A Systems Approach to Organic Agricultural Production

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PODF PRAIRIE ORGANIC DEVELOPMENT FUND

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A Systems Approach to Organic Agricultural Production

This training was developed and delivered by Dr. Martin Entz, PhD, Department of Plant Sciences, University of Manitoba. The material is intended to challenge readers to:

- critically evaluate their farm resources;
- map their farming operation in order to better visualize the farm as a system including the many connections; and
- strengthen their adaptive learning capacity.

The material also includes motivations and processes for transition and crop-livestock integration as a tool for sustainable production. The information on these specific production practices complement the systems thinking.

This written material is meant to be used in conjunction with the four (4) recorded presentations:

- Lesson 1: A Systems Approach to Organic Agricultural Production – Overview
- Lesson 2: Taking Stock of Farm Resources and Planning Processes
- Lesson 3: Learning Systems for Organic Agriculture
- Lesson 4: Whole Farm Planning with Crop-Livestock Integration

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Table of Contents

A Systems Approach to Organic Agricultural Production

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Introduction

"Agriculture is going through a profound revolution, one that rivals the industrial revolution of the 19th century and the green revolution in the 20th century. These previous changes transformed industries based primarily on local resources and principally served local markets to more complex systems using high levels of technology. These have evolved to become more fossil fuel intensive, less efficient in output per unit energy input, and more global in their markets. Some people define current agricultural changes only in terms of specific technologies, such as transgenic crops and site-specific input use determined by GPS spatial methods. Yet, there is a more profound change taking place mostly at the grass roots – a recognition that the resilience and sustainability of ecology and natural system have much to teach modern agriculture. Organic farming systems are one manifestations of this new awareness." Charles Francis, Professor, University of Nebraska.

According to the Organic Production Systems: General Principles and Management Standards , "Organic production is a holistic system designed to optimize the productivity and fitness of diverse communities within the agro-ecosystem, including soil organisms, plants, livestock and people. The principal goal of organic production is to develop operations that are sustainable and harmonious with the environment."

This publication describes some of the holistic thinking that both Charles Francis and the Canadian General Standards are referring to. The chapters challenge readers to critically evaluate their farm resources; map their farming operation in order to better visualize the farm as a system including the many connections; and strengthen their adaptive learning capacity. Additional chapters include motivations and processes for transition, and crop-livestock integration as a tool for sustainable production. Information on specific production practices complement the systems thinking – and these resources are linked to this document in Chapter 7.

Chapter 1. Introduction to Organic Farming

Organic Agriculture in Canada

The organic agricultural sector has been growing across the world, with over 50.9 million hectares worldwide in 2015 compared with only 11 million hectares in 1999 (360% increase; FiBLIFOAM, 2017). The number of organic farmers in Canada has also grown. After modest but steady growth from 1980 to 2008, organic farm numbers stalled in 2008 due to the global financial crisis of 2008. During the four years after this crisis, (2008 to 2013) organic farm numbers decreased slightly. However, since 2014, organic farm numbers in Canada increased again and today there are over 5500 certified organic farms in the country.

History of organic agriculture in Canada and around the World

The information below directly quotes from the Parliament of Canada. According to Helga Willer and Julia Lernoud of the Research Institute of Organic Agriculture (FiBL), the concept of "natural agriculture" appeared at the end of the 19th century in Germany and Switzerland. This model calls for a return to the land, limited use of machinery and permanent soil cover. Given their vegetarian convictions, proponents of natural agriculture also limited the use of animals on the farm, especially draft animals. Meanwhile, in 1924, Austrian Rudolf Steiner developed biodynamic agriculture, which also shunned the use of machinery and mineral fertilizers, and was based on esoteric principles such as following lunar cycles in crops. In the United Kingdom, the Soil Association was founded in 1946 and was one of the first organizations promoting soil conservation with practices such as zero tillage, permanent ground cover and crop rotation. In the United States, significant soil erosion in the Prairies in the 1930s, caused in part by intensive tillage, led to the emergence of similar organizations such as Friends of the Land that promoted alternatives to tillage, such as the use of compost on crops.

Until the 1970s, these different schools of thought operated independently for the most part, and the use and definition of the concept of organic agriculture varied from one organization to another. The International Federation of Organic Agriculture Movements (IFOAM) was created in 1972 to consolidate the organic movement across the world. Today, IFOAM has more than 750 member organizations, including producer, processor and consumer associations, research institutes and private companies in more than 100 countries.

In Canada, the history of organic agriculture reflects these international developments. Founded in 1953, the Canadian Organic Soil Association promoted soil conservation and biodynamic practices across the country in the 1960s. In the 1970s, McGill University developed the "Ecological Agriculture Projects" program, which became a key centre for information for those working in the area. The first certification bodies appeared in the 1980s. This institutionalization was completed with the introduction of the first Canadian organic standard in 1999, followed, in 2009, by regulations making compliance with standards mandatory for products for sale.

Principles of Organic Agriculture

Health – Organic agriculture should sustain and enhance the health of soil, plants, animals, humans and the planet as one and indivisible.
Ecology – Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.
Fairness – Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.
Care – Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

An example of long-term organic production research in Canada: The Glenlea long-term organic study

The Glenlea long-term organic plots are located on the University of Manitoba's Glenlea research station. These plots were started in 1992 and continue to provide important information for farmers and agronomists. You can learn more at the Manitoba Government's Agriculture YouTube Channel.

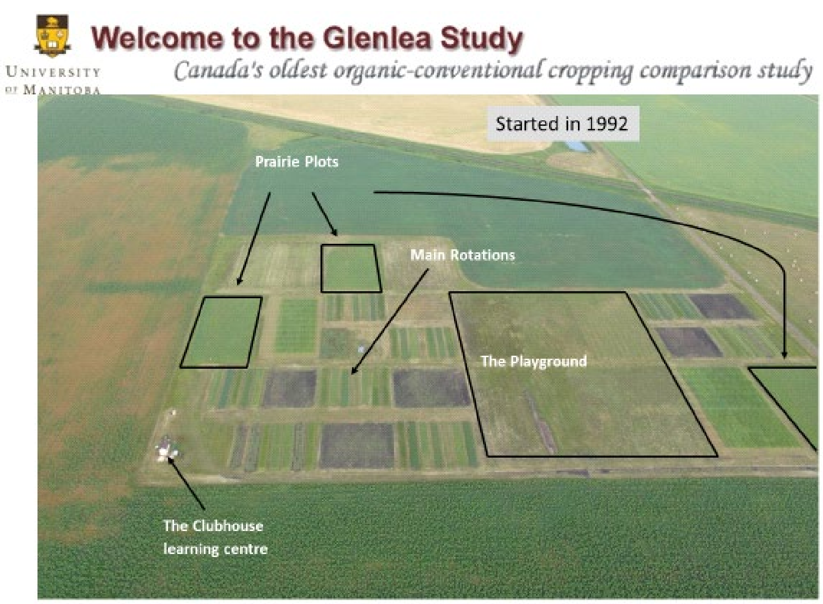
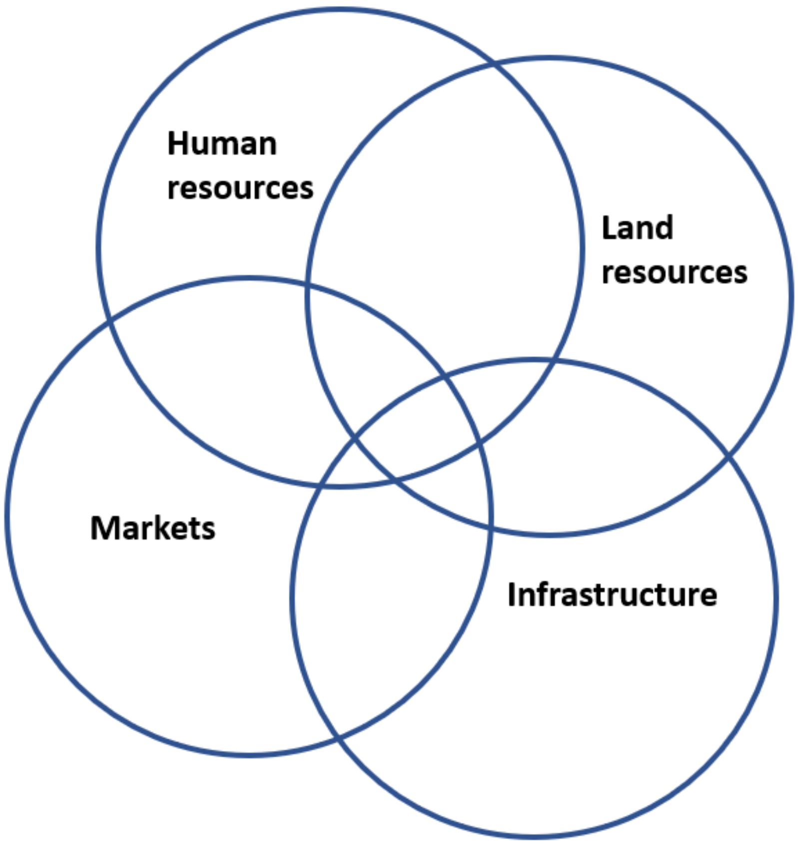


Photo credit: Gary Martens

Chapter 2. Taking Stock of Farm Resources to Optimize Organic Production

Taking stock of farm resources is an important step in long-term planning. These resources include land, capital, people, machinery, knowledge, and others.



Human Resources

Successful farming requires many skills, including the big three: 1) Production skills; 2) Marketing skills; and 3) Financial management skills. Ernesto, an Argentinian working in rural Australia, drilled home the point that "it is extremely rare for any one person to be good at all three." Therefore, it is important that you decide what your skills are and then find someone to assist where you need additional help. This may mean empowering another member of your immediate family, who has complimentary skills to yours, or reaching beyond your immediate family – to your "farmily."

The term "farmily" was coined by a community of farmers and farm workers in western Manitoba. It refers to all the member of the farm, including family members, full-time staff, seasonal and part-time workers, and extended family members who may own some of the farmed land or who may help during peak times such as harvest or calving. Other members could include financial planners, accountants, legal experts, etc. Taking time to understand the skills and interests of each person in the "farmily" is important.

Women make up roughly 30% of Canadian farmers. Yet, sexism is a real threat to health farm communities where women lead or co-lead farms. This article in The Conversation provides ideas on how to combat sexism faced by women farmers.

Land Resources

Taking stock of your land and soil resources is another important step in whole farm planning. "The Canada Land Inventory is a comprehensive multi-disciplinary land inventory of rural Canada, covering over 2.5 million square kilometers of land and water. Land capability for agriculture, forestry, wildlife, recreation, wildlife (ungulates and waterfowl) was mapped. Over 1000 mapsheets at the 1:250,000 scale were created during the 1960's, 70's, and early 80's. Although the information is old, and better information is available for some areas as part of more recent soil surveys, the interpretations are still largely valid, and many jurisdictions still use them for land use planning purposes.

There are seven classes used to rate agricultural land capability. Class 1 lands have the highest and Class 7 lands the lowest capability to support agricultural land use activities. Subclasses are used to identify specific limiting factors for each class. For more information on CLI classes, view the overview of classification methodology."

Detailed maps are available for each region of Canada. This link will take you a list of maps that can help you identify the soil type on your farm.

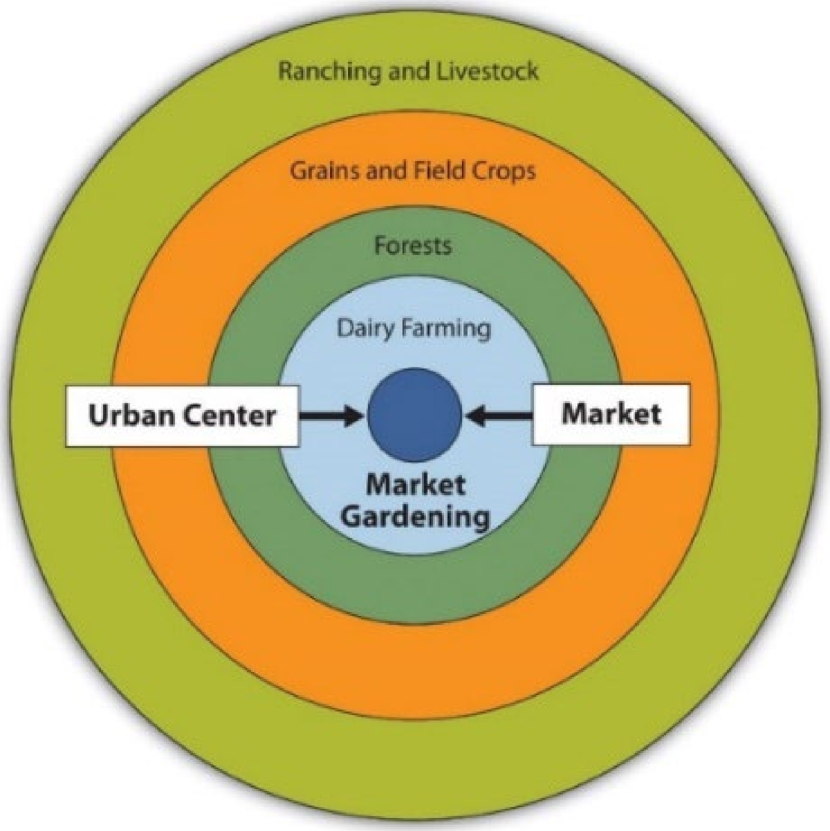
Most provinces have more detailed soils maps and these provide additional information such as salinity risk, drought and flooding risk, etc.

Province/Territory	Soil Survey Information
Yukon	https://sis.agr.gc.ca/cansis/publications/surveys/yt/yts174/index.html
North West Territories and Nunavut	https://sis.agr.gc.ca/cansis/publications/surveys/nt/index.html
British Columbia	https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/soil-nutrients/mapping-and-classification
Alberta	https://open.alberta.ca/publications/ss-22
Saskatchewan	https://sis.agr.gc.ca/cansis/publications/surveys/sk/index.html#DSS
Manitoba	https://www.gov.mb.ca/agriculture/soil/soil-survey/importance-of-soil-survey-mb.html#detailed
Ontario	https://geohub.lio.gov.on.ca/datasets/ontarioca11::soil-survey-complex/explore?location=47.937243%2C-60.208957%2C2.34
Quebec	https://www.irda.qc.ca/en/services/protection-resources/soil-health/soil-information/soil-surveys/
Maritimes	https://openpress.usask.ca/soilscience/chapter/soils-of-the-atlantic-provinces/

Markets

The physical location of any commercial farm is a factor that deserves some consideration. One especially important question is the farm's location relative to markets. This can sometimes influence what can be produced successfully and profitably.

Back in 1826, Von Thunen came up with a model of concentric agricultural land use that may still apply (to some extent) today. The model was first applied to analyze the agricultural land use patterns in Germany of the 19th century. The main assumption of Von Thunen's model is that agricultural land use is formed as concentric circles around the central market. The market consumes all the surplus production, which must be transported from the rural areas to the market.



When the model was developed 200 years ago farmers did not have access to the transportation or refrigeration systems of today. This is why vegetables and animal products were produced close to the urban centre (i.e., the market). Veggies and milk are bulky to transport and they spoil easily. Grains, on the other hand, can be stored for long periods of time, so these can be brought to market anytime. Beef cattle, sheep and other grazers can be herded ("cattle drive!") to slaughter facilities near the market. Some of the realities of this ancient land use model still apply and may play a role in land use and farm planning.

While the principles outlined by Von Thunen are out of date, some lessons remain. The theory challenges us to rethink our distance to market including the cost of shipping products long distances. Food miles, for example, have become an important factor in consumer's choice of food purchases. An analysis by Kissinger (2012) shows (Figure below) Canada's food miles related to C emissions by specific food group. Results clearly show that more local fruit and vegetable production would have a significant impact on addressing C emissions.

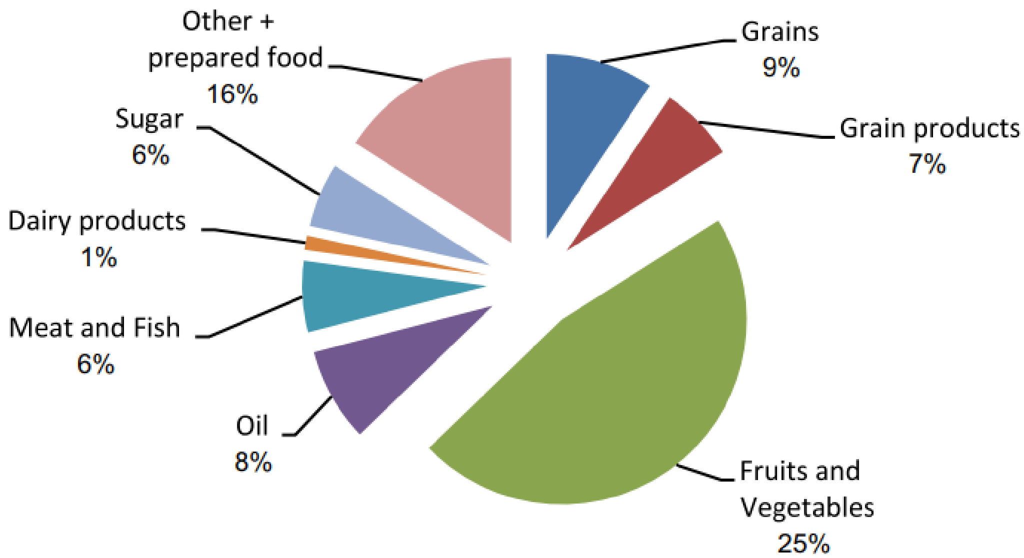


Fig. 1. Canada's food miles related CO_2 emissions by specific food group.

Infrastructure

Infrastructure considerations include water supply, roads, access to 3-phase electrical power, owned farm machinery, barns and feeding areas, crop storage, etc. Mapping the inventory of existing infrastructure resources can assist in planning new purchases, since new organic machines are becoming available, and some equipment required in conventional production will have less value in organic production (e.g., field sprayer).

Seeding rig for establishing small grain cereals and cover crops, Ontario

Taking stock, yes. But my farm has unique features

Every farm is unique. Even farms that have similar soils, climate, crops and infrastructure may differ in their social circumstances. For example, the age range of the farmily may be unique to that farm. Or perhaps the farm has a unique governance structure where all family members, even those who do not actively participate in day-to-day activities, hold farm shares.

One way to personalize the farm operation is through a mind mapping exercise. A mind map is a hand-drawn (or computer generated) one page map of all the components of your farming system. The map should include the basic farm structure and function, and it should link different related parts of the operation. For example, if a lot of tillage is used to control Canada Thistle, this could be linked to special soil conservation practices that mitigate the effects of that tillage. Here are a few tips:

- To make a mind map, you begin with a central topic, and then you move outward towards related topics (Rhodes, 2021). From those topics you can progress further into other related subtopics. Sometimes there are relationships between the subtopics, so you will find them cross referencing each other. Sometimes you will find these subcategories looping back into one another in a way that this is similar to how flow charts work.
- A great way to think about a mind map is to think of it as a planetary system, the sun being the central point which is being orbited by planets. Each planet is also being orbited by its own moon.
- Some of the smartest and most efficient people in history used mind maps regularly. Da Vinci used mind maps for note taking. Albert Einstein was an avid user of mind maps. He rejected many types of linear, numerical, and even verbal created ways of thinking. Einstein said "Imagination is more important than knowledge because imagination is unlimited." Not only do mind-maps help you to unfold your imaginative ideas, but they help you to bottle them in such a way that you can understand it, spread it, teach it, share it, and use it.
- Perhaps the most important thing about mind maps is that they will allow you to understand a topic in its entirety. You are also able to view the most critical elements of that topic at a glance. They also allow us to visually explain things to other people in a way that is very simple to understand. When we have content that is organized and structured it is much easier to understand ourselves and to teach to other people. In fact, it pushes and even forces clarity in thinking.
- You don't need to use a sophisticated computer program to create a mind map. You can draw one out very quickly on a standard sheet of paper. But, computer programs for mind maps are available.

- When you are mind mapping, you are able to move around all of your topics and subtopics. As you move the information you will find that a little tiny opening for creativity presents itself.

Below are two mind maps created by students after visiting organic farms (Figure 1 and 2). The third mind map (Figure 3) shows the ecosystem of wild oat management in organic production.

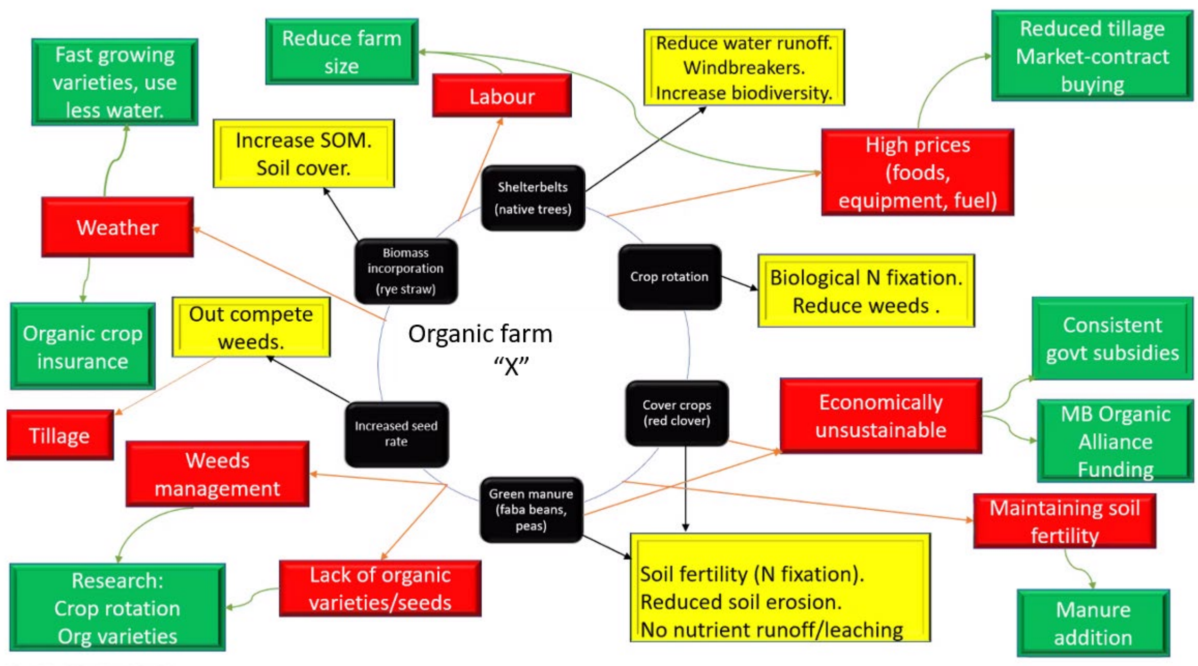


Figure 1. A mind map of an organic grain farm in Manitoba. Colour is used to depict positive factors (green) and negative factors (red). Author: Laetitia Mukungu, MSc student, University of Manitoba.

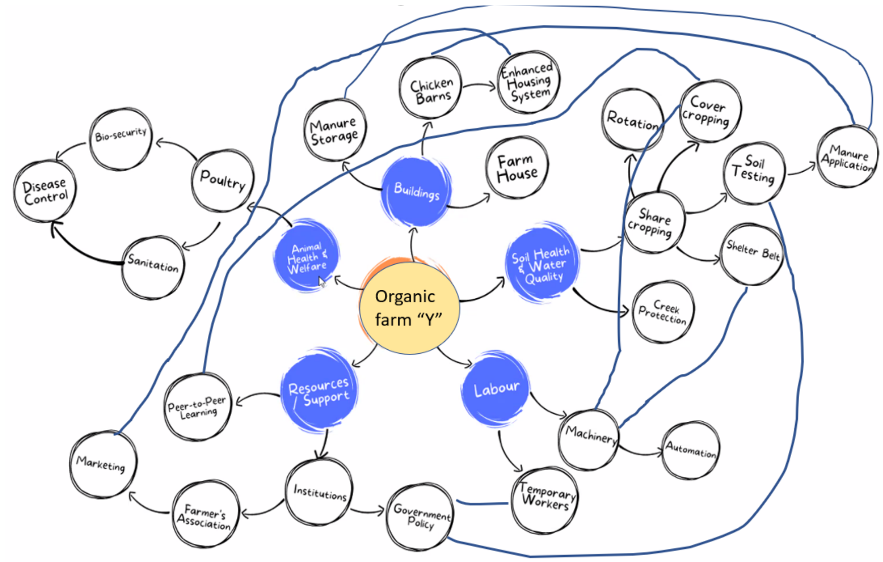


Figure 2. A mind map of an integrated grain-livestock organic farm, Ontario.

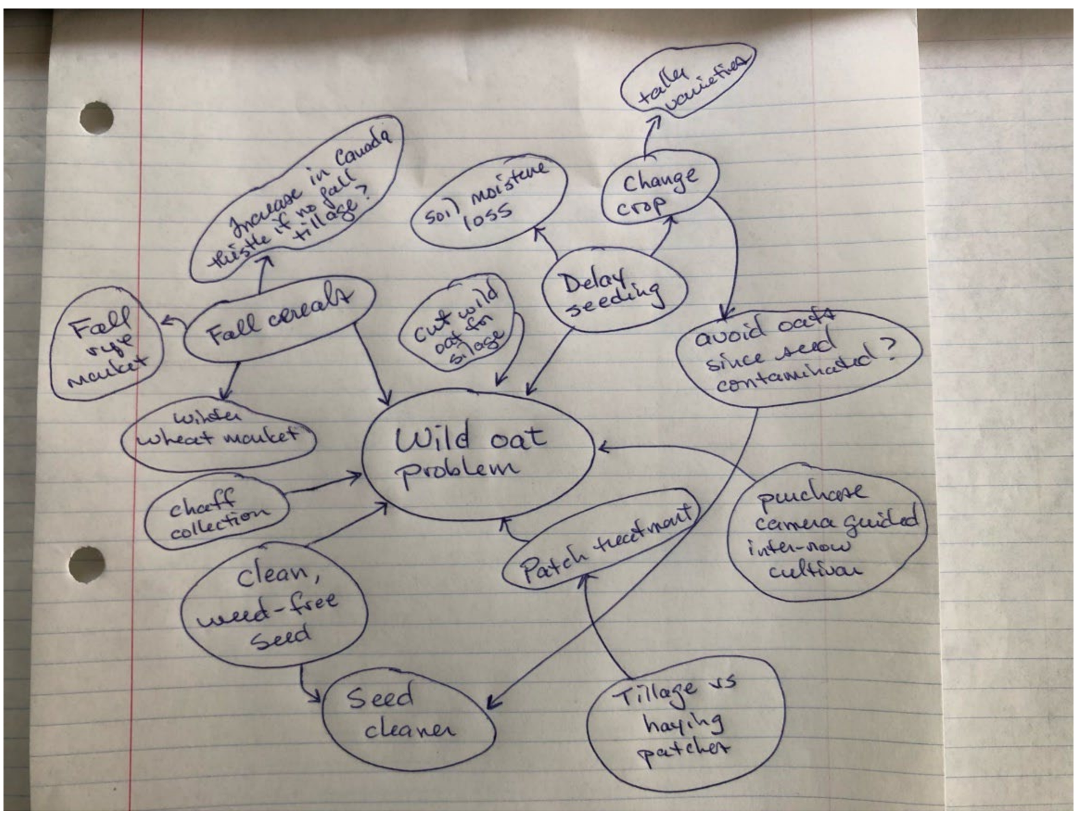


Figure 3. A mind map focused on wild oat management in a grain-based organic farming system.

Chapter 3. Planning Processes

"We don't plan to fail, but sometimes we fail to plan"

Agronomic planning

Planning tools for organic farming are widely available. This is thanks to the hard work of public servants, NGO staff and farmers working together to strengthen the organic industry. In Canada, the Canadian Organic Growers take a national approach to organic agriculture and their rich set of resources are available here. An important step early in the planning process is to become aware of these resources.

As a large country with diverse regions, site-specific planning resources are required. On the Prairies, for example, planning resources are available for Manitoba, Saskatchewan, and Alberta. Some organic farmers have benefited from training in Holistic Management. Details are available from many holistic management centres, such as Holistic Management®.

Goal setting

Setting goals is important in any business venture. This is something you may want some professional help with. An excellent overview of steps to become certified organic are available from the Manitoba Organic Alliance. Make sure to bring your farm mind map to any planning session. This way the plan can be tailored to your unique farm situation.

Landscape planning

We have discussed the soil resources for your farm earlier, but what about other features of the landscape. Think about how to manage or create non-crop areas such as shelterbelts, natural grass, forest areas or wetlands (Figure 4). The opportunities to add to the farm income through "ecological goods and services" are growing and so more diversity may indeed be better for the farm's bottom line.

Fig. 20.10 This small farm in Morocco demonstrates how agroecological practices can convert a barren landscape into a diverse and productive organic farm. (Photo credit: A. M. Hammermeister)

Figure 4. Left: Grass strips and raptor nest structure on organic farm in Montana. Photo credit: Vilicus Farms. Right: Plant diversity can make what seems a barren landscape into a productive organic farm in the drylands of Morocco. Photo credit: Andy Hammermeister.

Rotation_planning

Crop rotation **is** one of the most important and powerful tools available to organic farmers. The type of rotation may depend on whether you are already farming but switching from conventional to organic farming or whether you are starting a new farm. If you switching an existing farm, you should consider which of the crops you produce now can be successful in organic production. Wheat, oats, pea, soybean and forages can be switched with relative ease. Other crops such as canola will likely have to drop out of the farm system since GM contamination is difficult to manage. Corn, while also susceptible to GM contamination, is being produced organically with good success alongside conventional corn fields in places like Minnesota. You will need to find organically-approved seed sources for all crops and be especially aware of buffer zone requirements. If you are switching your corn and soybean production to organic, be sure to source non-GMO seed varieties or hybrids. Here is a guide to some of the production steps for beginning organic farmers that have been summarized by Manitoba Agriculture.

Table 1 shows some sample rotations used by organic farms across Canada. The rotation length varies from 3 to 7 years. While the rotation example from Quebec is only 3 years, it includes at least 5 crop species (soybean, wheat, corn cash crops plus several cover crops). While organic canola would be difficult to produce on the Prairies due to an abundance of GMO crops, it is included in the Ontario organic farm because of much less GMO canola in the region.

Table 1. Sample rotations on Canadian organic farms.

SE Saskatchewan	Alberta	Manitoba	PEI	Ontario	Quebec
Alfalfa seed 3 years	Green manure (cereal/pulse)	Green manure (grazed)	Red clover green manure	3 years legume/grass forage	Soybean
Hemp	Fall rye	Wheat or flax	Spring wheat	Winter canola	Winter wheat/pea or clover cover crop
Flax (underseeded to alfalfa)	Food grade pea/oat intercrop	Lentil or pea	Soybeans	Spelt	Corn (ryegrass cover crop interseeded)
or	Green manure (cereal/pulse)	Alfalfa hay (2 years	Pea/barley intercrop	Soybean	
Green manure (year 1)	Spring wheat	Wheat or flax	Oats underseeded to red clover	Oat/pea grain	
Spring wheat (year 2)	Pea/barley intercrop (feed)	Oats			
Two different rotations depend on soils	*Green manure every 3rd year*	*High diversity. Livestock integration*	*Diversity of legume species*	*Winter and spring seeded grains*	*Manure used to supply some N*

The last row in the table (bottom row in red) describes one of the unique features within each rotation that helps make that organic farm more sustainable. Each farm has a unique strategy. For example, the PEI farm uses a diversity of legume species. This helps to reduce legume root diseases. The Alberta farm adds a full season green manure every third year in the rotation. These green manure crops do not provide an immediate income that year, but the Alberta farmers feel that frequent green manure makes the whole rotation more profitable and sustainable. Increasing land prices makes taking land out of production for a full year more challenging, so even Prairie farmers are considering more “shoulder season” legume cover crops for adding nitrogen to the system.

Rising farmland values – impact on rotation choices

Rising farmland costs in Canada have forced organic farmers to intensify their practices. One example is switching from full season soil building legume cover crops (which result in no income that year) to shoulder season cover crops and intercrops. Figure 5 shows how much more productive the 2023 oat crop was when the rotation included adequate green manure cover crops vs growing oats with insufficient legumes in rotation. The challenge for organic farmers is to balance the design of profitable crop rotations with things like adequate N supply. "Shoulder season" cover crops are widely used on organic farms in Eastern Canada, and are now being tried on Prairie organic farms as well. Another option to strike that balance between N supply and economics is to graze full season green manure crops with livestock.

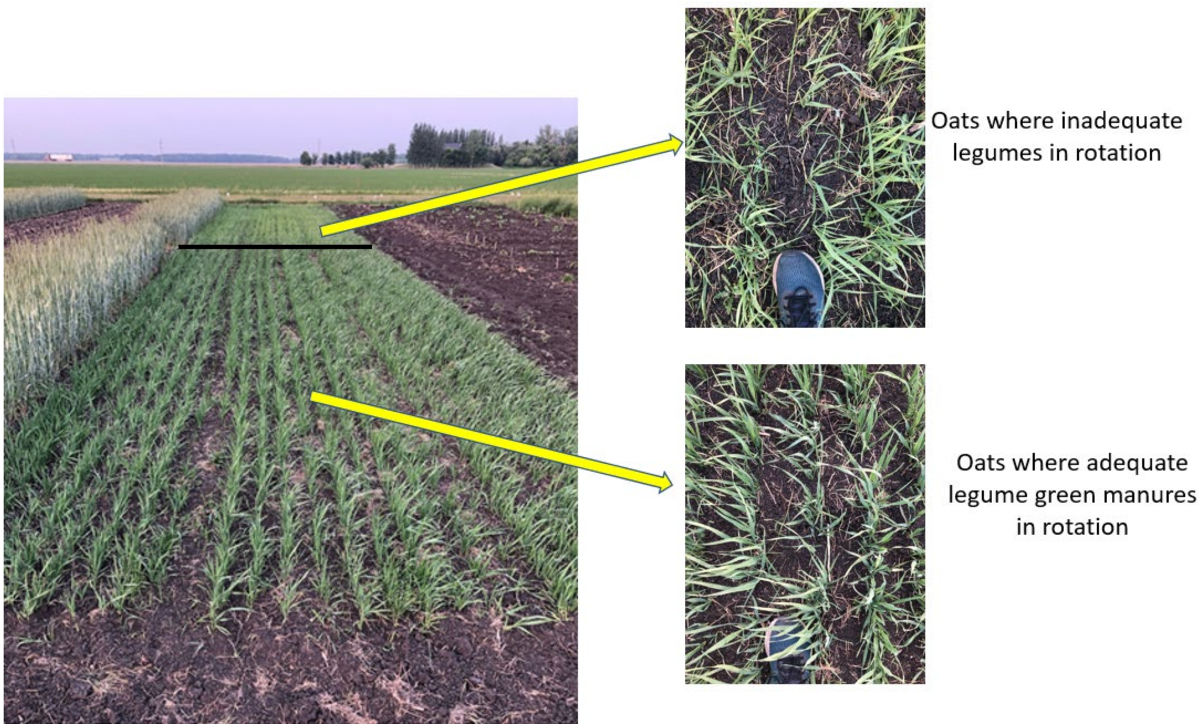


Figure 5. Oats grown in a legume green manure intensive system (bottom of plot) compared with oats grown in a grain only rotation (top of plot). Glenlea long-term study, June, 2023.

Data collection and record-keeping

Record keeping is important in any business. In addition to keep track of costs and income, organic farmers are encouraged to monitor the biological performance of their farming systems as well. These measurements include soil testing; nutrient budgeting; soil health; and pests.

Business planning

In any business, it is important to know 1) the cost of production; 2) the market value of what is produced; and 3) the risk involved in that production. Cost of production calculations have been prepared by Manitoba Agriculture for various organic crops and this information is available here. Price discovery for organic crops for product is improving. The OrganicBIZ website publishes crop prices regularly throughout the year. Income variability helps to define the risk of a particular crop or enterprise. Research at Glenlea has shown that organic yields can be more variable than yields on conventional farms but that a good crop rotation and attention to nutrient management reduces income variability in organic production.

Research at Indian Head, SK compared a wheat-wheat-fallow rotation (monoculture) with a rotation of 3 years alfalfa-fallow-wheat-wheat (integrated forage-grain system) over 30 years (Figure 6). While net income was similar for the two systems, income variability, or financial risk, was much lower for the integrated rotation. The other factor considered in the analysis was crop insurance (square boxes is where all-purpose crop insurance premiums were applied; circles indicated no crop insurance). The results demonstrate that the rotation more effectively reduced income variability than crop insurance. The results also show that the integrated system performed, economically, close to the efficiency frontier – which is a measure of "as good as the economics can get."

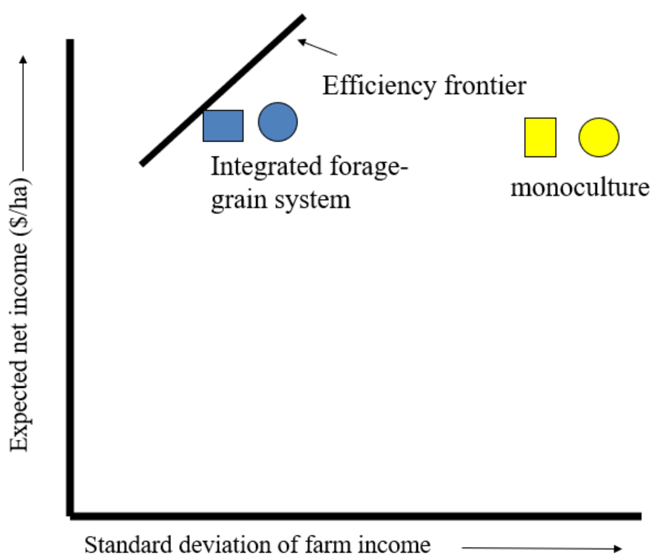


Figure 6. Economic performance of two crop rotations over a 30-year period (Zentner *in* Campbell et. 1990). The efficiency frontier represents the limit of economic efficiency that is possible.

Marketing organic products

Organic farmers use a wide range of marketing approaches. Direct marketing is used by many fruit and vegetable growers in the form of farmers' markets or community supported agriculture. Some grain farmers also sell their grain in a community supported agriculture model.

Farmers markets are growing. For example, while farmers markets had all but disappeared in Manitoba 30 years ago, the overall economic impact of farmers markets in Manitoba in 2022 is estimated at $134 million. The average shopper spends $46.44 during each market visit and the types of products purchased range from meats, grains, vegetables, fruits and cut flowers (to name a few). There are many other direct farm organizations. See the example of Direct Farm Manitoba.

When it comes to marketing organic grains, recent emphasis has been on quality. Here is a podcast where farmers and grain buyers discuss how to produce and maintain grain quality.

Another resource is SaskOrganic's Grain Marketing Webinars YouTube Channel.

Other resources are available through farm media such as OrganicBIZ.

Farm size

Economists have documented the relationship between farm size and profitability. The term that some use is TFP (total factor productivity). Many economists have proposed that the relationship between farm size and TFP is a "U" shape, with smaller and larger farmers performing better than medium sized farms (Figure 7). Foster and Rosenzweig (2017) concluded that farms in the middle are too large to rely solely on family labour (and thus incur agency costs associated with the use of hired labour) and are not large enough to efficiently adopt labour saving machinery. Considering farm data from 1982-2012 in the US Corn Belt, Rada and Fuglie (2019) found that across five farm size classes, not only are larger farms operating at higher TFP levels, but a clear productivity disadvantage emerges when grain operations fall under 100 acres (40 ha). "The largest farm size class appeared to be increasing TFP at a slightly faster rate compared to other farms. Similar results have been reported in Australia. Some researchers have proposed that machinery outsourcing could help smaller farms make efficient use of capital and close the productivity gap with larger ones. Renting machinery services helped narrow but did not close the TFP gap between smaller and larger farms."

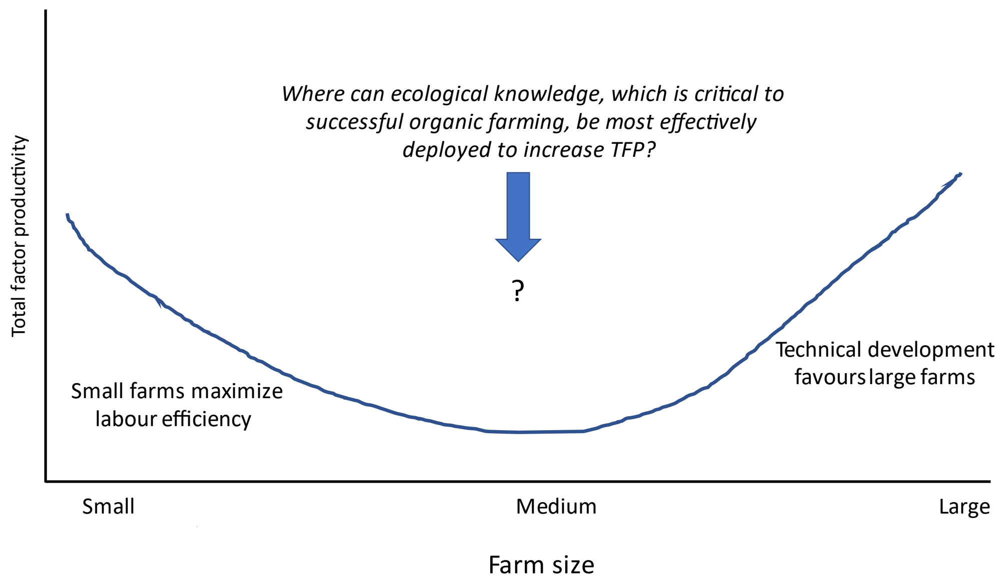


Figure 7. Examples of total factor productivity as a function of farm size.

Do organic farms follow this same trend? Are medium sized organic farms doomed to low TFP? It is very likely that the principle of "U" does apply to organic farms as well since machinery is expensive and these expenses are best recouped when spread across more acres. But one big difference is that while conventional farms rely on chemical and machine technology, organic farming relies on ecological practices, which often take more management time and labour. This *may* give medium sized organic farms an advantage since they are often better able to apply ecological management than very large organic farms. For example, would farm size dictate which of the systems tested in the Indian Head rotation (monoculture or integrated forage-grain shown in Figure 6) are most feasible?

An example of the need for complex rotations comes from a long-term organic-conventional comparison studies in Beltsville, Maryland. Results show that the more complex (6 year) organic rotation (corn-soybean-wheat-alfalfa) was less dependent on organic price premiums, relative to conventional production in chisel tillage or no-till, compared with the less complex 3 year (corn-soybean-wheat) or 2 year (corn-soybean) organic crop rotations (Figure 8). Therefore, ecological complexity within the rotation improved the economic performance of the organic cropping system. The question that organic farmers need to ask themselves is what is the optimum farm and labour pool size to allow the more complex rotations to be adopted.

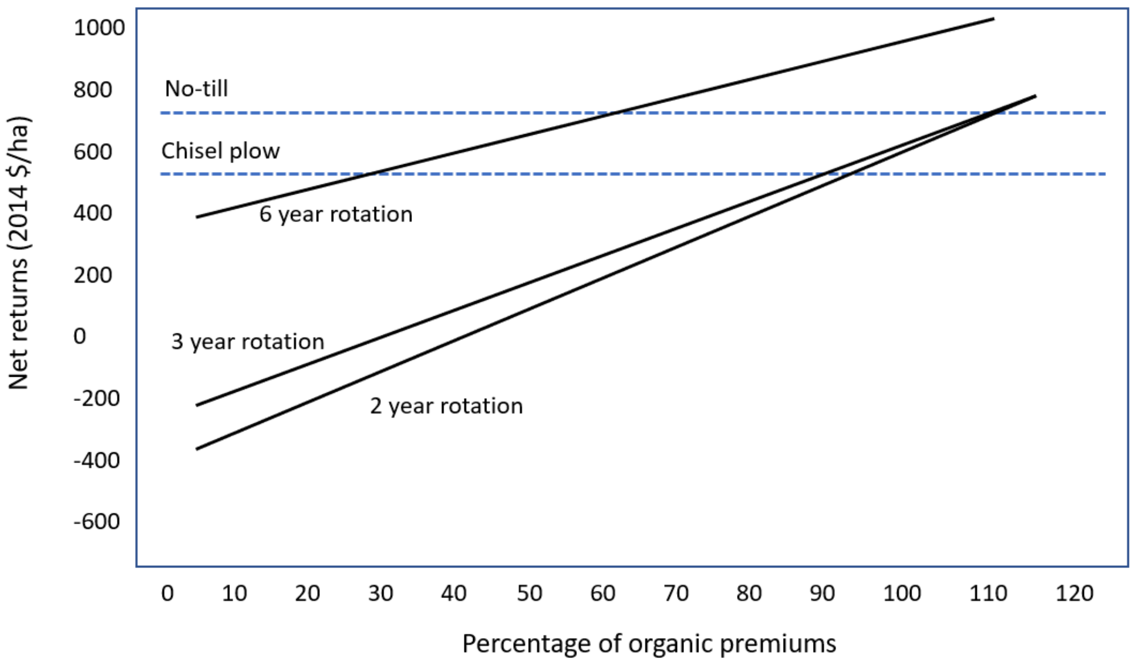


Figure 8. Effect of increasing organic price premium from 0 (conventional prices) to 120% of the organic price premiums received for each crop in each year on mean net returns to the three organic cropping systems (2006-2014). Dotted lines indicate the mean returns for No-till and Chisel Till systems. Redrawn from White et al. 2019.

Another factor that has been shown to increase TFP on medium sized farms is extension. Researchers found that public education investments had a positive effect in most farm sizes. Economists are recognizing that a one-size-fits-all policy no longer works. Learn more here.

Chapter 4. Learning Systems for Organic Agriculture

Learning systems for organic agriculture are, in some important ways, different from learning systems in conventional agriculture. In this lesson, we will cover the following points about learning systems for organic crop production:

- History shapes our thinking
- Defining ecological knowledge
- Adaptive learning cycle – practice makes perfect
- Thinking in systems

Our historical influences
Because Canadian farming systems were originally modeled after those in Northern Europe, understanding the evolution of these European farming systems is important. The Northern European cropping systems evolved from a "2 crop rotation" (fallow-cereal) in the 1500's to complex 7-year crop rotations in the early 1900's (Figure 9). These century old 7-year crop rotations are actually an excellent model for organic farming in much of Canada today.

However, once Haber-Bosch nitrogen fertilizer became widely available in the 1930's (though first produced in 1910), European farmers switched from multi-year rotations with livestock integration to simplified rotations. Today, Northern European cropping systems are dominated by two main crops (winter cereal and winter canola).

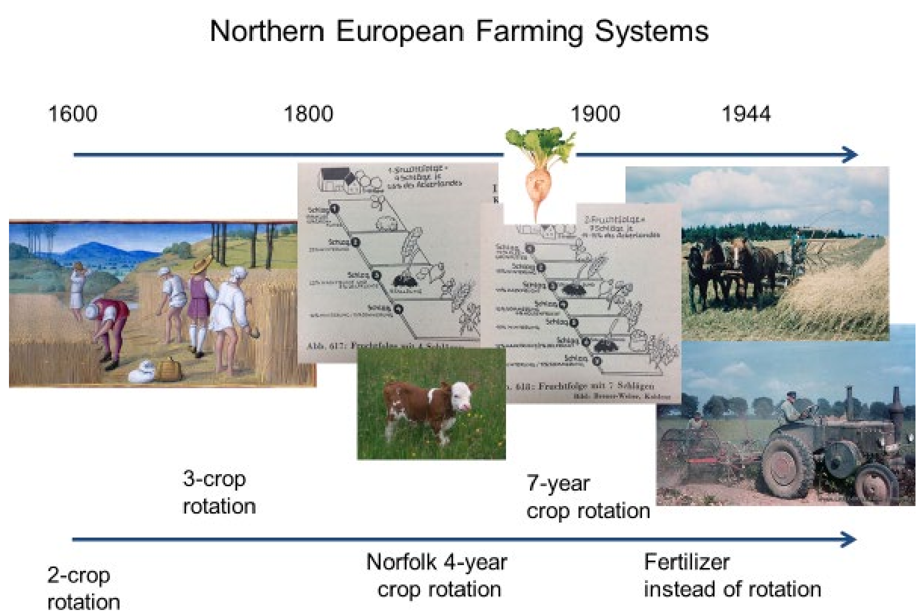


Figure 9. Evolution of farming practices in Europe over 400 years.

Indigenous systems of agriculture existed in Canada long before European contact, and continued to evolve after contact. Indigenous systems of agriculture inform modern organic farming systems today. For example, grain intercropping, now being practiced by many organic farmers, was practiced by Indigenous cultures for centuries (Figure 10). The images below show a re-creation of the "3 sisters" cropping system (left). The bison scapula discovered in southwest Manitoba in 2018 (right) demonstrates that indigenous cropping systems involved soil disturbance.

Figure 10. Examples of indigenous crop production systems (three sites, left) and tools (hoe scapula, right) in Manitoba.

Ecological knowledge

Sustainable, complex organic farms rely on ecological knowledge. What is ecological knowledge? Some of the ecological knowledge terms are described below, followed by examples from Canadian organic farms. Plant species diversity is an ecological tool for stabilizing pasture productivity in adverse growing conditions (Figure 11).

Figure 11. Don Guilford, rancher from Clearwater, Manitoba explaining plant species diversity on native pasture during a University of Manitoba Agroecology student tour.

Ecological Knowledge Terms

- **Biotic factors** are living things (e.g., plants and animals) and abiotic factors are non-living things (e.g., soil, water, air, light, nutrients).
- An **ecosystem** is all the biotic (living) and abiotic (non-living) components that interact within an area at once. Think of a farm, or even a farm field, as an ecosystem. Use a mind map to show the parts and the connections within that farm ecosystem.
- **Ecosystem services** are services and resources provided by the ecosystem. For example, wetlands provide groundwater recharge, which keeps farm wells producing water for humans and livestock.
- A **population** is a group of organisms of the same species living together in the same area at the same time.
- A **community** is defined as all of the populations that live in the same place at the same time. What are all the different populations on your farm? Remember to include living (biotic) and non-living (abiotic) populations. Note that tractors are part of the abiotic farm population.
- **Abundance** is the total number of individuals of a species that live in a specific area. For example, how many Canada Thistle shoots per unit area in the field? What is the abundance of cattle grazing on an 80-acre green manure field?
- **Allelopathy** is the effect of a plant's metabolic products on the growth of nearby plants. Fall rye is one of the most allelopathic crop plants that we grow.
- **Amensalism** one species is inhibited/destroyed while the other is unaffected. For example, grasshoppers will eat the oats but not peas in an oat/pea intercrop.

- **Biodiversity** is the variation of species in an ecosystem. How many plant species are growing in a pasture?
- **Biota** is the total collection of organisms of a geographic region or a time period. This includes all lifeforms.
- **Carrying capacity** is the maximum capacity of an area which can sustain a certain population size. We typically think of carrying capacity in a grazing system – how many animals/acre?
- A **climax community** is a biological community that, through the process of **ecological succession**, has reached a steady state. A native pasture is often at its climax level.
- **Competition** is a mutually detrimental interaction between species which share limited resources.
- The **competitive exclusion principle** states that when two or more species coexist using the same resource, one must displace or exclude the other.
- **Decomposers** break down decaying or dead organisms. Some agronomists have buried underwear to study how quickly soil decomposers break down the cotton cloth.
- **Disturbance** can be physical (tillage, grazing) or chemical (spraying a herbicide).
- **Facilitation** is when one species benefits from the presence of another. For example, adding grasses to legume cover crops increases the N fixation rate of the legume plants.
- A **foodweb** is an interlocking pattern formed by a series of inter-connecting food chains. The foodweb can include beneficial (e.g., crop harvest) and non-beneficial (e.g., insect pest) organisms.
- A **generalist species** can thrive under many environmental conditions and make use of a variety of different resources. Grasshoppers is an example, though the grasshopper population will build up in hot, dry cycles.
- **Interspecific competition** is between individuals of different species. For example, wild oats and wheat.
- **Intraspecific competition** is among individuals of the same species. For example, oat plants seeded at a very high seeding rate will compete with each other.
- **Mutualism** is when two species both benefit from a relationship. For example, certain intercrop combinations where both crops benefit, either in terms of nutrient access or pest management.
- **Mycorrhizae** are fungal associations and symbiotic relationships between plant roots and fungi. These fungi increase the area of roots. Ninety percent of land plants are naturally mycorrhizal.

- The **niche** is the role that an organism plays in an ecosystem including both the environmental conditions it needs and its interactions with other organisms. Wild mustard and redroot pigweed are non-mycorrhizal plants so their niche is soils with high levels of available phosphorous (because mycorrhizal fungi help plants access soil P).
- **Primary succession** is the first step of **ecological succession** after an extreme disturbance, which usually occurs in an environment devoid of vegetation and other organisms. Primary succession is demonstrated when annual weeds grow in a field immediately after tillage.
- **R-selection** is a form of selection that occurs in an environment with plentiful resources and it tends to favour individuals that reproduce early, quickly and in large numbers. The example here is annual weed species such as green foxtail or wild mustard.
- **Species richness** is the number of species in a given area. Richness of plant species increases the accumulation of soil carbon.
- **Succession** is the directional change in structure of a community gradually over time. Perennial weeds like quackgrass or Canada Thistle are later successional weeds.
- **Symbiosis** is an interaction between two different biological organisms. One of the most popular examples of this is bacteria in nodules. These rhizobia (and other) bacteria make N for the plant and the plant, in turn, supplies carbon to the bacteria.

Applying ecological knowledge for perennial weed control

Canada Thistle (left side of image) has a deep and complex root system, which provides it with the ability to emerge from great depths (Figure 12). Repeated tillage is required to eliminate this weed, however competition and cutting in a forage crop is more effective for its elimination. Dandelion (right side of image), on the other hand, has only one dominant taproot. This makes dandelion much more susceptible to tillage than Canada thistle. This demonstrates the importance of understanding the ecology and biology of weeds to maximize control measures in organic production.

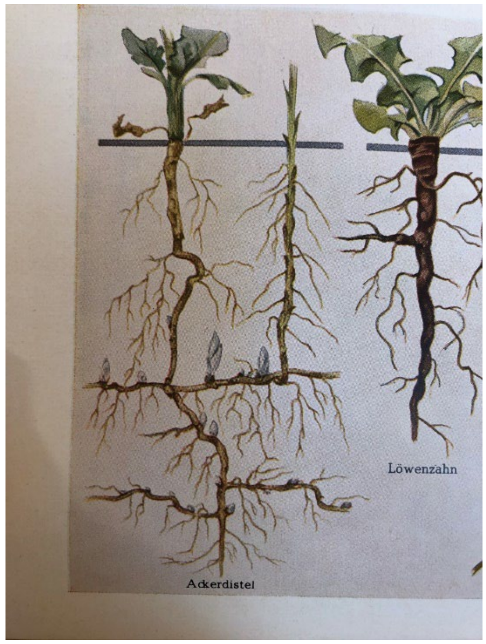


Figure 12. Artist depiction of root systems for Canada Thistle (left) and dandelion (right). Germany, 1910.

Adaptive Learning

How do we learn new things when we have done farming a certain way for so long? Think about when you learned something new. The concept of adaptive learning has been used by humans throughout history. The model shown below puts the adaptive learning process into a model which is easy to follow.

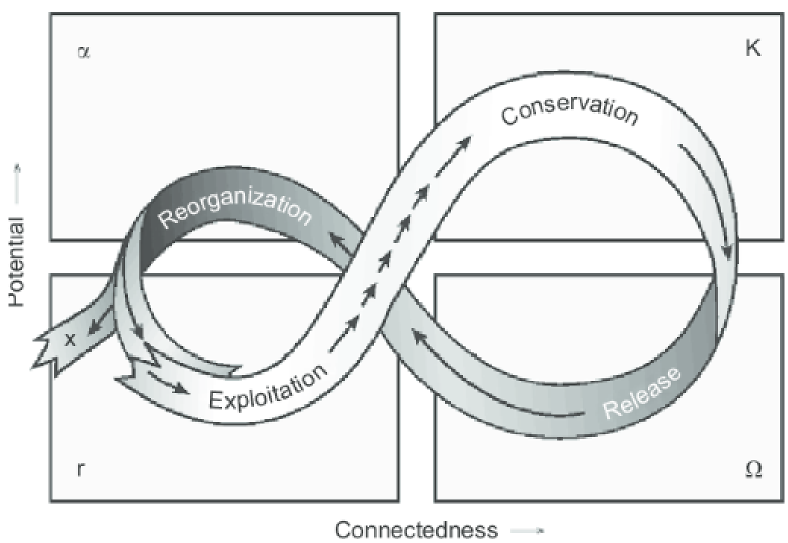


Figure 13. Four-phase adaptive cycle (Holling, 1986). (from Panarchy by Lance H. Gunderson and C.S. Holling: figure 2.1, p. 34. Copyright 2002 Island Press).

“Conservation” (k) is the zone where you have a system and it seems to be working fine. So why change? One reason for change may be that something no longer works in that system (e.g., herbicide resistant weeds for conventional farmers; too much soil erosion for organic farmers). The “Release” (Ω) zone represents having to change the system. An example is a farmer who “releases” from the idea that using the same herbicide year after year will continue to kill weeds. “Reorganization” (∞) is where you learn something new that could apply to your farming system. An example relating to weeds is that the farmer thinks about integrated weed management. Finally, the “Exploitation” phase is where you put your new idea into practice.

Adaptive learning is critically important in organic farming. You can also learn from other organic farmers, so be sure to attend on-farm field days. In your farm mind map, be sure to include your thoughts on gaining new knowledge through adaptive learning.

Learning to think in systems

All agriculture involves systems thinking. But systems thinking in organic agriculture is often more complex than conventional forms of agriculture. This is because organic agriculture involves strong consideration of biological, ecological, mechanical and chemical transformations – often happening at the same time.

The Weinberg model (Figure 14) has helped many agriculture students understand the difference between individual farm components and the farm system. This figure places different agricultural activities and processes in the context of complexity and randomness. Randomness refers to the predictability of farm components, while complexity can reflect more diverse crop rotations.

Zone 1 contains farm components which are limited in their randomness and complexity. In other words, these are farm components that are quite predictable in their function. An example is an air seeder. While the machine itself is very sophisticated and complex, its function in the farm system is straight forward and predictable. It places seed into the soil. Zone 1 is referred to as the zone of “organized simplicity” (Figure 14).

Zone 2 has high levels of randomness. Perhaps the two most random factors in agriculture are weather and markets. Both are difficult to predict with accuracy. Zone 2 is referred to as the zone of “unorganized complexity”. Things in this zone are complex, and the unorganized nature of this complexity makes it difficult to predict with accuracy.

Zone 3 has modest levels of randomness and encompasses a range of complexities. Zone 3 is referred to as the zone of systems. The term, "organized complexity," indicates that while things are complex, there is a level of organization involved. The organizer is the farm manager. Zone 3 is the zone of farming and cropping systems. Zone 3 is where farmers and agronomists work.

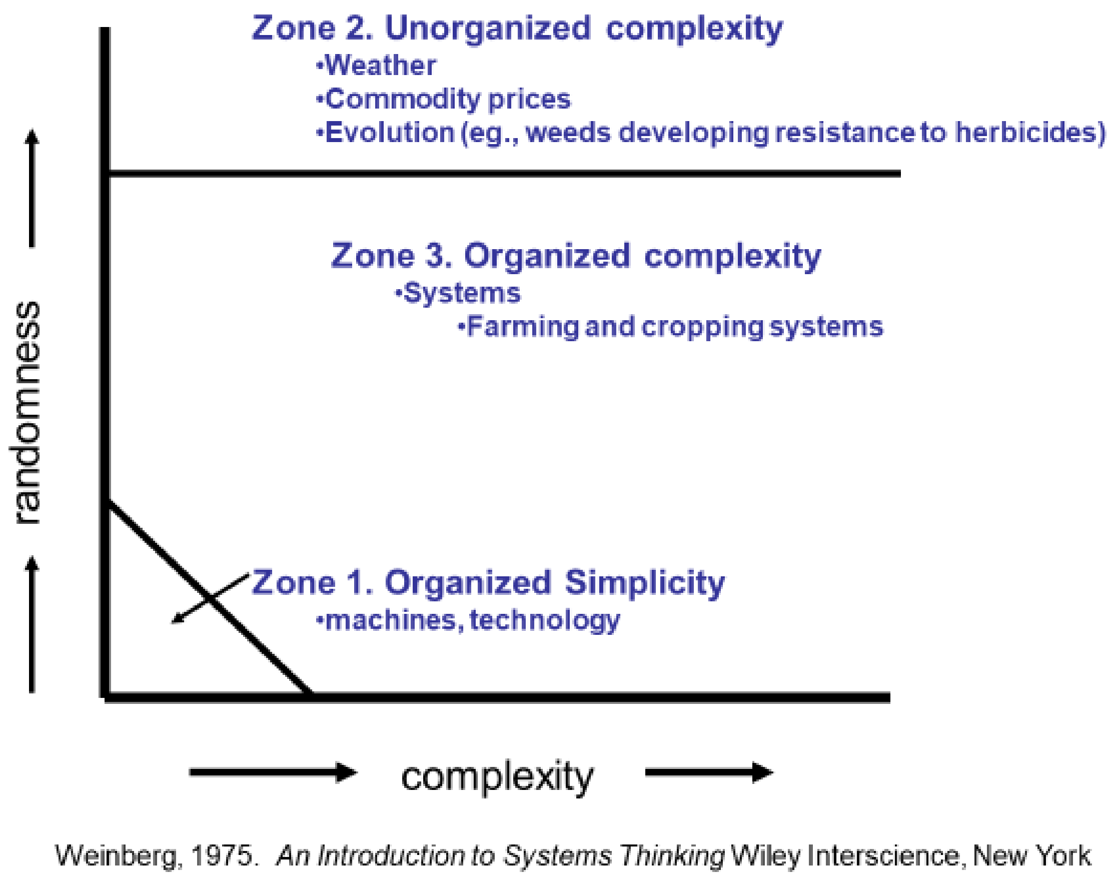


Figure 14. Types of systems with respect to methods of thinking. Redrawn from Weinberg 1975.

Think about systems that you have experienced and try placing the different system components into zones 1, 2 and 3.

Learning from other practitioners
Organic research and extension workers regularly receive messages from farmers wanting to learn more about organic farming. Sometimes the farmers are interested in using organic techniques on their conventional farmers, while other times they want to convert all or a portion of their existing farm to certified organic production. There are now very good resources for these farmers at access. Here are three Prairie groups who

connect farmers to relevant resources: Pivot and Grow from Organic Alberta; SaskOrganics; and the Manitoba Organic Alliance. These are grass-roots organizations that host conferences and field days and provide resource material in various formats.

I encourage inquiring farmers in get in touch with existing organic farmers. This is because organic farmers hold important knowledge about how to design and sustain a profitable and productive organic system. I encourage new organic farmers to attend local organic field days and farm field walks (Figure 15).

Figure 15. Learning systems in organic agriculture. Left: farmer to farmer conversation in field. Middle: organic farm tour. Right: organic farmers visit University of Manitoba organic field day listening to (then) PhD student Caroline Halde, now Dr. Halde, Laval University.

Chapter 5. The Transition to Organic Farming

There are many motivations to switch all or a portion of the farm to certified organic production. Some of these are given in Figure 16. The main focus in this lesson is to review logistical, agronomic and economic aspects of transition to a certified organic system.

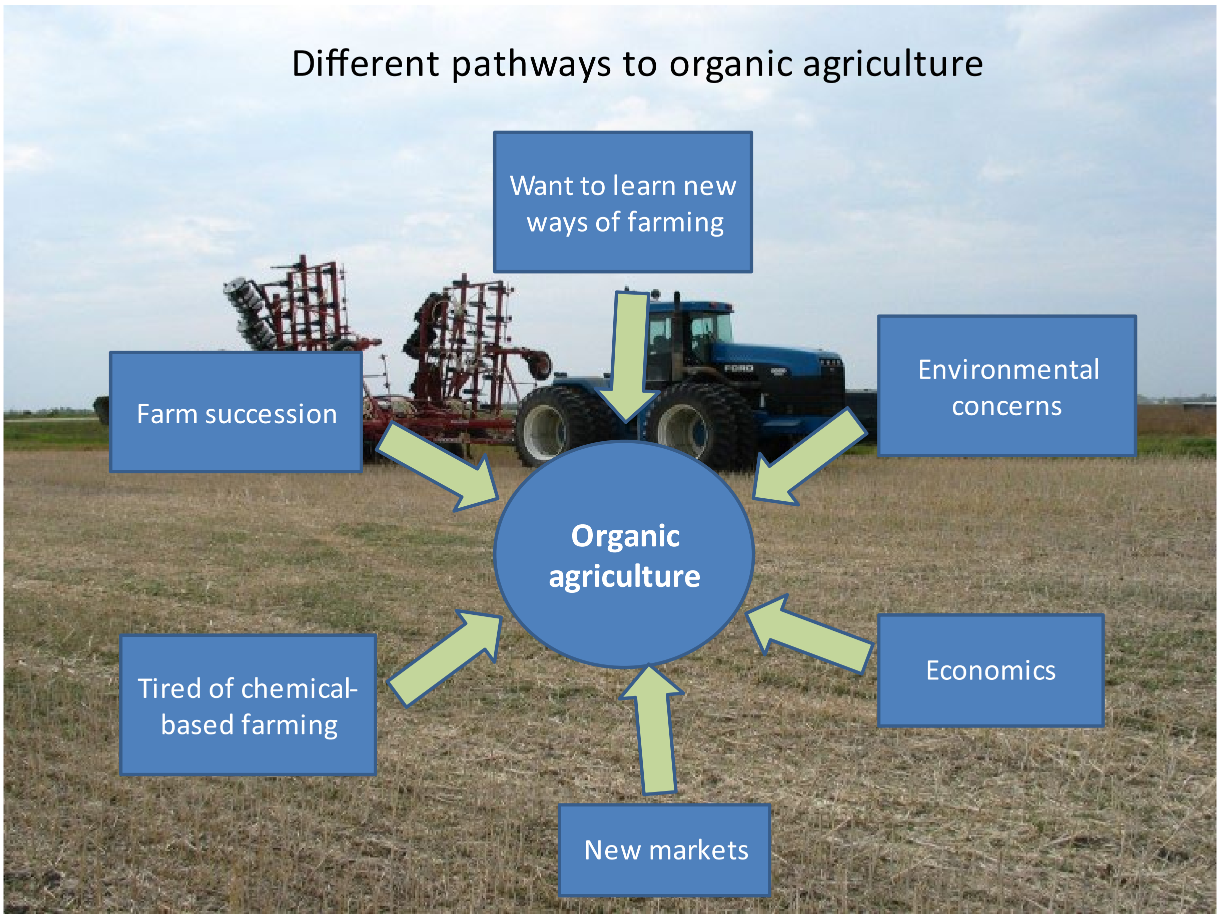


Figure 16. Some motivations for switching or certified organic production

Logistical considerations

Among the important logistical steps in transition to organic are the length of the transition process, the need to engage a certification agency, and knowledge about how to keep organic and conventional operations and crops separate (important when fields being transitioned over time). It is also important to learn about the Canadian organic standards. A pdf of the standards is available here.

For most farm operations, the transition period is 36 months (Figure 17). The figure below gives a basic outline of such a transition for a grain farming system. The rule is that the first certified organic crop must be harvested 36 months after the last prohibited substance was applied. Here is an example. If the last conventional crop was canola and the farmer applied a fungicide in July and did not add any herbicide or inorganic fertilizer in fall, the first certified crop could be harvested 3 years (or 36 months) later.

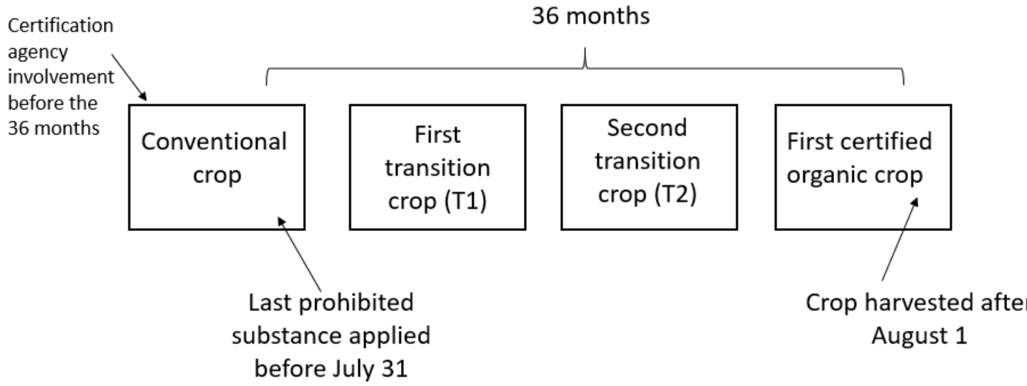


Figure 17. A typical pathway to certified organic production with the 36-month transition period.

Here is the exact language from the Canadian Organic Standards Section 5.1.2 of the pdf. "When new production units are added to an existing organic operation, the operator shall provide records to show that prohibited substances have not been used for at least 36 months (see 5.1.1) and verification shall be conducted before the first harvest of product from this new production unit." Note: verification means that an inspector from a certification agency has visited the farm operation and checked all the paper work.

There are instances where the transition period is shorter. For example, if a field has been in perennial forage for many years and no prohibited inputs were used, a certifier may recommend a transition period of 15 months (Figure 18). However, just as in the grain farm case above, the certification agency should be contacted well in advance of the transition process.

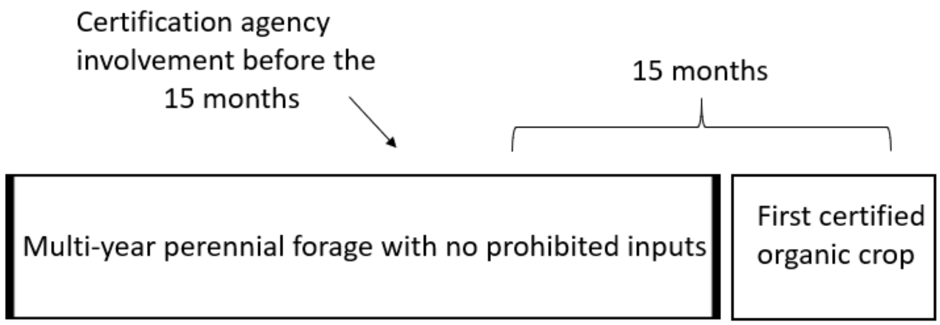


Figure 18. A typical pathway to certified organic production with the 15-month transition period.

Here is an additional section from the Canadian Organic Standard which describes the 15-month period. "The Regulations also require that, in the case of an initial application for an organic certification of field crops, the application shall be filed 15 months before the day on which the product is expected to be marketed. During that period of time, compliance with this standard will be assessed by the certification body and this assessment must include at least one inspection of the production unit, during production, in the year before field crops may be eligible for certification and one inspection, during production, in the year field crops are eligible for certification."

There are many different organic certification agencies to choose from. In most cases, certification agencies are private contractors who employ trained certifiers and who charge a fee for certification. The Organic Producers of Manitoba Association (OPAM) is a cooperative who provide certification services. However, they still charge for certification inspection, just like the private companies do. The Pivot and Grow website has a list of organic certification companies operating in Canada.

Agronomic considerations

Weeds – Fields that have serious weed problems should not be considered for transition to organic. Weeds of greatest concern are field bindweed, Canada Thistle and wild oats. These weeds should be controlled before transitioning the field using standard agronomic practices within a conventional farming system. Broadleaved weeds, such as wild mustard, redroot pigweed, lamb's quarters are less of a concern. These weeds are difficult to eradicate since the seeds live for years in the soil seedbank, however they are easier to manage in an organic farming system than Thistle and wild oats. Quackgrass is also a weed of concern, especially in sandy soils. Quackgrass is usually easier to control than Canada Thistle.

One of the best transition strategies is to grow a 3-to-5-year perennial forage crop before the organic grain crop. The data below was collected from 52 commercial fields across Manitoba in 1993. The 24 "CC" fields were in continuous grain production while the 28 "AC" fields were cereal after a 3-to-5-year perennial forage stand. The weeds were counted in spring, after crop emergence but before any in-crop herbicide application. Source: Ominski, P.D., Entz, M.H. and Kenkel, N., 1999. Weed suppression by Medicago sativa in subsequent cereal crops: a comparative survey. *Weed Science*, pp.282-290.

TABLE 2. Density, frequency, uniformity, and relative abundance values for *Medicago sativa*/cereal fields (A.C. Fields) and continuous cereal fields (C.C. Fields) in 1993.[a]

	Relative abundance		Density		Level of significance	Frequency		Uniformity	
Species common name	C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields	Log scale	C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields
			plants m^{-2}			%			
Wild oat	53.03	13.14	27.15	1.26	≤ 0.05	83.33	46.43	54.79	11.43
Green foxtail	44.63	23.86	22.32	2.66	≤ 0.01	75.00	64.29	45.83	26.25
Wild mustard	31.68	32.43	10.63	7.90	≤ 0.10	79.17	57.14	38.13	22.68
Wild buckwheat	31.38	39.71	9.15	6.10	NS	83.33	85.71	40.00	42.14
Annual smartweed spp.	20.85	16.59	6.78	1.80	NS	66.67	57.14	20.21	13.75
Quackgrass	19.79	19.09	7.58	3.70	NS	50.00	42.86	20.83	15.54
Common lambsquarters	15.47	28.99	3.16	5.70	NS	54.17	57.14	18.75	25.71
Canada thistle	13.69	2.52	2.33	0.27	≤ 0.01	54.17	7.14	15.63	2.68
Catchweed bedstraw	12.71	6.76	6.40	1.50	NS	20.83	10.71	13.13	6.07
Field pennycress	7.28	17.86	0.49	3.00	NS	41.67	46.43	5.63	14.46
Dandelion	1.98	28.34	0.08	4.35	≤ 0.01	12.50	64.29	1.25	28.93
Volunteer alfalfa	0.59	39.56	0.03	6.38	≤ 0.01	4.17	85.71	0.21	40.18
Redroot pigweed	3.55	5.32	0.26	0.51	NS	20.83	17.86	2.50	5.00
Perennial sowthistle	5.95	1.48	0.76	0.11	< 0.10	29.17	7.14	5.42	0.71
Persian darnel	4.54	0.00	2.88	0.00	NS	4.17	0.00	4.17	0.00

[a] Weed and crop species with (1) nonsignificant differences between field types or (2) population densities less than 1 m^{-2} are not included in this table.

Results for "Density" column in the table above show that the perennial forage significantly reduced Canada Thistle and wild oat plant density. Reductions in density were also observed for green foxtail, smartweed, quackgrass, perennial sowthistle and others.

Soil nutrient status - The second major consideration before and during transition regards soil nutrients. It is important that the level of available soil phosphorous is adequate. If fields have soil P levels below 10 ppm Olson P, they should be "stocked" with P before transition. One way to increase soil P level is to add inorganic fertilizer P before the transition. Alternatively, fields can be supplemented with manure or compost during or after transition. However, this only applies if animal manure is available.

A common mistake is that farmers and agronomist assume an old hayfields or pastures will make good candidates for organic grain production since they are rich in nutrients. Experience has shown that old hayfields are often very P deficient and this can lead to very poor growth of subsequent organic grain crops. This video explains such a situation in Manitoba.

Machinery considerations are also important. Investments in good tillage equipment should be considered. Of importance is a good disc for incorporating green manure cover crops and breaking up perennial forage stands. The other investment is a grain swather, since transition or organic crops may be weedy and require swathing to dry down the crop (and weeds) in preparation for threshing. Some organic farmers have purchased grain cleaning equipment in order to separate intercrops or prepare grain for marketing. However, many organic farmers take their grain to commercial grain cleaners for cleaning since it is more time efficient (Note: these grain cleaners would need to be certified to clean organic grain).

Specialized weeding equipment has become popular in recent years. Implements such as the Combcut, camera-guided interrow cultivation equipment for narrow row crops, and various tine harrows for weeding are now available and are being used by Canadian organic farmers. These implements can be viewed at on-farm field days and at trade shows. Farmer-to-farmer knowledge exchange is important to optimize use of these implements.

Figure 19. Left: Tine harrow, spin spreader for cover crops. Photo credit: S. Beaton. Right: Combcut. Photo credit: K. Stanley

Grain storage facilities for organic crops need to be properly identified. This is especially important in the early transition phase when farmers still have some conventional production. It is important that organic and conventional grains be kept separated at all times.

Economic considerations

Transition crops cannot be treated with any prohibited substances (e.g., herbicides or fertilizers) but do not normally receive a price premium. Therefore, transition cropping can be very stressful for farmers.

There are a number of ways to reduce the economic risk associated with transition crops.

- Select crops that, based on your experience, have the greatest chance of a positive net return. I encourage farmers and students to use the Manitoba Agriculture organic cost of production analysis to determine which crop can yield above the economic breakeven point.
- Select crops that are competitive with weeds. For example, oats and barley are more competitive with weeds than wheat, soybean or peas.
- Select disease resistant varieties. Fungicides are not an option.
- Use high seeding rates; 30 to 40% higher than normal. Some farmers double seeding rates.
- Seed grain intercrops.
- Reduce the weed emergence window by seeding immediately after spring tillage – the same day if possible.

Growing perennial forage can be one of the best strategies during the transition period. This assumes, however, that farmers have a market for the forage. It is important to ensure that the perennial forage field has sufficient nutrients to allow a profitable organic cash crop to be produced once the field is certified organic.

Chapter 6. Whole Farm Planning with Crop-Livestock Integration

The crop-livestock integration concept

Information in this section was mostly sourced from the following book chapter: Entz, M.H. and Thiessen Martens, J.R., 2009. Organic crop–livestock systems. *Organic farming: The ecological system*, *54*, pp.69-84. All citations listed below are available by downloading this open access paper.

The traditional "mixed farm" represents an elegant form of crop-livestock integration (Figure 20). The principal role of livestock in a farming system is recognized as the ability to convert biomass from leys or pastures, which is otherwise unusable, to economically viable products and to increase flow rates of nutrients. Integration also represents an ecological approach to production of both crops and livestock.

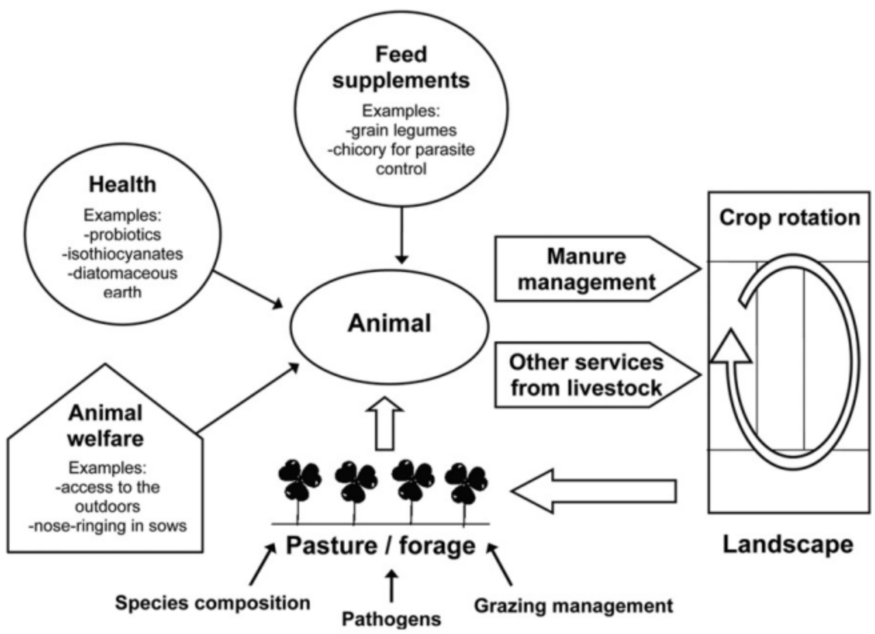


Figure 20. A conceptual mixed organic farm showing the connections and flows within the crop livestock system. From: Entz and Thiessen Martens (2009).

Before widespread use of inorganic fertilizer and pesticide inputs, integration of crops and livestock was seen as a way to increase food production for an expanding human population (Granstedt, 2000). In the early 1900's, western Canadian scientists concluded that mixed farming was important for "permanence" of agriculture. However, these pronouncements were not heeded as farmers opted rather to use fallow methods that exploit the soil resource. Thoughtful observers of agriculture today are envisioning crop–livestock integration as an important principle in the development of sustainable food production systems.

Farmer-philosopher Wendell Berry (1977) described the process of crop and livestock specialization as "[taking] a solution and [dividing] it neatly into two problems." Clark and Poincelot (1996) concluded that cheap fossil fuel energy was ultimately responsible for marginalizing pasture and that by deemphasizing pasture in beef and dairy production, we have "abandoned the one real advantage that ruminants had over other classes of livestock." Schiere et al. (2002) pointed out that as the degree of integration between crops and livestock declines, the need for fossil fuel energy in the agricultural system increases. Patriquin (1999) suggested that livestock are underutilized in organic systems and that organic codes have been weak in regard to integrating livestock into farms.

From Diversification to Integration

Crop–livestock integration involves more than raising both crops and livestock on the same farm. Clark and Poincelot (1996) identified an integrated farm as one in which livestock are incorporated to perform tasks and services to other enterprises, not just to produce a marketable product. "Integration of function rather than mere diversification" should be the goal of such systems (Schiere et al., 2002). On diversified farms, success of one component can compensate for failure of another, while in integrated systems the components rely on one another through their ecological interactions.

To what extent have organic farmers adopted crop–livestock integration? In Denmark, farmers converting to organic systems increased grassland area by 20% and increased livestock production by 6% (Langer, 2002). One question involves scale - does integration on organic farms occur more at the local or on-farm scale, or also at the regional scale with areawide integration? Langer (2002) concluded that diversification with livestock was greatest on smaller farms, indicating that farmers have gone to mixed farming systems (Figure 21) and suggested that the synergies between crops and livestock production may be better satisfied on small rather than large farms. However, when Prairie organic grain farmers spread manure from neighbouring cattle farms onto their organic land, they are involved in an area-wide crop-livestock integration (Figure 21).

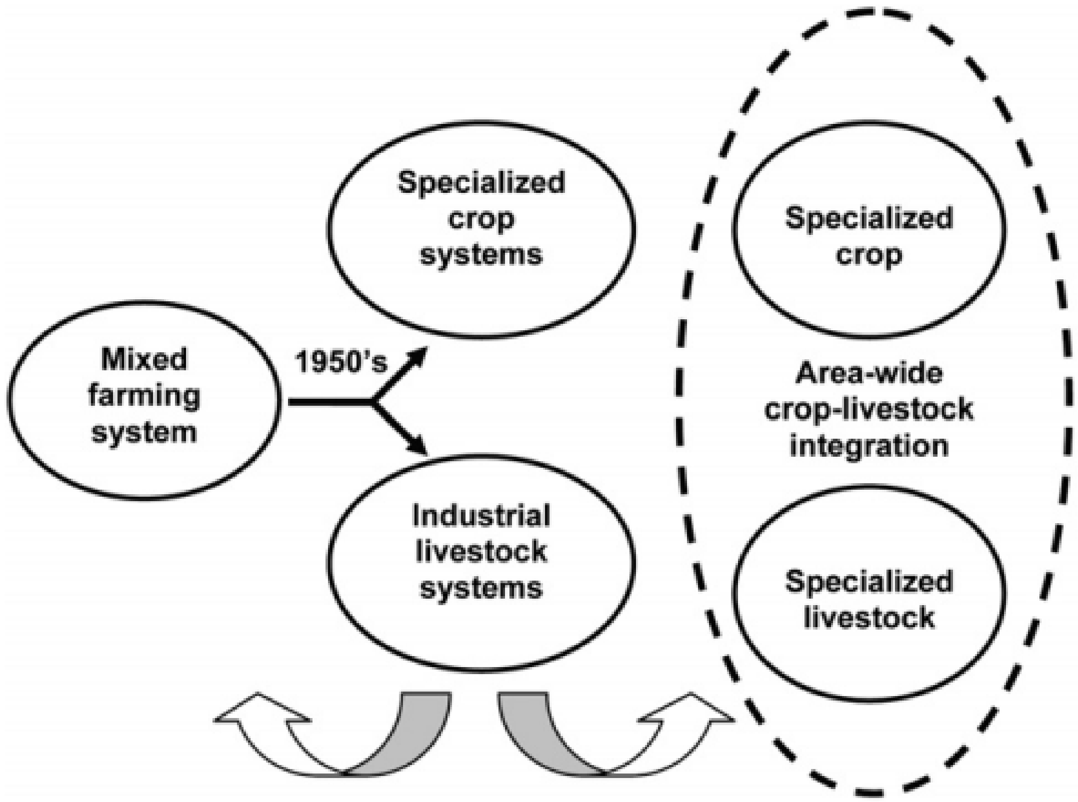


Figure 21. A state-and-transition model describing the evolution of integrated crop–livestock systems. Curved arrows represent the two directions of integration.

Nutrient flows in local vs. areawide crop-livestock integration

Perhaps the most important reason for crop–livestock integration is to allow for nutrient sharing between crop and livestock systems and to accelerate the nutrient cycling process. While N is the primary limiting nutrient in organic systems (Watson et al., 2002), P is of special concern since it cannot be fixed through symbiosis in the same way that N is fixed, and organic farming tends to deplete soil P reserves (Mäder et al., 2002). A survey of stockless organic grain farms in Manitoba and North Dakota showed very low soil P levels on fields farmed organically for over 30 years (Entz et al., 2001). Even lower available P has been recorded on organic farms in Australia (Cornish, 2007).

Integration on a mixed farm can create a semiclosed system (Pearson, 2007). In a survey of 15 long-term organic dairy farms in Ontario with one animal unit per hectare, Lynch (2006) found that whole farm nutrient balance averages for N, P, and K were +75, +1, and +11 kg/ha/yr , respectively. N_2 fixation with legumes accounted for 60% of total farm N inputs. About one-fourth of survey farms imported little P as feed or feed supplements; these farms had a small negative farm P balance (−1.5 kg P/ha/yr.).

Cornish (2007) reported positive P balances (0.69 to 7.15 kg P/ha/yr.) for some biodynamic dairy operations in Australia. These results indicate that mixed farms that use local integration (Figure 21) can be sustainable from a nutrient balance perspective; however, stock density must be sufficient.

Specialized crop or livestock systems require areawide integration for nutrient sharing (Figure 21). Even some mixed farms require additional P (Cornish, 2007). Animal-based P is often the best source since rock P is largely unavailable due to high soil pH and low water availability. Areawide integration for nutrients can take many forms. The most common form is movement of composted manure from larger-scale poultry or dairy farms to stockless organic farms. Some organic certification bodies allow long-distance manure transport, while others do not. A less-common form of integration is to move certified organic livestock to the stockless farm on a short-term basis. This system mimics the "night-time corralling" used in West Africa (Powell et al., 2004).

Proximity of crop and livestock operations is key to the success of areawide integration. Hoshide et al. (2006) examined regional integration between potato and dairy producers in Maine, where manure is applied to land where it had not been applied previously. Limitations to this arrangement were distance between farms (ideally < 25 km) and basic trust between individuals, which required lengthy relationships. Schiere et al. (2002) demonstrated that as the distance between specialized crop and livestock production units increases, labour and energy costs of any integration also increase. Further, while specialized production results in more by-products that may be consumed by livestock, on-farm availability of bran and oilcakes is likely to decrease particularly on small farms due to increasingly centralized grain and oilseed processing. For organic farms, the issues of proximity and availability of by-products are important since the number of organic farms in a given area is generally relatively small.

Knowledge of manure nutrient concentration and crop-specific nutrient requirements is critical for efficient use of animal manure, especially since the manure is typically in short supply and manure transport is expensive. Using compost as a N source leads to overapplication of P, as well as potential for N leaching. Using manure to replace P means applying low rates of compost. Some farmers have built special machines that enable low rates of compost to be applied uniformly to land (Figure 22).
A future issue may be to include humans in the areawide nutrient integration. Should this be considered if human waste can be kept separate from industrial wastes? Sir Albert Howard thought so. Pearson (2007) argued that human waste must be considered in future "semiclosed" agricultural systems, and the role of struvite in organic agriculture is being actively pursued.

Figure 22. Custom built manure spreader to allow low rates of compost to be applied. Quebec.

Nutrient flows in crop-livestock integrated systems

Visualizing the nutrient flows in an integrated crop-livestock system is important. How are the nutrients moving through the system? Is nitrogen on the same path as phosphorous? Figure 23 shows our hypothetical organic "mixed" farming system and identifies the sources of N and P in the system.

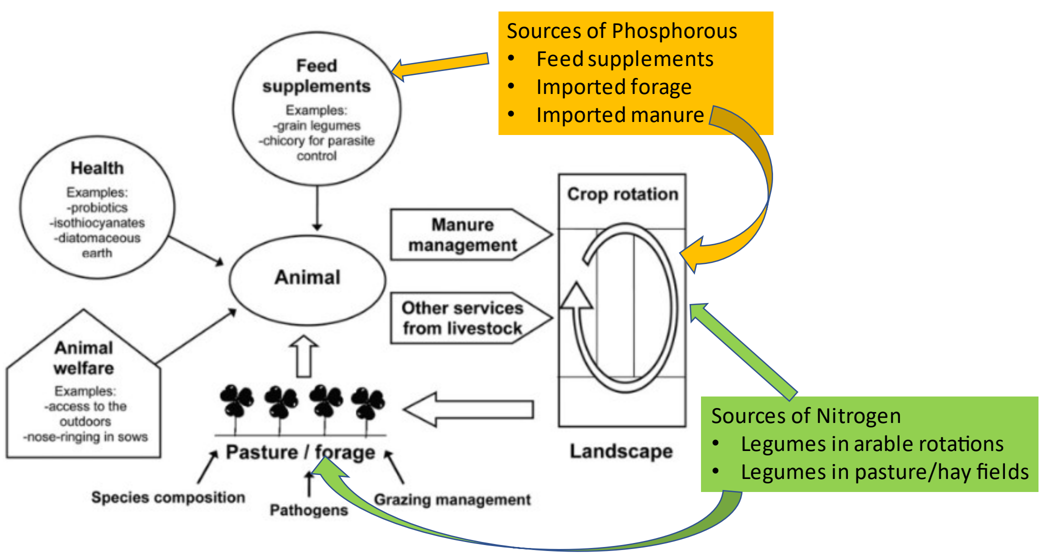


Figure 23. Crop-livestock integrated farming system showing opportunities to import nitrogen and phosphorous into the farming system.

Quantifying nutrient stocks and flows

It is important to take a scientific approach to nutrient management in an organic crop-livestock system. This involves collecting data on the nutrient content of the farm products as well as the manure (Figure 24).

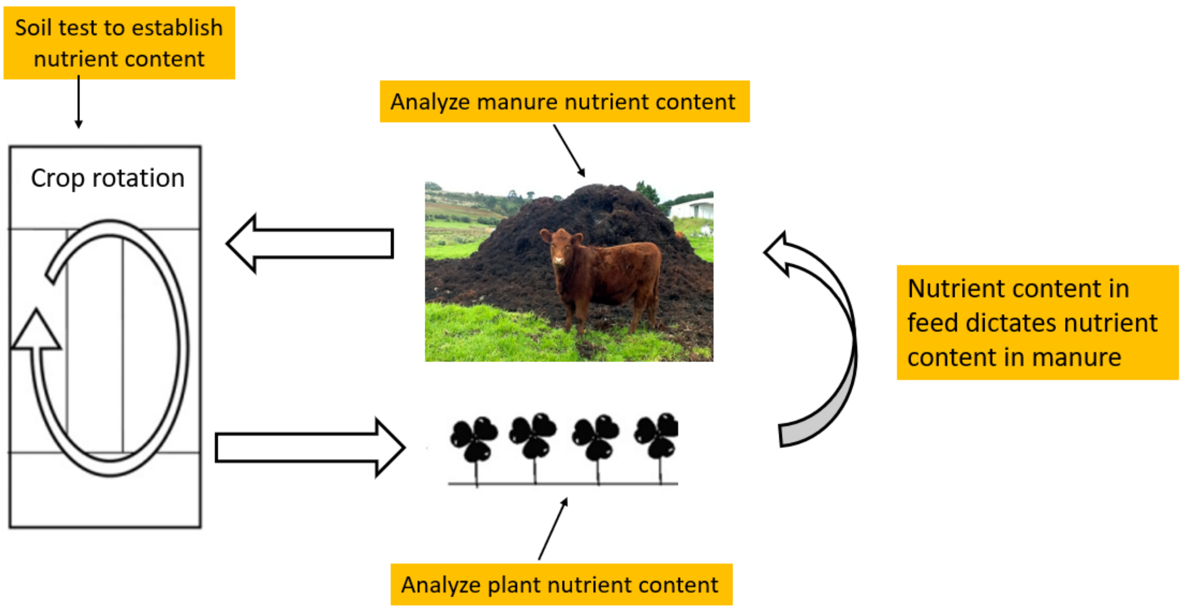


Figure 24. The flow of nutrients in the crop-animal-manure system showing opportunities to test nutrient status.

Examples of Integrated Crop–Livestock Systems

Common organic crop–livestock systems in North America are beef–forage–grain and dairy–forage–grain (Table 2). Other examples involving ruminants and crops sometimes focus on different goals. For example, in Java, small ruminants are confined and offered forage in excess of animal requirements with the goal of producing large quantities of high-quality manure compost (Table 2).

Type of integrated system	Animal species	Plant species	Reference
1. Mixed farming with beef cattle, Ontario, Canada	Beef cattle	Alfalfa (*Medicago sativa* L.) hay, cereal, perennial pasture	Clark and Poincelot (1996)
2. Mixed farming with dairy cattle, Germany	Dairy cows	Alfalfa hay, cereal, perennial pasture	Haas et al. (2007)
3. *Dehesa* system, Spain	Pigs, beef cattle	Oak (*Quercus* spp.) trees, natural herbaceous cover	Gliessman (2007)
4. Polyface farm, Joe Salatin, Virginia	Pigs, beef cattle, chickens	Forage hay, corn (*Zea mays* L.), wood chips (perennial trees), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), oat (*Avena sativa* L.)	Pollan (2006); www.polyfacefarms.com
5. Chicken–orchard systems, California and Denmark	Chickens	Walnut trees (*Juglans regia* L.), apples (*Malus* Mill.), fall-planted cover crop	Gliessman (2007); Hermansen et al. (2004)
6. Cut-and-carry system for manure production, Upper Java	Small ruminants	Herbaceous perennial	Tanner et al. (2001)
7. Mixed grazing	Beef, pigs	Perennial pasture	Nation (2005); Sehested et al. (2004)
8. Central Italy	Sheep	Perennial pasture, cereals, hazelnut (*Corylus* L.), vineyard	Ronchi and Nardone (2003)
9. Integrated farming system, India	Ducks, dairy cows, fish, goats	Rice (*Oryza sativa* L.), azolla (*Azolla* spp.), vegetables	Jayanth (2006)

Table 2. Examples of crop-livestock integration used in organic agriculture. From Entz and Thiessen Martens (2009).

Being omnivores, pigs offer many options as a component of integrated farming systems. Nation (2005) described a system from 1916 where pigs were used as followers behind ruminants and would eat the cows' manure (Table 2). At Polyface Farm in Virginia, Joel Salatin uses pigs to compost beef cattle manure; the pigs are enticed into the beef manure pack with sweet wood chips and cereal grains. Similar systems are used in Germany in organic pig and beef cattle systems. More purpose-built barns for organic livestock production are being constructed in Canada (Figure 25).

Figure 25. Purpose built organic pig barn with outdoor access, 3-Gen Organics. Wallenstein, Ontario. Photo credit: Brett Israel.

Livestock have been used for millennia in agroforestry systems. Systems that include chickens and tree fruit or nut production can be found in different parts of the world. In Spain, pigs actually consume seasonally produced acorns in native oak stands. Highly integrated and complex crop–livestock systems come from places like India and Vietnam, where farmers combine animals with fish and various plants (Jayanth, 2006, Table 2). Even mushrooms (fungi) and azolla (Azolla spp.) (N-fixing fern) are parts of these systems. Animal manures in these systems are sometimes used in biogas production.

Managing Integrated Crop–Livestock Systems

Managing integrated crop–livestock systems requires consideration of a wide range of components, including animals, crops, soil, buildings, and landscape, as well as the expected weather patterns. Important also are the relationships among these components (Figure 20). Organic production standards requiring animals to have outdoor access and opportunity for social interaction present new challenges as well as opportunities for disease and parasite management, especially in poultry and pigs. Therefore, special consideration must be given to keeping animals healthy, and new health care approaches are needed. The integration must also allow services from animals to the land and the landscape to be captured and applied. All of this presents new and interesting challenges for farmers and researchers.

Central Role of Pastures within Crop Rotations

Benefits of crop–livestock integration are to a large extent due to perennial N_2–fixing plants that are included in the rotation (Campbell et al., 1990; Entz et al., 1995; Schiere et al., 2002). Perennial legumes improve soil quality, reduce salinization, and add more N to the soil than annual legumes (Entz et al., 2002). Perennial legumes can supply 60% of total farm N inputs into organic dairy farms, for example (Lynch, 2006). When these perennial plants are grazed instead of hayed, fewer nutrients are removed from the soil system (Baron et al., 2002), and hence nutrient management can be controlled through animal management. Due to their perennial habit and cutting regime, alfalfa (Medicago sativa L.) hay crops provide excellent control of some of the worst weeds on organic farms—wild oat (Avena fatua L.), Canada Thistle [Cirsium arvense (L.) Scop.], and wild mustard (Sinapis arvensis L. ssp. Arvensis) (Entz et al., 1995, 2001). Nitrate leaching is a serious risk when a legume-intensive rotation and/or animal manure is used (Drinkwater et al., 1998), but long-term field experiments show that periodic planting of deep-rooted alfalfa in the rotation eliminates the leaching risk (Campbell et al., 1994). Perennial pastures sequester more soil C than annual plant systems and also place the C deeper in the soil profile (Gentile et al., 2005). This ability of perennial plants to increase soil organic matt er is critical for long-term sustainability of organic systems, as it represents an investment in the future (Schiere et al., 2002).

Pasture botanical composition is important for animal productivity and health. Tannin-containing legumes (e.g., Birdsfoot trefoil) can be particularly important since condensed tannins, such as polyphenolic proanthocyanidins, reduce parasitism in young ruminants (Heckendorn et al., 2007). Häring et al. (2007) found that tannin concentration in sainfoin averaged 5 to 9% (dry matter basis) and increased with leaf age. Red clover contains formenonetin, which has been shown to inhibit Escherichia coli (Duncan et al., 2000).

Integrating green manure and grazing systems

Information in this section was sourced from the following review paper: Thiessen Martens, J. and Entz, M., 2011. Integrating green manure and grazing systems: A review. *Canadian Journal of Plant Science*, *91*(5), pp.811-824. All citations listed below are available by downloading this open access paper.

Organic farmers use biological N fixation (BNF) out of necessity, and they do so by incorporating legume plants into the farming system. Improved economics of legume green manure crops could increase adoption of this practice in organic production. One approach for obtaining immediate value from a cover crop or green manure is to integrate grazing livestock into the system (Gardner and Faulkner 1991; Sulc and Tracy 2007). Figure 26 shows livestock grazing green manures in Manitoba.

Figure 26. Left: Beef cattle grazing annual green manure on Howpark Farm, Brandon, MB. Right: Sheep grazing green manures in research experiments, Ian N. Morrison Research Farm, Manitoba.

Green Manure Productivity

A variety of annual legumes are commonly grown as green manure crops in the Prairie Provinces, including field pea, black lentil and chickling vetch, as well as sweet clover, which is a biennial. Other less common annual green manure species include fababean, hairy vetch, woolypod vetch, Tangier flatpea, annual medics and berseem clover. Perennial forage species such as alfalfa and red clover can also be grown as single-year stands and treated as annual green manures (Bullied et al. 2002).

Under typical growing conditions in the Black soil zone, annual legume green manures can generally produce 5000 kg/ha of dry matter (DM). In drier regions such as the Brown soil zone, annual green manure biomass production could generally be expected to reach 2500 kg/ha (McCartney and Fraser 2010).

Legume green manure crops obtain 40-80% of their N requirements through fixation (Sarrantonio 1998), which subsequently becomes available to other crops. The quantity of N supplied by a green manure crop depends on the DM production by the legume, the concentration of N in the plant material, and the proportion of N obtained by fixation rather than by uptake from the soil. Sarrantonio (1998) suggests that the N contained in the above-ground portion of the plant is roughly equivalent to the amount of N fixed. The N concentration of legumes is typically between 25 (Peoples et al. 2001) and 30 g/kg DM (Zentner et al. 2004). With typical green manure DM yields of 2500 and 5000 kg/ha , for the Brown and Black soil zones, respectively, N contribution to the system would be 63 to 75 kg/ha for the Brown soil zone and 125 to 150 kg/ha for the Black soil zone, assuming that none is lost from the system. Badaruddin and Meyer (1990) found that a legume green manure crop provided 150 kg/ha of N to a subsequent wheat crop in North Dakota.

Suitability of Green Manures for Grazing

The forage nutritive value of annual legume green manures is generally high because they are typically young plants when terminated (Gardner and Faulkner 1991) and contain higher concentrations of protein and minerals than grasses (Hafley et al. 1987; Fraser et al. 2004). The crude protein (CP) concentration of annual legumes such as hairy vetch, chickling vetch, clovers, medics, and peas ranges from about 8 to 29% (Hafley et al. 1987; Shrestha et al. 1998; Fraser et al. 2004). These authors also indicated that for many of the species studied, forage quality parameters would meet the nutritional requirements of beef cows. The optimal CP concentration for animal production varies by species and physiological stage, and ranges from 7 to 19% DM (Buxton and Mertons 1995). Thus, the protein level of some annual green manure legumes may actually be too high for optimal nutrition. Carr et al. (1998) found that increasing the cereal component of a cereal-pea forage intercrop from 93 to 185 seeds m2 reduced forage CP; thus, intercropping annual forage legumes with cereals may bring the CP of the annual green manure into a more desirable range. Legume CP concentration decreases with plant maturity (Hafley et al. 1987), so grazing green manures at a more mature stage of development may also accomplish this goal.

Reports on palatability of annual green manures vary. While many sources state that hairy vetch makes good forage (Undersander et al. 1990; Miller and Hoveland 1995; Hannaway and Larson 2004), others state that ‘‘livestock do not relish it’’ (SAN 1998, p. 119) or that cattle will need to be trained to eat it (Kansas Rural Center 1998). Cowpea and soybean [Glycine max (L.) Merr.] are reported to be highly palatable to grazing lambs (Sheaffer et al. 1992). In an intensive grazing system, livestock are readily trained to eat a variety of forages, including those they did not previously find palatable (Marten 1978; Thiessen Martens, unpublished observation, 2009, 2010).

Annual legume crops also vary in their adaptation to grazing. Many large-seeded annual legumes (grain legumes) do not regrow well after cutting or grazing, while small to medium-seeded legumes such as berseem clover and vetches offer some regrowth potential (Fraser et al. 2004). Even so, close grazing of hairy vetch will remove axillary buds and limit regrowth; thus, it should not be grazed before it is 15 cm tall (Miller and Hoveland 1995; Sheaffer and Evers 2007). Grazing can also affect the productivity of forage plants through soil compaction, herbage fouling and nutrient redistribution (Follett and Wilkinson 1995).

Depending on the design of the grazed green manure system, regrowth after grazing may or may not be desirable. For instance, a farmer wishing to terminate an annual green manure crop without the use of tillage may use the crop's poor grazing tolerance to good advantage. With most annual green manures, an intensive ''once over'' grazing system, resulting in little or no regrowth, may be easiest to manage.
Rapid plant development may present a logistical challenge for grazed green manure systems. From an N fixation perspective, optimal time of annual green manure termination is at mid-bloom, when biomass production has peaked and before seed set has occurred. Large-scale grazing of annual green manures may require the use of staggered seeding dates and/or planting of several green manures with varying dates of maturity in order to graze all green manure crops at an appropriate stage. Growing a forage mixture that includes a legume with regrowth potential may offer some flexibility in harvest date: Ross et al. (2005) reported higher CP with earlier first cutting of an oat (Avena sativa L.) berseem clover intercrop, but no effect on total DM yield due to compensatory growth by berseem clover after the first cut.

Since the primary purpose of growing a legume green manure crop is soil fertility enhancement, specifically with N, the impact of grazing livestock on nutrient cycling is of utmost importance. Integrating herbivores into the system can affect nutrient distribution in the grazed area and nutrient turnover rates and can influence potential pathways of nutrient loss, such as leaching and ammonia volatilization, while also removing nutrients as animal products (Russelle 1992; Follett and Wilkinson 1995; Whitehead 1995, 2000).

Example of an innovative organic grazed green manure cover crop system
The figure below (Figure 27) describes two scenarios for grazing green manures to supply nitrogen to an organic farming system in Manitoba. Both systems started with a fall rye cover crop seeded in autumn. In the top scenario, sheep grazed the fall rye until the end of May, at which time the land was tilled and seeded to a mixture of peas and oats for late season grazing. This system resulted in a net N gain of 109 kg N/ha. In the bottom scenario, the fall rye was harvested for grain. However, in early spring, a red clover cover crop was seeded into the fall rye and this clover was available for late-season grazing. This system had a net N contribution of 36 kg N/ha. Both systems provided forage for live weight gain of the sheep.

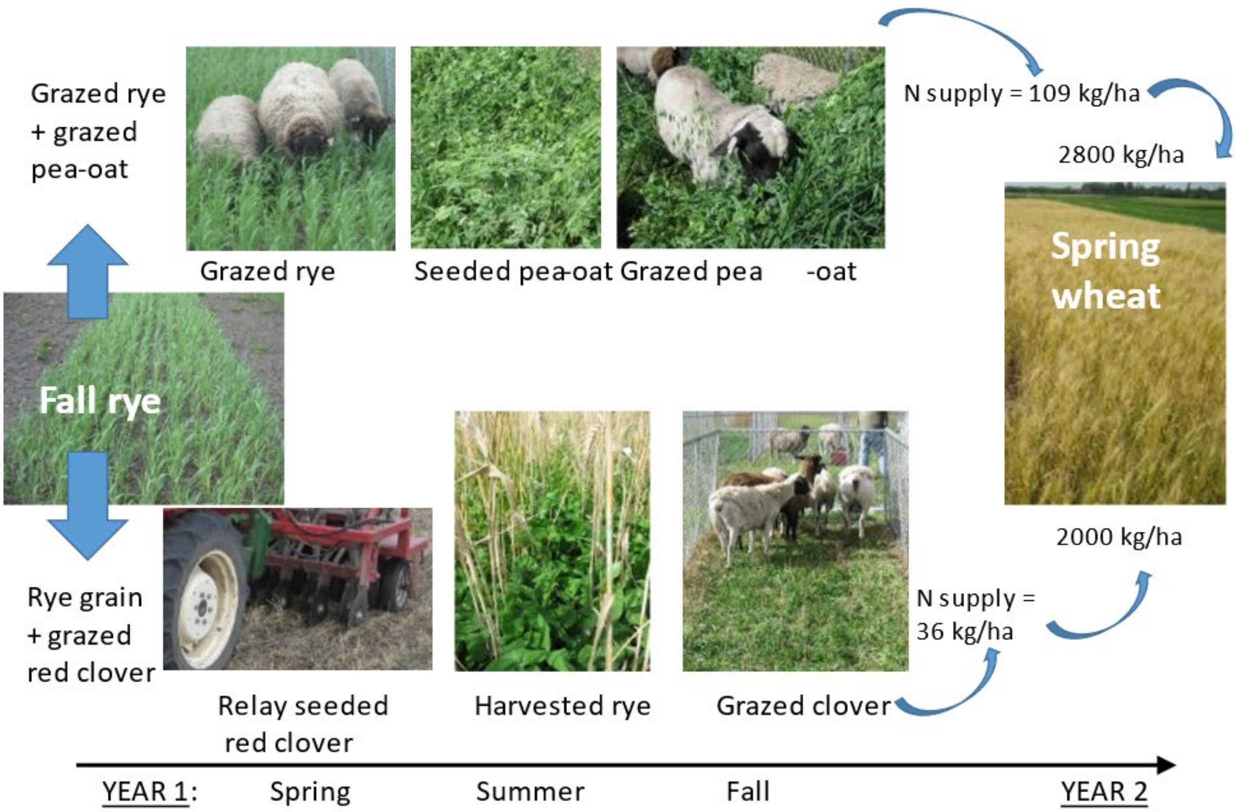


Figure 27. Two scenarios for grazing green manures to supply nitrogen to an organic farming system. University of Manitoba research, Carman, MB.

Animal production

Based on reports of biomass production and known animal productivity parameters, it is possible to estimate the potential for animal live weight gain (LWG) in a grazed green manure system. Estimates of forage requirements per unit of LWG for grazing livestock vary by livestock species and physiological stage as well as forage quality. In general, feed conversion efficiencies for forage-fed sheep and beef cattle range from 9:1 to 17:1 [calculated from Sheaffer et al. (1992), Orr et al. (1995), Estermann et al. (2001, 2003) and Speijers et al. (2004)]. With forage DM production of 5000 kg/ha , a forage utilization of 50% and a feed conversion ratio of 14, animal LWG from a grazed green manure system would exceed 175 kg/ha. With the same assumptions but a forage DM production of 2500 kg/ha , animal LWG would near 90 kg/ha.

Economics of Integrated Crop-Livestock Systems

Anderson and Schatz (2003) reported increased net returns ranging from $2500 to $22000, an increase of almost $9000 in net worth and a much-reduced coefficient of variation in income in mixed farms compared to crops-only operations in North Dakota. This demonstrates the economic benefit of integrated crop-livestock systems in general.

Less research has been conducted on the economics of grazing green manures and cover crops, especially in short-season regions. However, the few reports available suggest that grazing green manures and cover crops increased the profitability of these systems. Profitability analyses on various crop rotations in Wyoming indicated that substituting a fall-seeded, spring-grazed green manure for the fallow phase of a winter wheat rotation increased net returns in the fallow or green manure year by about $15/acre ($37/ha) because of meat sales; income variability was also significantly reduced in rotations that included a grazed green manure instead of fallow (Krall 2002; Haag et al. 2003). A preliminary report from Montana indicated that a fall-seeded annual green manure of peas or lentils grazed in spring could increase net returns by $10/acre ($24.70/ha; Montana State University News Service 2008). Researchers in warmer climates such as the south-eastern US have observed annual net returns of $185 to $200/ha from grazing winter cover crops (cited in Franzluebbers 2007) and even up to $365/ha greater net return over variable costs with grazed winter and summer cover crops compared to ungrazed cover crops (Franzluebbers and Stuedemann 2007).

Major Cost and Benefit Factors in Grazed Green Manure Systems

The primary economic benefit of integrating grazing livestock into green manure systems is the animal live weight gain (LWG) or milk production that can be attained as a result. The size of this benefit depends on the productivity of the green manure (i.e., forage biomass produced), productivity of the animals and the value of animal products. Let’s assume prices for feeder cattle (901 + lb) and lambs (50-100 lb) at $2.20 to $2.55/kg and $3.70 to $4.40/kg, respectively. With these prices and a LWG of 175 kg/ha in the Black soil zone, as discussed above, gross revenue from grazing green manures could range from $385 to $770/ha. With a LWG of 90 kg/ha in the Brown soil zone, gross revenue could range from $198 to $396/ha.

Obvious costs involved in a grazed green manure system include the costs of establishing the green manure crop as well as grazing infrastructure (fences, water sources, etc.) and the labour required to manage such a system. These are costs that most organic farmers already incur, whether they graze the green manures or not. However, for farmers who do not typically produce green manures, these are additional costs not normally incurred. Capital investments required to move from a stockless system to a grazing/mixed farm system are high, and create financial challenges for adopting such a system (Wilkins 2008). Establishing a new rotational grazing system (including materials for fencing and watering systems) can cost $3070/acre (Undersander et al. 2002). According to Anderson and Schatz (2003), adding cattle to a typical 1200-acre (485 ha) North Dakota farm (dry lot system) would increase annual operating capital requirements by $7200-$8200, but would also allow farmers to spread depreciation of farm machinery over more than one enterprise.

Integrating livestock into crop systems can increase labour requirements by more than 50% over crops-only systems, but only a portion of the additional labour competes directly with crop-related activities. In grazing green manures, most of the grazing management would take place in midsummer, when crop-related labour demands are lower than at seeding or harvest. For a farm that already has livestock, the additional labour and infrastructure required to implement a grazed green manure system would be relatively low. However, it may still require additional costs for fencing and providing water on land that was not previously grazed.

Chapter 7. The Agronomy of Organic Farming

Information on the agronomy of organic farming can be accessed through the Organic Alberta "Pivot and Grow" website. These 5 sessions were prepared and delivered by Martin Entz and include the following topics:

Lesson 1 - Designing Cropping Systems with a Focus on Nutrient Management
Lesson 2 - Crop Establishment and Seeding Systems, Tillage and Weed Control
Lesson 3 - Pest Management with a Focus on Disease, Insects (and Weeds)
Lesson 4 - Soil Management for Organic Production: Putting Theory into Practice
Lesson 5 - Questions & Answers

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Note: Unless otherwise indicated, all photos were taken by the author.

Citations

Campbell, C.A., Zenter, R.P., Janzen, H.H. and Bowren, K.E., 1990. *Crop rotation studies on the Canadian prairies* (No. 1841/E).

Entz, M.H. and Thiessen Martens, J.R., 2009. Organic crop–livestock systems. *Organic farming: The ecological system*, *54*, pp.69-84.

Holling, C.S. 1986. (From Panarchy by Lance H. Gunderson and C.S. Holling: figure 2.1, p. 34. Copyright ß 2002 Island Press). Holling, C.S.1978. Adaptive environmental assessment and management. International Institute for Applied Systems Analysis, Wiley.

Kissinger, M., 2012. International trade related food miles–The case of Canada. *Food policy*, *37*(2), pp.171-178.

Ominski, P.D., Entz, M.H. and Kenkel, N., 1999. Weed suppression by Medicago sativa in subsequent cereal crops: a comparative survey. *Weed Science*, pp.282-290.

Rhodes, J.S., 2021. Mind Maps. Published By: JJ Fast Publishing, LLC
Rada, N.E. and Fuglie, K.O., 2019. New perspectives on farm size and productivity. Food Policy, 84, pp.147-152.

Thiessen Martens, J. and Entz, M., 2011. Integrating green manure and grazing systems: A review. *Canadian Journal of Plant Science*, *91*(5), pp.811-824.

Weinberg, G.M., 1975. An Introduction to General Systems Thinking: Dorset House.

White, K.E., Cavigelli, M.A., Conklin, A.E. and Rasmann, C., 2019. Economic performance of long-term organic and conventional crop rotations in the Mid-Atlantic. *Agronomy Journal*, *111*(3), pp.1358-1370.

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