The Glenlea long-term field study: A primer

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"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).

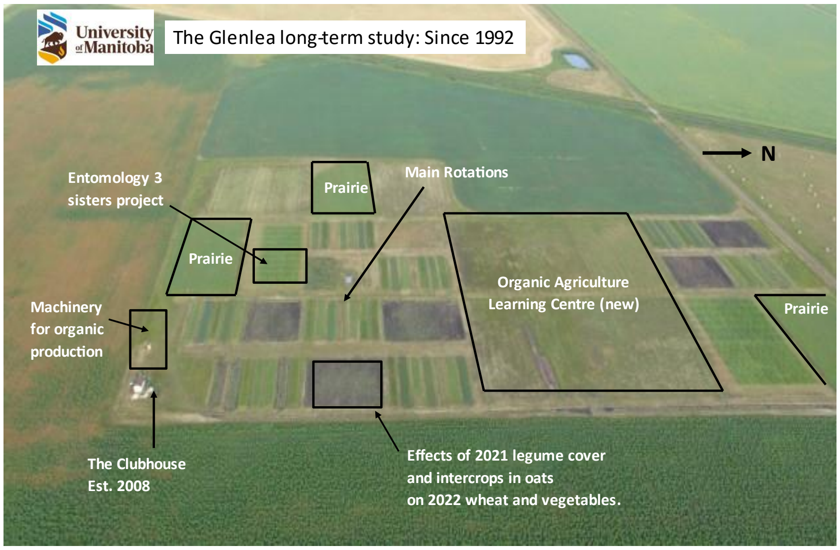


Photo credit: Gary Martens

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.

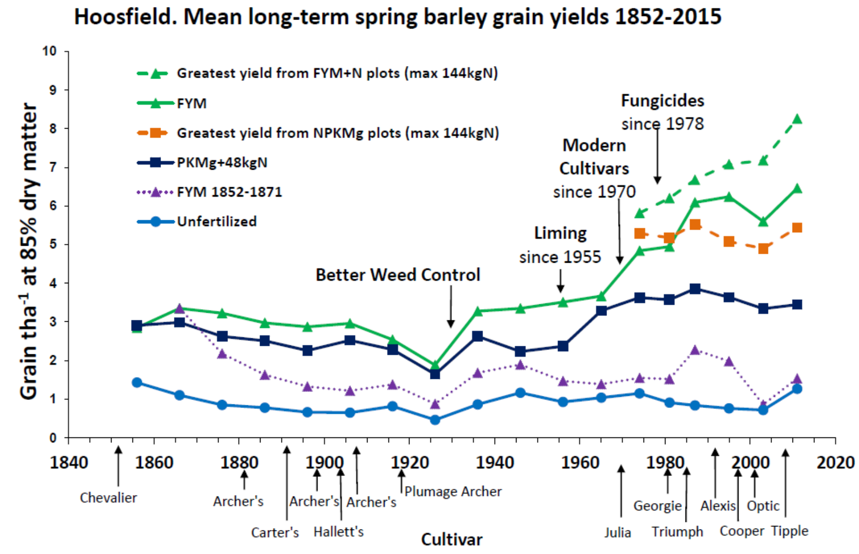
Glenlea part of an international network of long-term organic field experiments

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).

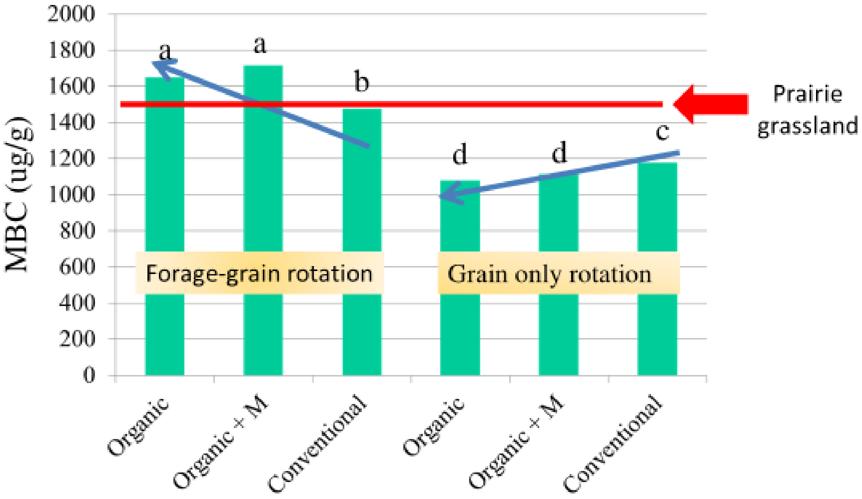


Results from the Glenlea study

1. Soil Carbon, Nitrogen and Phosphorous

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).

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. Glenlea is one of 15 long-term studies in Canada to be included in this historic survey. Results of the SHI survey, conducted by Dr. Charlotte Norris, are shown in Table 1.

Results show that total C was high for all systems except the grain only organic system. MBC was high for conventional as well as forage-grain organic systems. MBC was low for the grain only organic system. Therefore, results for total and living C show a positive trend for organic forage-grain systems, but not for the organic grain only system. These results reflect those of Braman et al. (2016).

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 %**	**Microbial biomass carbon Total plfa nmol/g** ***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	283	140	6.46	180	364
Forage-grain organic	4.2	277	135	7.47	176	538
Forage-grain organic plus manure	4.5	309	189	7.45	184	561
Grain only conventional	4.5	303	141	6.49	148	370
Grain only organic	3.7	171	124	7.15	155	361
Prairie	4.4	248	114	6.69	127	406

*Definitions of “capacity” and “insurance”, 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). One question that arises when PMN is high regards the risk of nitrate leaching. Figure 1 shows nitrate concentrations to 300 cm. Some evidence of N leaching is seen for both organic forage-grain systems.

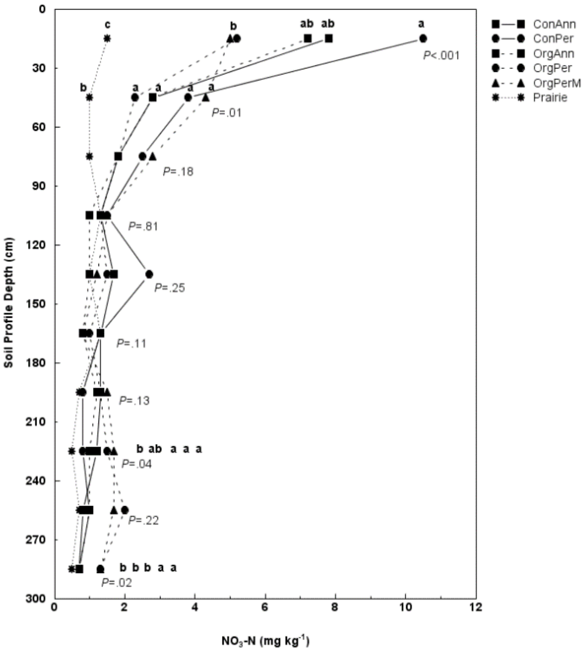


Figure 4. Soil nitrate concentration for 30cm soil depth increments taken from samples collected in May, 2018. Stainsby, unpublished.

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. 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 over one growing season; a growing season was 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?

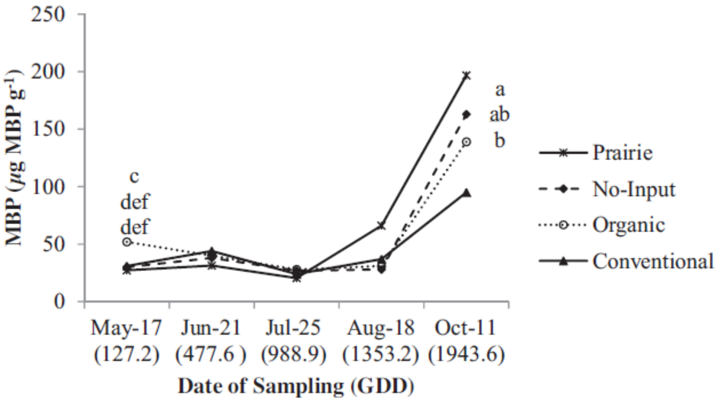


Fig. 5. Microbial biomass phosphorus (mg MBP g _1) in organic without compost (No-Input), organic with compost (Organic), conventional (Conventional) and a restored native perennial grassland (Prairie) treatments over the 2011 growing season at Glenlea, Manitoba, Canada Letters signify differences ($P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

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. 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."

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).

Canada thistle 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 how the alfalfa reduced thistle growth. 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. This is one reason why the forage-grain rotation has been able to produce acceptable grain yields over time (Figure 7) in spite of Canada thistle presence.

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

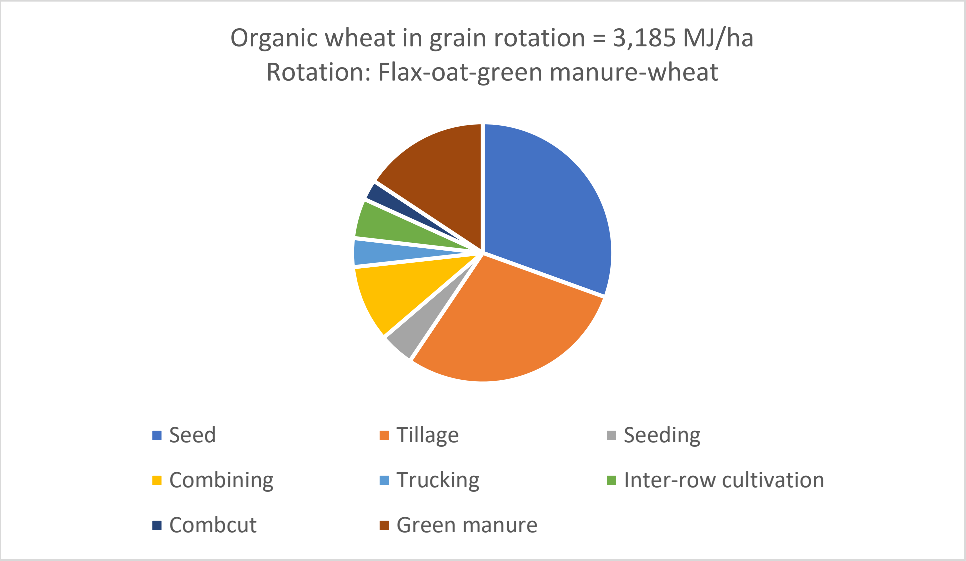


Figure 1. Fossil fuel energy input for wheat in the organic grain-only rotation. Average wheat yield 2500 kg/ha @ *18.7 MJ/kg = 46,750 MJ/ha/3185 = 14.6 energy conversion

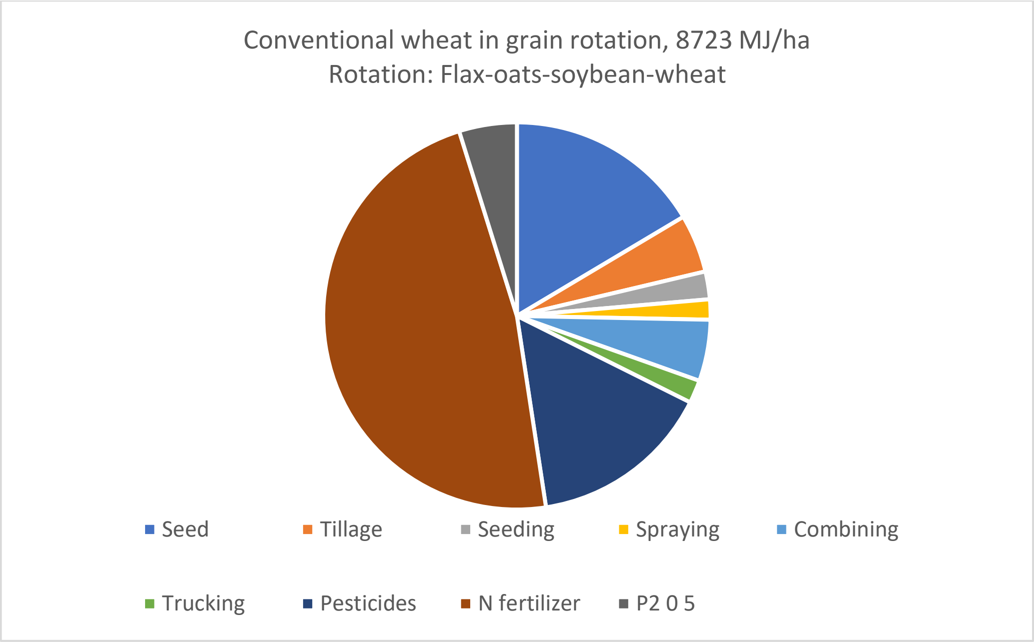


Figure 2. Fossil fuel energy input for wheat in the conventional grain-only rotation. Average wheat yield 4000 kg/ha @ *18.7 MJ/kg = 74,800 MJ/ha/8723 = 8.5 energy conversion

*Energy in wheat from laboratory bomb calorimeter tests (18.7 MJ/kg).

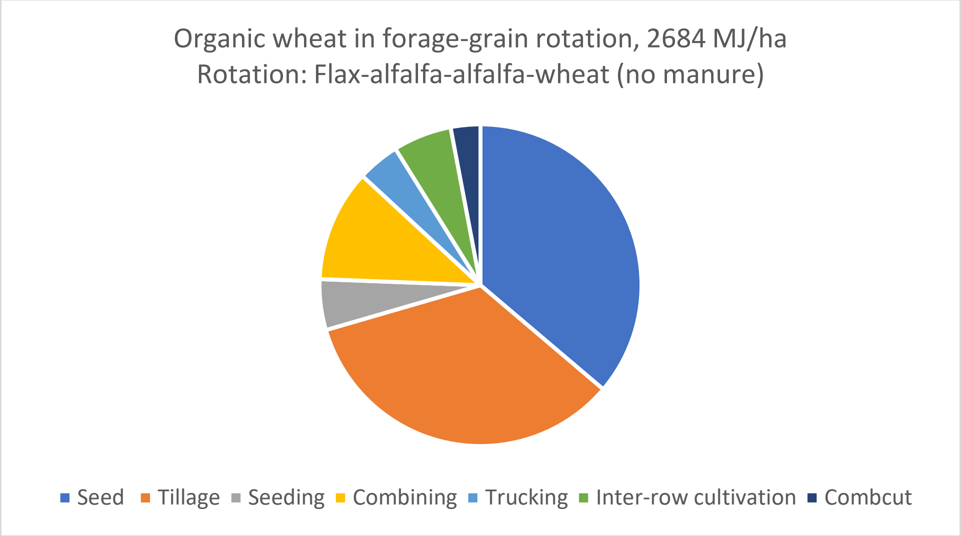


Figure 3. Fossil fuel energy input for wheat in the organic forage-grain rotation without manure. Average wheat yield 1400 kg/ha @ 18.7 MJ/kg = 26,180 MJ/ha/2864 = 9.1 energy conversion

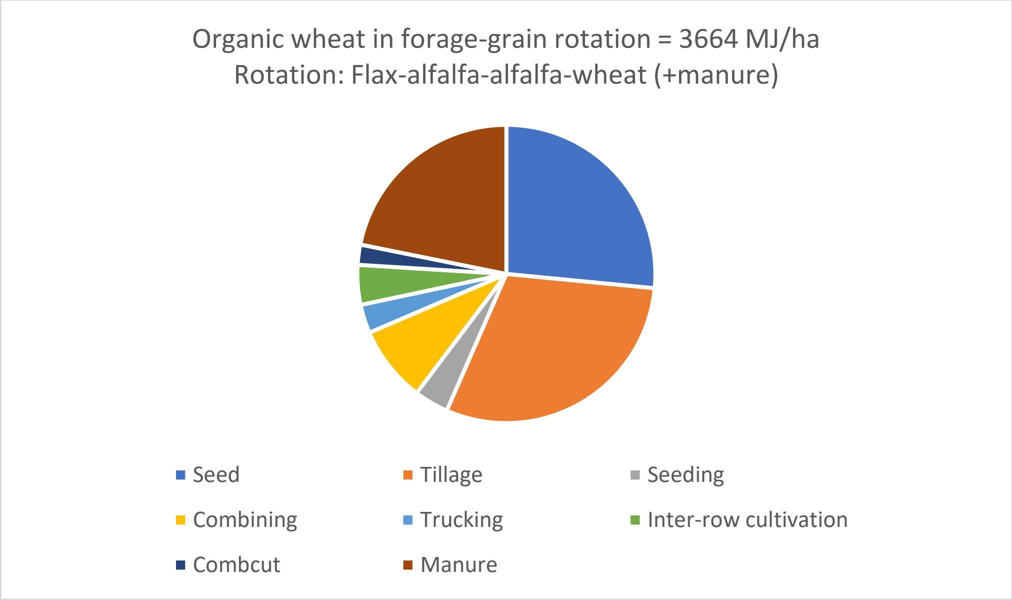


Figure 4. Fossil fuel energy input for wheat in the organic forage-grain rotation with manure. Average wheat yield 3000 kg/ha @ 18.7 MJ/kg = 56,100 MJ/ha/3664 = 15.3 energy conversion

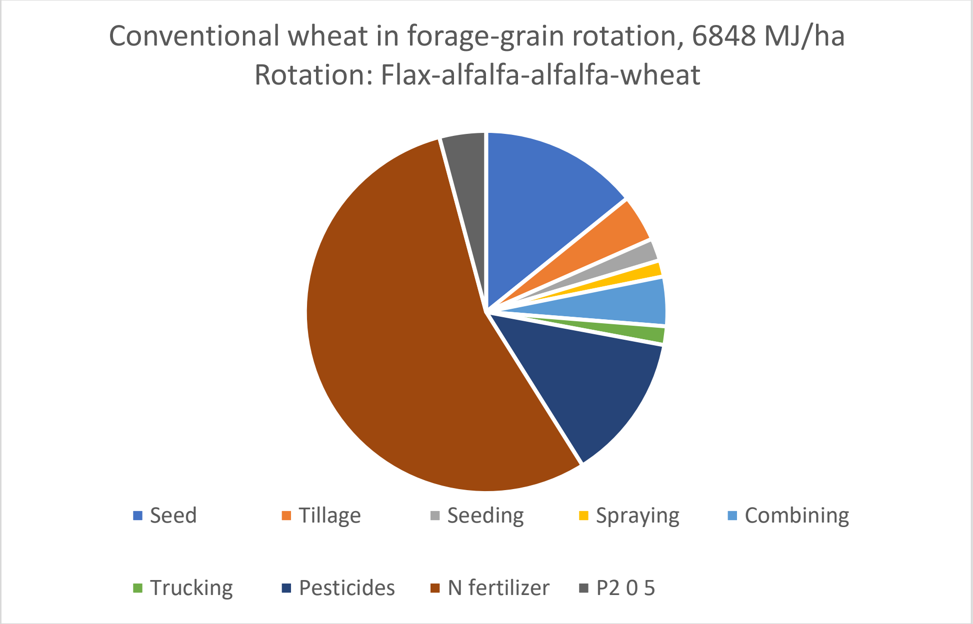


Figure 5. Fossil fuel energy input for wheat in the conventional forage-grain rotation. Average wheat yield 4400 kg/ha @ 18.7 MJ/kg = 82,280 MJ/ha/6848 = 12.0 energy conversion

Energy 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.

4. Learn more about the Glenlea rotation using these resources

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

5. Acknowledgements

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