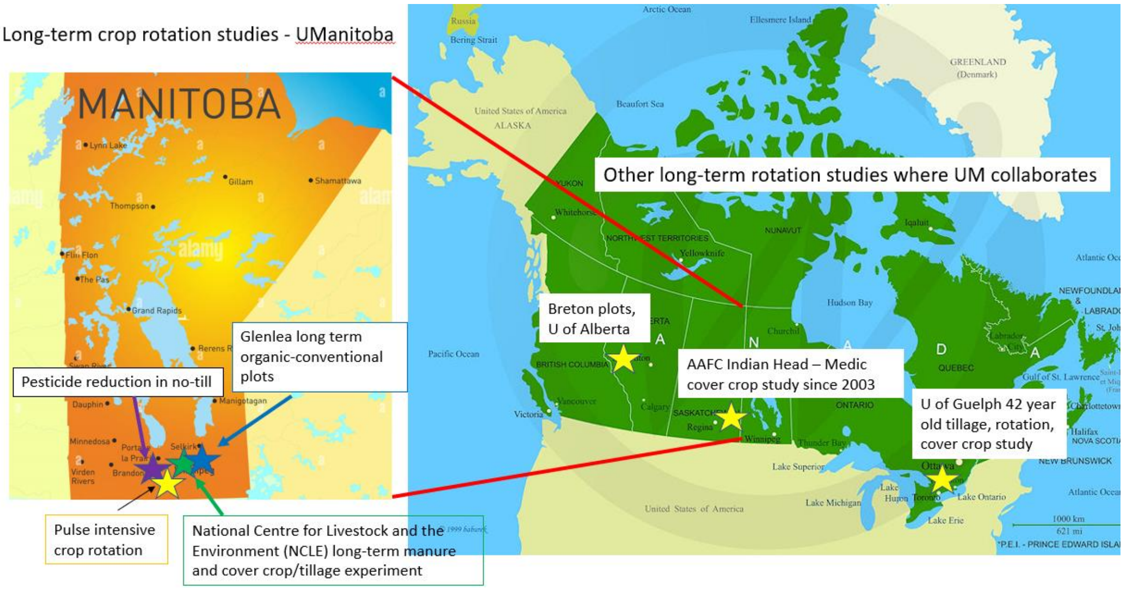
Long-term agronomic research at the University of Manitoba

June, 2023

Prepared by Martin Entz

Long-term crop rotation studies - UManitoba



Other long-term rotation studies where UM collaborates

Breton plots, U of Alberta

AAFC Indian Head – Medic cover crop study since 2003

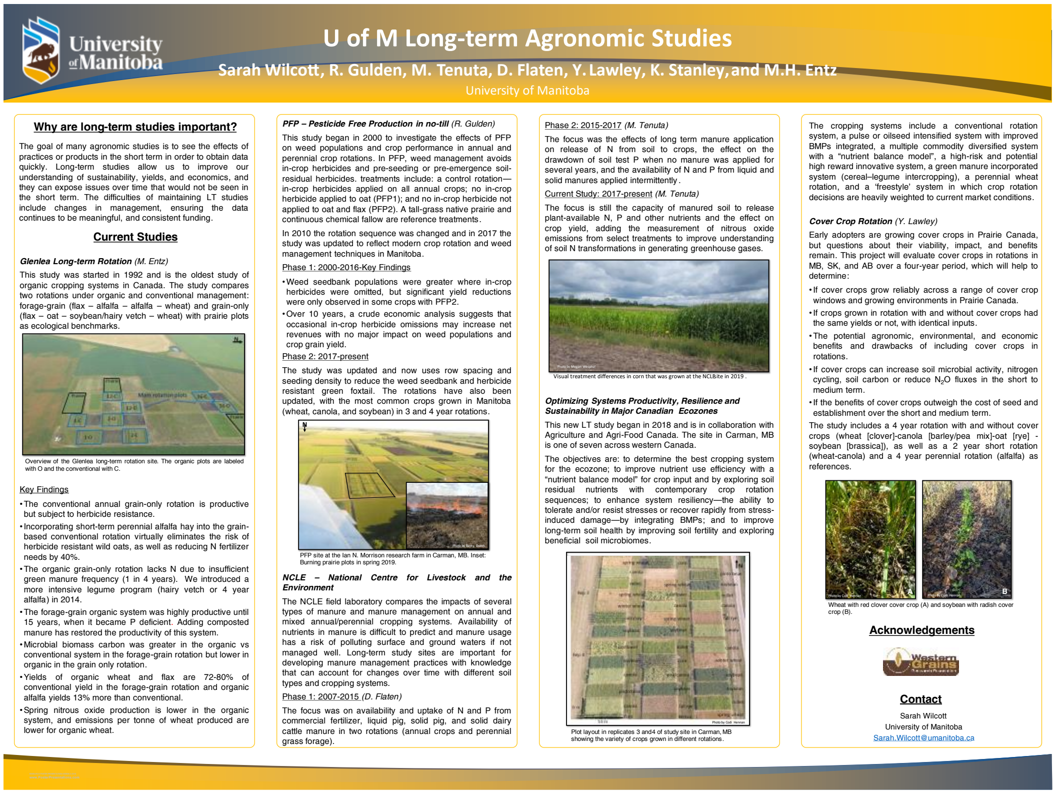
U of Guelph 42 year old tillage, rotation, cover crop study

Glenlea long term organic-conventional plots

Pesticide reduction in no-till

Pulse intensive crop rotation

National Centre for Livestock and the Environment (NCLE) long-term manure and cover crop/tillage experiment



U of M Long-term Agronomic Studies

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Why are long-term studies important?

The goal of many agronomic studies is to see the effects of practices or products in the short term in order to obtain data quickly. Long-term studies allow us to improve our understanding of sustainability, yields, and economics, and they can expose issues over time that would not be seen in the short term. The difficulties of maintaining LT studies include changes in management, ensuring the data continues to be meaningful, and consistent funding.

Current Studies

Glenlea Long-term Rotation *(M. Entz)*

This study was started in 1992 and is the oldest study of organic cropping systems in Canada. The study compares two rotations under organic and conventional management: forage-grain (flax – alfalfa – alfalfa – wheat) and grain-only (flax – oat – soybean/hairy vetch – wheat) with prairie plots as ecological benchmarks.

Overview of the Glenlea long-term rotation site. The organic plots are labeled with O and the conventional with C.

Key Findings

- The conventional annual grain-only rotation is productive but subject to herbicide resistance.
- Incorporating short-term perennial alfalfa hay into the grain-based conventional rotation virtually eliminates the risk of herbicide resistant wild oats, as well as reducing N fertilizer needs by 40%.
- The organic grain-only rotation lacks N due to insufficient green manure frequency (1 in 4 years). We introduced a more intensive legume program (hairy vetch or 4 year alfalfa) in 2014.
- The forage-grain organic system was highly productive until 15 years, when it became P deficient. Adding composted manure has restored the productivity of this system.
- Microbial biomass carbon was greater in the organic vs conventional system in the forage-grain rotation but lower in organic in the grain only rotation.
- Yields of organic wheat and flax are 72-80% of conventional yield in the forage-grain rotation and organic alfalfa yields 13% more than conventional.
- Spring nitrous oxide production is lower in the organic system, and emissions per tonne of wheat produced are lower for organic wheat.

PFP – Pesticide Free Production in no-till *(R. Gulden)*

This study began in 2000 to investigate the effects of PFP on weed populations and crop performance in annual and perennial crop rotations. In PFP, weed management avoids in-crop herbicides and pre-seeding or pre-emergence soil-residual herbicides. treatments include: a control rotation—in-crop herbicides applied on all annual crops; no in-crop herbicide applied to oat (PFP1); and no in-crop herbicide not applied to oat and flax (PFP2). A tall-grass native prairie and continuous chemical fallow are reference treatments.

In 2010 the rotation sequence was changed and in 2017 the study was updated to reflect modern crop rotation and weed management techniques in Manitoba.

Phase 1: 2000-2016-Key Findings

- Weed seedbank populations were greater where in-crop herbicides were omitted, but significant yield reductions were only observed in some crops with PFP2.
- Over 10 years, a crude economic analysis suggests that occasional in-crop herbicide omissions may increase net revenues with no major impact on weed populations and crop grain yield.

Phase 2: 2017-present

The study was updated and now uses row spacing and seeding density to reduce the weed seedbank and herbicide resistant green foxtail. The rotations have also been updated, with the most common crops grown in Manitoba (wheat, canola, and soybean) in 3 and 4 year rotations.

Photo by Becky Dueck

PFP site at the Ian N. Morrison research farm in Carman, MB. Inset: Burning prairie plots in spring 2019.

NCLE – National Centre for Livestock and the Environment

The NCLE field laboratory compares the impacts of several types of manure and manure management on annual and mixed annual/perennial cropping systems. Availability of nutrients in manure is difficult to predict and manure usage has a risk of polluting surface and ground waters if not managed well. Long-term study sites are important for developing manure management practices with knowledge that can account for changes over time with different soil types and cropping systems.

Phase 1: 2007-2015 *(D. Flaten)*

The focus was on availability and uptake of N and P from commercial fertilizer, liquid pig, solid pig, and solid dairy cattle manure in two rotations (annual crops and perennial grass forage).

Phase 2: 2015-2017 *(M. Tenuta)*

The focus was the effects of long term manure application on release of N from soil to crops, the effect on the drawdown of soil test P when no manure was applied for several years, and the availability of N and P from liquid and solid manures applied intermittently.

Current Study: 2017-present *(M. Tenuta)*

The focus is still the capacity of manured soil to release plant-available N, P and other nutrients and the effect on crop yield, adding the measurement of nitrous oxide emissions from select treatments to improve understanding of soil N transformations in generating greenhouse gases.

Photo by Megan Wesphal

Visual treatment differences in corn that was grown at the NCLE site in 2019.

Optimizing Systems Productivity, Resilience and Sustainability in Major Canadian Ecozones

This new LT study began in 2018 and is in collaboration with Agriculture and Agri-Food Canada. The site in Carman, MB is one of seven across western Canada.

The objectives are: to determine the best cropping system for the ecozone; to improve nutrient use efficiency with a "nutrient balance model" for crop input and by exploring soil residual nutrients with contemporary crop rotation sequences; to enhance system resiliency—the ability to tolerate and/or resist stresses or recover rapidly from stress-induced damage—by integrating BMPs; and to improve long-term soil health by improving soil fertility and exploring beneficial soil microbiomes.

Photo by Codi Hennan

Plot layout in replicates 3 and4 of study site in Carman, MB showing the variety of crops grown in different rotations.

The cropping systems include a conventional rotation system, a pulse or oilseed intensified system with improved BMPs integrated, a multiple commodity diversified system with a "nutrient balance model", a high-risk and potential high reward innovative system, a green manure incorporated system (cereal–legume intercropping), a perennial wheat rotation, and a 'freestyle' system in which crop rotation decisions are heavily weighted to current market conditions.

Cover Crop Rotation *(Y. Lawley)*

Early adopters are growing cover crops in Prairie Canada, but questions about their viability, impact, and benefits remain. This project will evaluate cover crops in rotations in MB, SK, and AB over a four-year period, which will help to determine:

- If cover crops grow reliably across a range of cover crop windows and growing environments in Prairie Canada.
- If crops grown in rotation with and without cover crops had the same yields or not, with identical inputs.
- The potential agronomic, environmental, and economic benefits and drawbacks of including cover crops in rotations.
- If cover crops can increase soil microbial activity, nitrogen cycling, soil carbon or reduce N_2O fluxes in the short to medium term.
- If the benefits of cover crops outweigh the cost of seed and establishment over the short and medium term.

The study includes a 4 year rotation with and without cover crops (wheat [clover]-canola [barley/pea mix]-oat [rye] - soybean [brassica]), as well as a 2 year short rotation (wheat-canola) and a 4 year perennial rotation (alfalfa) as references.

Photo by Codi Hennan

Wheat with red clover cover crop (A) and soybean with radish cover crop (B).

Acknowledgements

Western Grains

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The Glenlea long-term field study

Martin Entz, University of Manitoba
June 7, 2023

"The years teach much the days never know" Ralph Waldo Emerson, 1844

The Glenlea study

The University of Manitoba is home to Canada's oldest organic crop rotation study, where organic systems have been compared to conventional systems for over 30 years. At Glenlea, grain only and forage-grain rotations are grown under both organic and conventional production. Glenlea allows scientists to understand the potential of different farming systems (in particular organic, the fastest growing food sector in Canada) on food production, food quality and the environment. The Glenlea long-term study includes a large grassland plot in each of the three replicates. This unique feature allows Manitoba's dominant arable farming systems to be compared with nature's agriculture–grassland. Few studies in the world include such an ecological benchmark treatment (Figure 1).

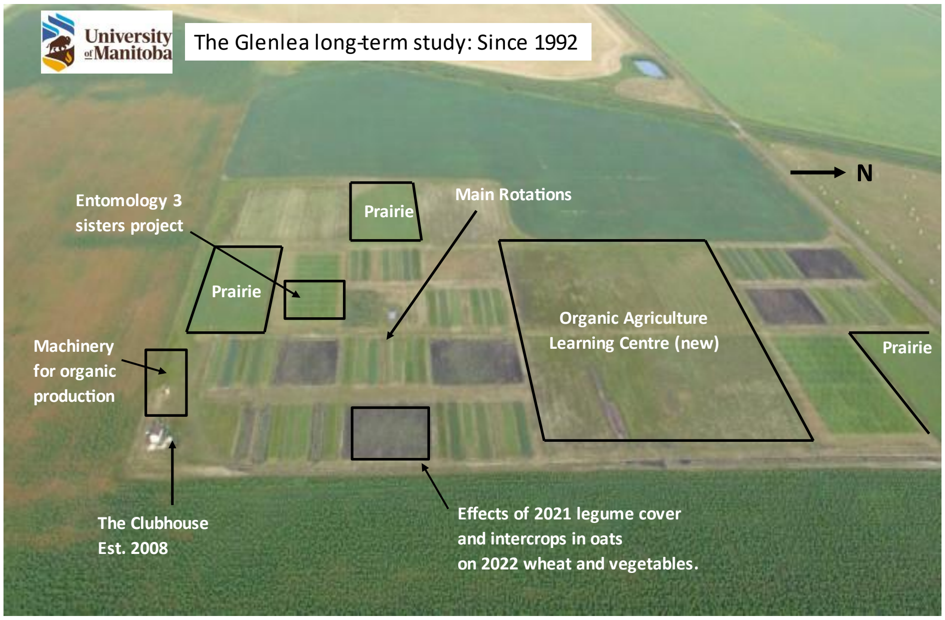


Photo credit: Gary Martens

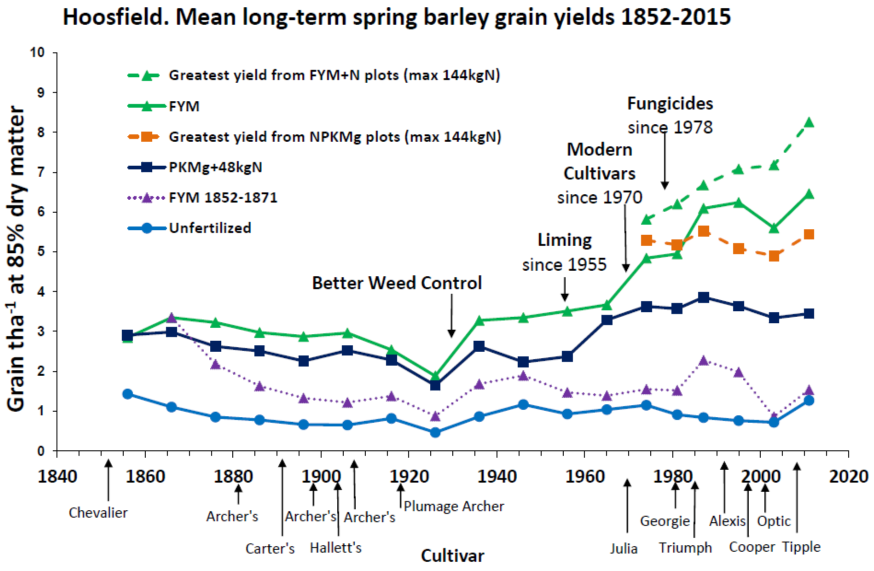
Figure 1. Aerial view of the Glenlea long-term organic study. *The Glenlea long-term organic field study is located on original lands of Anishinaabeg, Cree, Oji-Cree, Dakota peoples, and on the homeland of the Métis Nation.* Photo credit: Gary Martens.

Glenlea part of an international network of long-term organic field experiments
There are about 50 long-term studies in the world where organic and conventional agriculture are studied together in comprehensive comparison experiments (Figure 2). Of these, only 10 are older than Glenlea.

Figure 2. Locations where data was derived for meta-analysis on organic farming's effect on soil microbial abundance – see dot for Glenlea. Source: Lori M, Symnaczik S, Mäder P, De Deyn G, Gattinger A (2017) Organic farming enhances soil microbial abundance and activity—A meta-analysis and meta-regression. PLOS ONE 12(7).

Other long-term studies? There are many, here are just a few examples:

- "ABC rotation, Agriculture and AgriFood Canada, Lethbridge, Alberta. Started in 1911.
- Rothamsted plots, Rothamsted, England. Started in 1843 (see below).
- Sandborn field, University of Missouri. Started in 1888. https://www.bing.com/videos/search?q=sanborn+field&docid=608024961009846073&mid=D97D89E6716BE5EF6EA6D97D89E6716BE5EF6EA6&view=detail&FORM=VIRE
- Breton plots, University of Alberta, started in 1930.
- South American crop-livestock integrated study, La Estanzuela, Uruguay, started 1963.
- Fertility fields, University of Manitoba, started in 1926 (ended in 1960's).

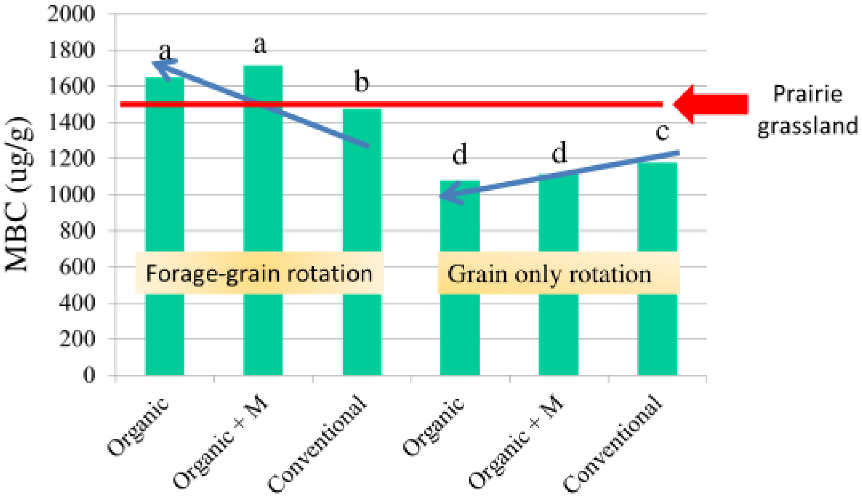


Results from the Glenlea study

1. Soil carbon, nitrogen, phosphorous and pH

Over time, issues around soil health have become a greater focus at Glenlea. Our first work was conducted by MSc student Alison Nelson looking at aggregate stability and soil C content (2001). She observed less total soil carbon in the organic grain-only plots, but higher wet aggregate stability. This puzzled us. The Canadian studies that I was familiar with at the time showed that aggregate stability was dependent on total C. However, the long-term organic plots in Switzerland supported our observation and also provided an explanation. The explanation was that organic plots had higher living carbon (microbial biomass C) but not necessarily total C, and this living C was important for aggregate stability. Sarah Braman's MSc focussed on microbial C and carbon use efficiency. She discovered that in the forage-grain rotation, organic systems had higher microbial biomass carbon (MBC) than the conventional plots. However, in the grain only rotation, the organic plots had less MBC than the conventional plots (Figure 3) (Braman et al. 2016).

Figure 3 Microbial biomass carbon under organic (Org), Org with manure added and conventional (Conv) management for forage-grain (FG) and annual-grain (AG) rotations across all sampling dates.



Braman, S., Tenuta, M. and Entz, M.H., 2016. Selected soil biological parameters measured in the 19th year of a long term organic-conventional comparison study in Canada. *Agriculture, Ecosystems & Environment*, *233*, pp.343-351.

Sarah did not find any differences in carbon use efficiency (CUE), or the soil metabolic quotient (as it is often called in the older literature). She learned that all soils at Glenlea had a CUE within a "healthy soil range". This speaks to the very good quality of Red River Valley soils.

The most recent soil C work was conducted in collaboration with the Soil Health Institute (SHI). Glenlea is one of 15 long-term studies in Canada (Norris et al. 2022) that was included in this historic survey. Some highlights of the SHI survey are shown in Table 1. Results show that total C was high for all systems except the grain only organic system. Low soil C in the grain only organic system is a worry, and we are increasing the emphasis on cover crops to boost C additions to this system. Water soluable carbon (also referred to as dissolved organic matter) is readily incorporated into soil organic matter, especially the long-term C pool referred to as Mineral Associated Organic Matter (Lavellee et al. 2020). At Glenlea, the Prairie had significantly greater soluable C compared with all other treatments (at least 25% more), and this is likely one reason why the Prairie experiences higher soil organic matter accumulation, including deeper in the soil profile (Bell et al. 2012). The forage-grain (conventional and organic with manure) and the grain only organic systems had the next highest soluable C levels (Table 1). The conventional grain only system had the lowest soluable C level. Future soil C studies at Glenlea will measure the ratio of mineral associated and particulate organic matter pools.

Table 1. Selected soil health parameters from the Glenlea long-term study assessed from surface (0-15 cm) soils collected in May, 2018.

Cropping System	**Total C %**	**Water extractable carbon** mg C/kg *Capacity	**Potentially mineralizable nitrogen PMN mg N/kg**	**pH**	**N-Acetyl β-Glucosaminidase mg pNP kg-1 soil hr-1** *Insurance	**Phosphomonoesterase (alkaline buffer)** mg pNP kg-1 soil hr-1 *Insurance
Forage-grain conventional	3.9	272	140	6.46	180	364
Forage-grain organic	4.2	258	135	7.47	176	538
Forage-grain organic plus manure	4.5	297	189	7.45	184	561
Grain only conventional	4.5	244	141	6.49	148	370
Grain only organic	3.7	272	124	7.15	155	361
Prairie	4.4	402	114	6.69	127	406
	P=0.09	P<0.001	P<0.01	P<0.01	P=0.06	P<0.01

*Definitions of "capacity" and "insurance", from Dr. Bobbi Helgason, Univ of Saskatchewan.

For potentially mineralizable nitrogen (PMN); the organic grain-only system had among the lowest values. The highest levels of PMN were in the manure amended forage-grain plots (Table 1). This observation demonstrates the high N supplying capacity of the forage-grain system, especially in the organic system where some compost is added. As N supplying power of soil increases, so does the risk of nitrate leaching. Figure 4 shows nitrate concentrations to 300 cm. Significantly more nitrate N was observed in the deepest depths for the forage-grain organic systems. This suggests leaching of nitrate N. We have started growing cover crops after alfalfa/grass breaking in order to capture the N, in an attempt to reduce its leaching potential.

Soil pH has been measured in numerous Glenlea studies including by MSc student Cathy Welsh (Welsh et al. 2009); PhD student Ru Li (Li et al. 2012) and by the SHI. Results from the SHI are given in Table 1. It is clear that organically-managed soils have a more neutral pH than conventionally managed soils; the differences between conventional and organic systems were first detected in year 13 of the study. Similar results were observed in other long-term organic vs conventional studies, such as the DOK trial in Switzerland (which has been running since 1978). Here is an excerpt from Dr. Li's PLOS One 2012 Glenlea paper "Farming management practices (organic versus conventional) rather than crop rotation (Grain-Only versus Forage-Grain) appeared to have a strong impact on shifting the abundance of soil bacterial communities, which could translate to changes in soil quality and productivity. Most soil properties including C: N ratio, total N, total C, Olsen P, and organic matter, did not play a major role in shaping bacterial communities. However, pH had the strongest effect on the bacterial community structure. Organic farming systems led to a neutral pH, which might be beneficial to Proteobacteria. On the other hand, conventional farming systems supported a higher percentage of Actinobacteria. Therefore, neither organic farming nor conventional farming can address all the aspects of beneficial soil bacterial communities, which is crucial to soil quality and productivity. Further research is required to investigate the shifts in diversity of beneficial bacterial and fungal pathogens under different farming systems in the long run." The more neutral pH in organic systems vs conventional systems tells us that organic systems do not appear to acidify soils – unlike N fertilized conventional system, where pH is declining.

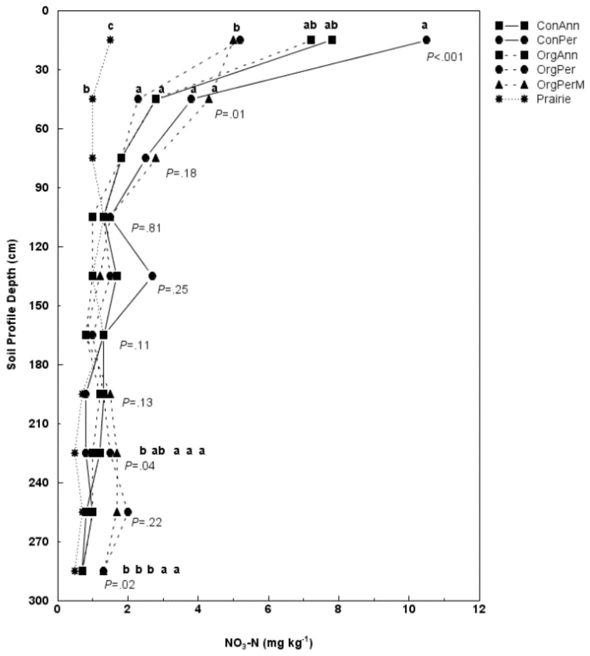


Figure 4. Soil nitrate concentration for 30cm soil depth increments taken from samples collected in May, 2018. Stainsby, unpublished.

Soil enzyme activity tended to be highest for the organic systems, especially the forage-grain organic systems (Table 1). Beta-glucosaminidase, which breaks down cellulose, was highest in forage-grain systems but low for both the conventional and organic grain only rotations. This evidence suggests that short-term perennial legume phases increase the soil's ability to break down straw and other C sources. Phospho-monoesterase, which makes P available from organic sources, was highest for the two organic forage-grain rotations. This is one case where the conventional forage-grain system did not score as high as the organic forage-grain systems. Why? It is likely due to higher levels of available P in the conventional forage-grain rotation. U of Guelph PhD student, Tandra Fraser (Fraser et al. 2015), also observed lower levels of phosphatase enzyme activity where P fertilizers were added at Glenlea.

Figure 5 shows levels of microbial biomass phosphorous (MBP) over one growing season; a growing season characterized by summer drought and soil rewetting in Sept/October (Braman et al. 2016). Results show a marked increase in MBP after soil wetting. This is likely due to bacterial growth stimulated by the greater water supply. Interestingly, the organic systems had significantly greater increases in MBP than the conventional systems. Connected to more enzyme activity?

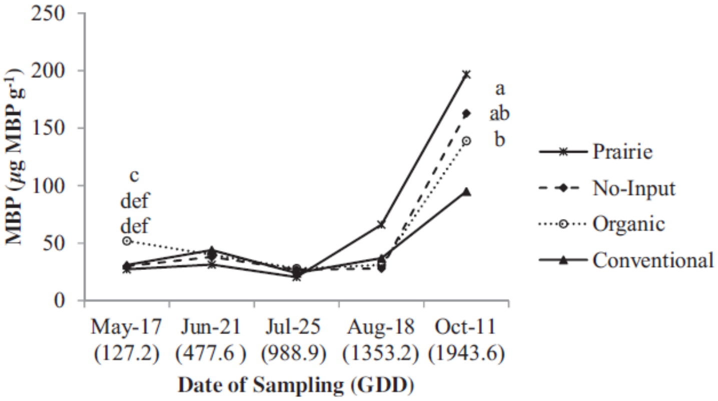


Fig. 5. Microbial biomass phosphorus (mg MBP g _1) in organic without compost (No-Input), organic with compost (Organic), conventional (Conventional) and a restored native perennial grassland (Prairie) treatments over the 2011 growing season at Glenlea, Manitoba, Canada Letters signify differences (P<0.05) between and across management and date only. Prairie not included in analysis.

2. Weeds

Weeds were the focus of many early studies at Glenlea, mainly because farmers and agronomists had many concerns about weeds in the early days of organic production. MSc student Shauna Mellish investigated both weeds and ground beetle diversity in the late 1990's. We combined her data with intensive weed data collection in 2003, resulting in the following datasets (Tables 2 and 3) (Entz et al. 2014).

Table 2. Total in-crop weed population density in flax in early June (pre-spray) at Glenlea, MB. Statistical analysis performed on log transformed data.

	Total Weed Density		
Cropping system	**1995**	**1999**	**2003**
	-----------------plants m^{-2}-----------------		
Grain only			
conventional	16	1889	1379
organic	12	532	2041
Forage-grain			
conventional	4	40	594
organic	6	110	1338
ANOVA (*P-value*)			
Rotation (R)	0.03	0.001	0.01
System (S)	0.27	0.0001	0.07
RxS	0.21	0.06	0.18

Table 3. Population density of major weed species in flax in early June (pre-spray) at Glenlea, MB in 2003. Statistical analysis performed on log transformed data.

	Weed Seedling Density					
Cropping system	**Green Foxtail**	**Wild Oat**	**Wild Mustard**	**Redroot Pigweed**	**Stink-weed**	**Canada Thistle**
	--------------------------------plants m^{-2}--------------------------------					
Grain only						
conventional	1212	60	5	42	21	2
organic	1731	55	126	1	24	13
Forage-grain (no manure)						
conventional	21	0	185	3	353	0
organic	50	1	1201	0	19	5
ANOVA (*P*-value)						
Rotation (R)	0.002	0.003	0.009	0.38	0.13	0.005
System (S)	0.06	0.005	<0.0001	<0.0001	0.02	0.0002
RxS	0.64	0.05	0.01	0.007	0.05	0.02

Results in Tables 2 and 3 show the powerful effect of the two-year alfalfa crop on weed management. For example, by 2003, total weed density in the organic forage-grain rotation was similar to total weed density in the conventional grain only rotation (Table 2). The forage-grain rotation resulted in fewer green foxtail, wild oat and redroot pigweed plants (Table 3), but ten times more wild mustard plants (Table 3).

<u>Canada thistle</u> is a persistent and troublesome weed in organic production. MSc student Pam Ominski studied thistle control options for organic production. Her field survey showed that when farmers included a 3 to 5 year alfalfa hay stand in the rotation, Canada thistle all but disappeared (Ominski et al., 1999). She then turned her attention to Glenlea. Pam was interested in the mechanisms by which alfalfa reduced thistle growth. In one study she compared rootstock biomass of thistle in three different crops, the grain only rotation, the two year alfalfa stand in the forage-grain rotation and a no crop control. Results showed that the two-year alfalfa crop did indeed greatly suppression Canada thistle root biomass in the upper 30 cm of soil.

Table 4. Thistle and alfalfa root biomass (0 to 30 cm) collected in autumn in three different cropping systems.

Cropping System	**Thistle root biomass in 0 to 30 cm soil depth**	**Alfalfa root biomass in 0 to 30 cm soil depth**
	t/ha	
Peas, then wheat	0.452	
Alfalfa for two years	0.148	4.440
No crop for two years	1.060	

3. Energy balance for wheat crops in the main crop rotations at Glenlea using long-term data

The energy efficiency of wheat in all the rotations at Glenlea is shown below. Results show that total energy embodied in the wheat grain was greatest in the conventional forage-grain rotation. The same rotation in organic production (with compost) produced 28% less caloric energy. The best organic system (forage-grain with compost) produced 20% less caloric wheat energy than the conventional annual grain system (ie., the predominant cropping system in the region).

The distribution of energy inputs is depicted in Figures 6 to 10. Energy inputs were lowest for organic systems and highest for conventional systems.

In terms of energy conversion efficiency, the systems ranked as follows: forage-grain organic (compost) > forage-grain conventional > annual grain organic > forage-grain organic (no compost) > annual grain conventional. The forage-grain organic (compost) had twice the energy conversion efficiency compared with the conventional annual grain system (16.3 vs 8.5).

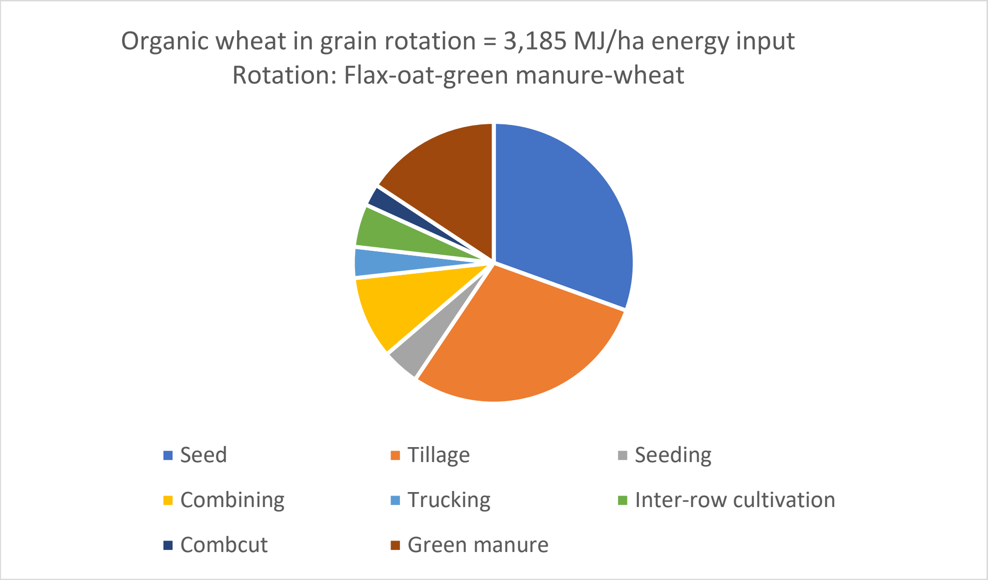


Figure 6. Fossil fuel energy input for wheat in the organic grain-only rotation. Average wheat yield 2000 kg/ha @ *18.7 MJ/kg = 37,400 MJ/ha/3185 = 11.7 energy conversion. *Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

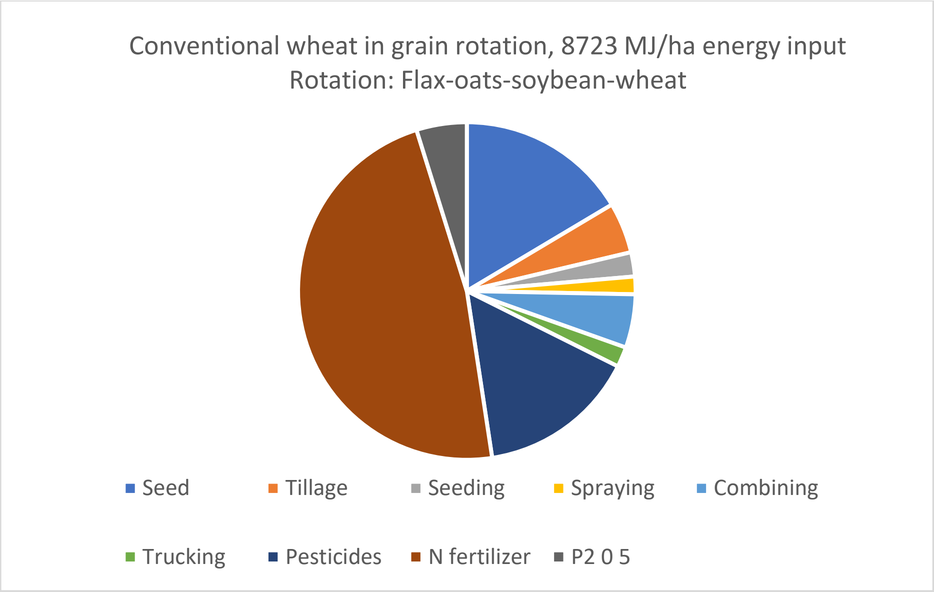


Figure 7. Fossil fuel energy input for wheat in the conventional grain-only rotation. Average wheat yield 4000 kg/ha @ *18.7 MJ/kg = 74,800 MJ/ha/8723 = 8.5 energy conversion. *Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

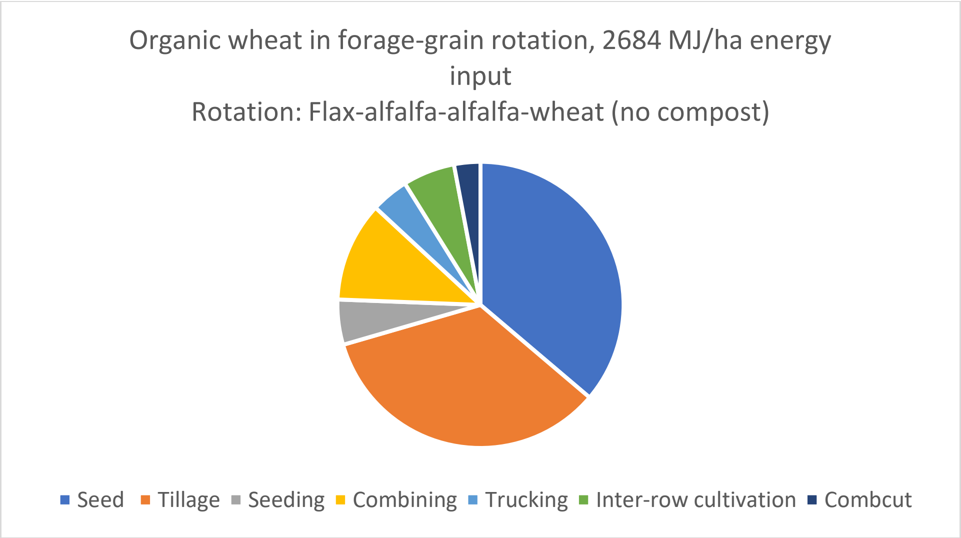


Figure 8. Fossil fuel energy input for wheat in the organic forage-grain rotation without manure. Average wheat yield 1400 kg/ha @ 18.7 MJ/kg = 26,180 MJ/ha/2864 = 9.1 energy conversion. *Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

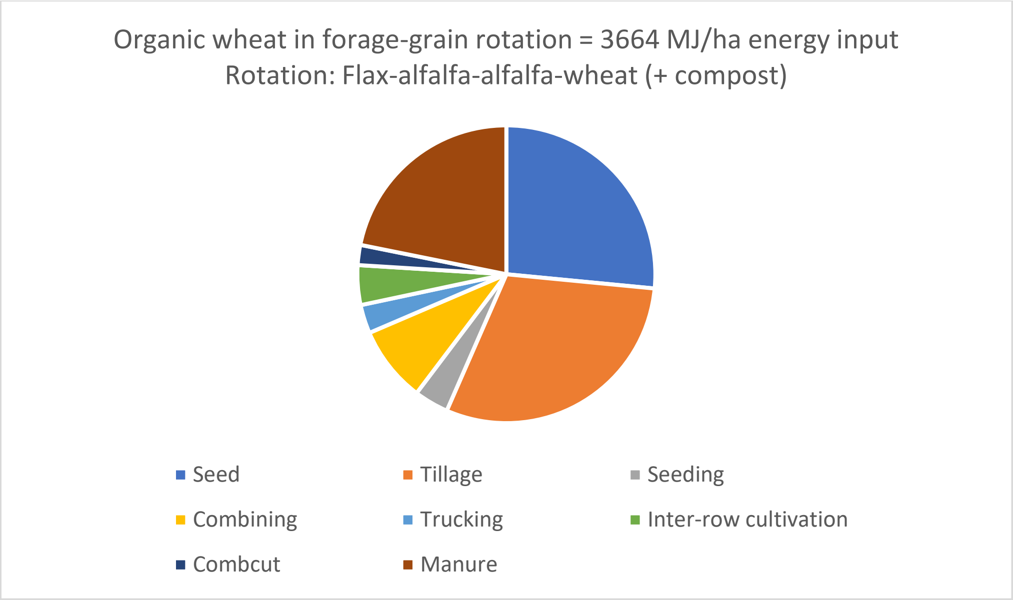


Figure 9. Fossil fuel energy input for wheat in the organic forage-grain rotation with manure. Average wheat yield 3200 kg/ha @ 18.7 MJ/kg = 59,840 MJ/ha/3664 = 16.3 energy conversion. *Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

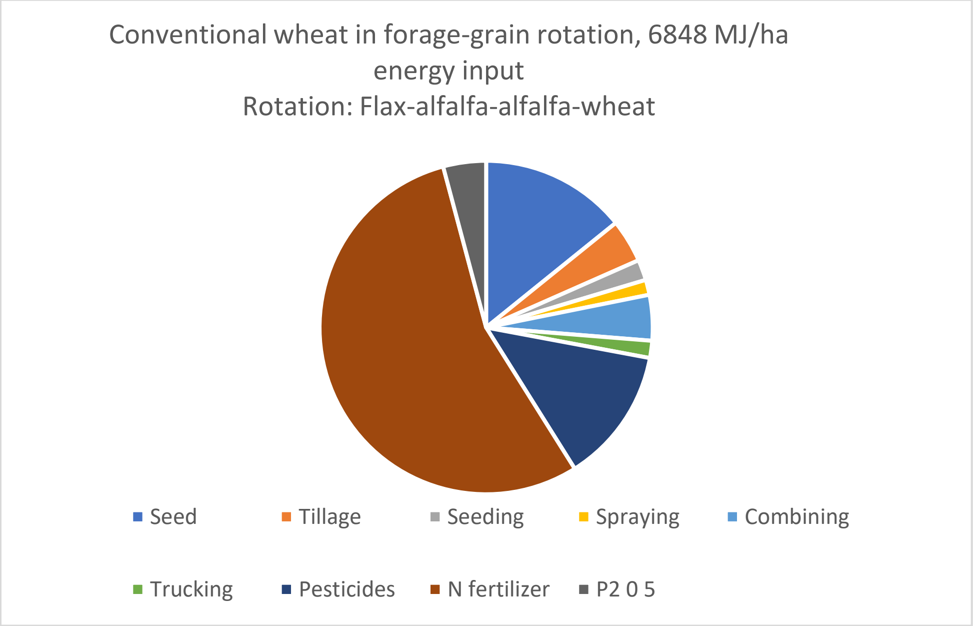


Figure 10. Fossil fuel energy input for wheat in the conventional forage-grain rotation. Average wheat yield 4400 kg/ha @ 18.7 MJ/kg = 82,280 MJ/ha/6848 = 12.0 energy conversion. *Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

Energy coefficient information from: Hoeppner, J.W., et al. 2006. Energy use and efficiency in two Canadian organic and conventional crop production systems. *Renewable Agriculture and Food Systems*, *21*(1), pp.60-67; Zentner, R.P et al. 2004. Effects of tillage method and crop rotation on non-

renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. *Soil and Tillage Research*, *77*(2), pp.125-136.

Future research

- Economic performance of all rotations and systems.
- Soil samples from Glenlea will be analyzed using spectral analysis by Dr. Mervin St. Luce, Agriculture and AgriFood Canada, Swift Current, SK.
- Grain samples for the past 20 years will be analyzed for micronutrient content by an MSc student co-supervised by Drs. Xiaoping Gao and Martin Entz.
- Measuring soil carbon in 1) Particulate vs 2) Mineral associated pools.
- Water resilience of all cropping systems. This involves adding supplemental water and restricting precipitation through the use of rainout shelters.
- Weed communities are being assessed in detail in 2023, including the soil seedbank.
- Reducing tillage in organic production. This involves using the wide blade cultivator for fall thistle control and direct-seeding grains in spring. Cover crop mulches (together with blade rolling) will be tested for weed suppression in organic systems.
- Robotic weed management in organic crops using the Garford robocrop. The machine will be adapted with “whipper snippers” for use in wet soil and reduced tillage systems.
- Testing organically developed wheat and oat cultivars in organic production systems – and comparing them with conventional varieties.
- Nitrous oxide emissions in organic vs conventional systems.

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https://umanitoba.ca/agricultural-food-sciences/long-term-agronomic-studies/glenlea-long-term-rotation

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