelt, spring wheat, Kernza® and khorasan (Kamut®). Their crop rotation is more "adaptive" than rigid - they assess what a specific field needs and adapt their choice of crop rotation to the needs, rather than applying a simple formula.

"We could do much more if we had more rain," Allison says. Then she laughs and says she doesn't want to sound like she's complaining. However, their choice of crops is restricted by moisture availability.

Their desire to increase diversity continues on a large scale (now raising cattle) and small scale (soil microbes). While the couple acknowledge that having livestock is challenging, they appreciate the many benefits of incorporating cattle into the agro-ecosystem from providing fertility, "mowing" through grazing and trampling forages, and adding another income stream.

Voices from the Field: Penny Lane Organic Farms

On Penny Lane Organic Farms, Stewart Wells and Terry Toews have been using a three- or four-year rotation with at least one cereal and one legume. The 2022 cash crops are fall rye, hard red spring wheat and lentils.

"If I was going to go back and start over again, I'd be very dedicated to the notion of having alfalfa or an alfalfa blend on a third or quarter of the farm each year," says Stewart. Currently, they grow alfalfa on 100-200 acres/year.

How do organic yields compare?

Average differences between organic and conventional yields provided by Dr. Martin Entz of the University of Manitoba:

- Alfalfa and perennial forages: equal to conventional
- Cereals (wheat, oats, barley): 70% of conventional
- Pulses: 60% of conventional
- Soybean: 60% of conventional
- Flax and sunflower: 55% of conventional

These yield comparisons are a culmination of different field experiments in dryland conditions on the Prairies, including the Glenlea long-term rotation, a survey Dr. Martin Entz conducted on organic farms 20 years ago, research from Agriculture and Agri-Food Canada-Saskatchewan, and findings from Montana State University.

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The Prairie Organic Development Fund (PODF) is an investment platform established to develop organic agriculture and marketing in the Canadian Prairies. PODF builds resilience by investing in organic provincial associations (Capacity Fund) and high impact programs (Innovation Fund) related to marketing, research, policy, education and capacity development that have broad public benefit to the organic sector. The fund is directed by a board made up of organic producers, grain buyers, organic brands, researchers and provincial organizations.

The **Canadian Organic Ingredient Strategy (COIS)** provides farmers with tools and support to incorporate organic farming practices that help meet the growing demand for organic foods in Canada. The tools developed as part of this project will help Canadian farmers benefit from increased knowledge and skills in organic farming methods, which can improve soil health and boost farm resilience in the face of changing markets and climate change.

Visit www.pivotandgrow.com to learn more about the tools created as part of COIS.