# CROP ROTATION

## THE 19-YEAR GLENLEA STUDY

***By Stuart McMillan***

**Rotation, rotation, rotation. It has been stated so frequently and exuberantly that organic growers may be excused for feeling as if they are being indoctrinated.**

Some days it feels like rotations have been promoted as a solution for nearly every ill in agriculture, if not the entire world. Although this is taking things to an extreme, the emphasis on rotation has been huge. There is good reason for this, as rotations have been found to influence many aspects of cropping systems. This, of course, is not new. Pliny the Elder wrote about the relevance of crop sequence (crop rotation) in 77 AD.

In 1992, the Glenlea long-term study was established in Manitoba under the guidance of Dr. Martin Entz. The study compares crop rotations on organic, conventional and no input fields, and a restored prairie. The restored prairie serves as the benchmark for comparisons to natural conditions. The rotation also compares a strictly annual crop rotation to one where perennial forages are included two out of four years. This sounds simple enough, but the results have been anything but simple. Over the years, the rotation study has allowed a myriad of questions to be investigated and provided research opportunities to scores of graduate students, and, more recently, Organic Science Cluster researchers.

### Crop production

Maintaining a rotation study for nearly two decades allows cumulative effects to be seen, a component that may be lacking from shorter term studies. For example, over the years it became apparent that the forage-annual system provided much better weed control than did the rotation made up entirely of annual crops. Despite the benefit in weed control, over time, Entz and other researchers realized that exporting forage for two years of a rotation causes a huge amount of nutrients to be lost. The solution is to return the nutrients in the forage back to the field

### Annual-only rotations

Wheat / Pea / Wheat / Flax (conventional and organic)
Wheat / Green manure / Wheat / Flax (conventional and organic)
Wheat / Flax / Oat / Soybean (conventional)
Wheat / Flax / Oat / Faba bean green manure (organic)

### Rotations including forage

Wheat / Alfalfa / Alfalfa / Flax (conventional and organic)
Annual + forage: Wheat / Flax / Mixed hay* / Mixed hay* (conventional and organic)

* Mixed hay contains alfalfa, red clover, timothy and orchard grass.

### Yields

Organic production is about so much more than simply achieving maximum yields. It is about a systems approach that balances agronomy, ecology and economy. Over the years, the Glenlea rotation has highlighted many benefits of the organic rotation.[1]

Compared to the conventional rotation, the organic rotations have higher levels of:

- pH
- Soil organic carbon
- Aggregate stability
- Arbuscular mycorrhizal (AM) fungi
- Insect biodiversity
- Micronutrients in crop seeds
- Energy efficiency


*Dr. Martin Entz at one of the field test sites.*

in the form of composted manure. This makes the rotation more sustainable. Entz describes the alternative, "When the organic forage is harvested for hay, and nutrients from manure are not returned back, the system collapses."[1]

Applications of composted cattle manure also led to an increase in forage yields. With added manure, organic forage yields approached conventional yields, while in the system without manure, the organic forage yields were two-thirds of the conventional forage production. Entz explains, "If there is no forage production, then there is no nitrogen fixation from the forage, and then the whole system starts ratcheting down."[1]

Organic wheat yields have been substantially lower than conventional yields throughout the rotation. However, the addition of manure to the organic rotation increased the yields of wheat.[1]

Overall, flax yields have not responded as well under organic management compared to conventional. Even with the addition of manure, flax yields remained poor under organic management.[1] Flax in the organic rotation without forages had extremely high weed levels. There were fewer weeds in the flax when forages were part of the crop rotation, but weed levels were still challenging. The manure stimulated weed biomass to the point it reached 1000–1500 kg/ha of weeds. A more reasonable amount of weeds in a Manitoba organic flax crop would be 500–600 kg/ha.

## Phosphorus

When an experiment is carried out over many years, the impact of certain practices becomes apparent. Phosphorus (P) has been highlighted as a key concern for organic farms by studies and experience around the world. In 2001, Drs. Entz and Gulden, along with Manitoba organic farmer Robert Guilford, published results from 13 organic farms in the eastern Canadian Prairies and North Dakota.[2] They found that most farms had sufficient soil nitrogen, potassium and sulphur levels, but had low, or extremely low, levels of soil test P. However, the farms had subtle differences in management, soil type and other factors that made overarching conclusions challenging.

The Glenlea site enabled Entz and his graduate students to examine P dynamics in a controlled manner on organically managed land over many years. Subsequently, P dynamics have been studied across Canada and some of the results were shared at the Canadian Organic Science Conference in February 2012.

One question that has arisen is: If phosphorus is in such critical shortage, why is the deficiency not always reflected in lower crop yields? The answer may lie in the fact that P exists in many different states in the soil. Some are fully available to plants and others are either weakly available or unavailable. Most Canadian agricultural soils have huge P reserves, but the phosphorus is often off limits to plants because it's tightly bound to aluminum or calcium. Between 20–80% of the phosphorus in the soil can be in a less available inorganic form. The other pool of P is labile (available) mineral or organic forms. Specific soil tests measure only certain portions of P.

Discrepancies between soil test P levels and crop yields may be due in part to an inaccuracy in testing methods. If organic pools of P are higher under organic management, and P cycles more quickly in organic conditions, perhaps more P could be available than certain tests would suggest. Kim Schneider cited research that found a poor relationship between the common testing method in Canada (Olsen soil test P) and crop yield.[3, 4] Although her study looked at 14 organic dairy farms in Ontario and Nova Scotia, the results have been supported by findings from Glenlea.

Kim Schneider showed that levels of phosphorus were similar between organic and conventional dairy farms when the unavailable P fraction was included.[3, 4] She found that under organic management, organic P was significantly higher in the soil. In addition, as soil test P decreased, colonization by arbuscular mycorrhizal fungi (AMF) increased. Schneider's research supports the Glenlea findings.[6] Schneider found significant differences in the AMF community under organic management compared to conventional management. The difference in species may influence P uptake.

**Regardless of whether manure was added or not, there was more life in the soil under organic management compared to conventional.**

Tandra Fraser of the University of Guelph presented research that looked at different P extraction methods.[5] Her results show that the specific method used to extract P from soil samples had a substantial impact on measured P levels.

Fraser's study built upon work done at the Glenlea rotation a few years earlier.[6] The Glenlea study found that the most plant-available sources of P were all lower under organic management, but the unavailable P fraction was similar to conventional after 15 years of organic management. Replacement of P may be essential for the long-term success and sustainability of organic cropping rotations. The Glenlea study also found higher mycorrhizae colonization of crops and higher mycorrhizae populations under organic management.

Fraser described the role for long term rotational studies like Glenlea. "Although it is nice to go out onto farms and do the sampling there," she said, "it is very difficult, if not impossible, to find a conventional vs. organic comparison with exactly the same management."

## Soil health

In organic farming, abundant and diverse soil life is needed to help decompose plant materials, cycle nutrients, and build soil structure. Graduate student Sarah Braman looked at the microbes under the Glenlea rotations.[7] The type of crop rotation had a large effect on soil life, playing a greater influence in the organic than the conventional plots. The rotation with forages was much better from a microbial perspective.

Microbes were much more abundant and slightly more active under organic management than conventional. Regardless of whether manure was added or not, there was more life in the soil under organic management compared to conventional. The size of the microbial populations in organic rotations even approached levels seen in the restored prairie.

In terms of nutrients contained in the microbes, the prairie and no input organic systems built up the highest microbial phosphorus. Both systems also have high levels of soil organic matter. The carbon in soil organic matter promotes phosphorus retention in microbes. All of the organic systems had higher microbial biomass P than the conventional, but lower than the restored Prairie rotation.

Conventionally managed soils showed a decrease in health over time.[7] Organic and no input systems are more resilient to extreme weather conditions than conventional systems. Under organic management, soil health can be better maintained in response to extreme weather compared to conventional soil.

A recent Glenlea study with Dr. Lindsay Bell from the University of Toowoomba, Australia, showed that there might be a downside to the organic rotations, regardless of whether they include forages.[8] His research looked at soil organic carbon down to a depth of 120 cm. The organic system, even with the

At the Canadian Organic Science Conference, Entz recalled leading a tour of Glenlea. The group started the tour in front of a weedy flax field that most farmers would view as a disaster (and some might assume was the failure of organic farming). Entz then pointed out this was the conventional rotation that had developed herbicide-resistant wild oats.


*Field of flax in Nova Scotia.*

addition of manure, is not adding carbon to the deep soil compared to the conventional system. Although it may run contrary to expectations, the organic systems did not perform as well as the conventional if only the carbon content of the deep soil was considered.

The study of carbon at depth showed that the Prairie plot had huge amounts of carbon in the subsoil. Entz suggested the unconventional solution that in the longer term, adding prairie plants and perennials may be needed to maintain soil health. How one goes about recreating prairie-like plant communities in the sea of farm fields making up the region remains to be seen, but these humble plots may be guiding organic agriculture in new directions.

## Summary

Entz analyzed the following criteria of the Glenlea rotation:[1]

- Agronomic performance (wheat yield, weed populations and available nutrients);
- Soil quality (soil organic matter, mycorrhizal fungi);
- Biodiversity;
- Energy efficiency; and
- Pollution risk from P.

Entz's study found that the best performing rotations were:

1) organic rotation with forages and manure, and

2) the conventional rotation of only annuals.

The organic systems outperformed the conventional systems for most parameters. In particular, the organic systems were better for environmental and pollution risk parameters, but conventional rotations produced higher crop yields.

The grain-only organic system had a number of limitations and the poorest performance. The addition of compost reversed the declines that were occurring in the organic forage grain system after the initial years. Wheat yields and P balance both started to improve after 2007 when compost was returned to the system.

Long-term rotations require ongoing financial and physical contributions to keep going. Entz highlighted both the challenge and opportunity in this. "Keeping long term studies going is challenging, but once you get it going, people do take an interest." After nearly twenty years, the Glenlea rotation has brought interest and awareness to organic agriculture. While it has highlighted a few challenges that must be addressed, the rotation has shown the multiple benefits that can be gained from a properly designed long-term organic rotation.

*Learn more about Glenlea and Natural Systems Agriculture at www.umanitoba.ca/outreach/naturalagriculture*

*The Organic Science Cluster projects described in this article are funded by Agriculture and Agri-Food Canada, the Canadian Wheat Board and the Canadian Seed Growers Association.*

*Photo credits: Andy Hammermeister (pg. 23), Joanna MacKenzie (pg. 25)*

### References

1. Entz, M, C Welsh, S Mellish, Y Shen, M Tenuta, JR Thiessen Martens, KC Bamford & J Hoeppner. 2012. Multi-criteria analysis of the Glenlea Rotation: the first 19 years.*

2.Entz, MH, R Guilford & R Gulden. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. *Can. J. Plant Sci.* 81:351–354.

3.Schneider, KD, RP Voroney & DH Lynch. 2012. Is plant available phosphorus limiting in organic farm soils?*

4. Schneider, KD, RP Voroney, DH Lynch, M Main, K Dunfield, C Hamel, & I O'Hallahan. 2012. Phosphorus availability on organic dairy farm soils: A closer look at the evidence.*

5.Fraser, T, DH Lynch, M Entz & K Dunfield. 2012. Soil phosphorus pools and sorption capacity in long-term organic and conventional management systems.*

6.Welsh, C. 2007. Organic Crop Management can Decrease Labile Soil P and Promote Mycorrhizal Association of Crops. Graduate thesis, University of Manitoba, Dept. of Soil Science. http://mspace.lib.umanitoba.ca/bitstream/1993/312/1/Catherine_Welsh_MSc_Thesis.pdf

7. Braman, S, M Entz & M Tenuta. 2012. Soil health after 19 years under organic and conventional agricultural management.*

8. Tenuta, M, M Entz, L Bell & B Vanden Bygaart. 2010. Soil organic carbon in long-term crop rotation and management studies in south central Manitoba and the Red River Valley. www.umanitoba.ca/afs/ncle/Reports/Tenuta_Entz_MSAPP_FReport_Soil_C_2010.pdf

**Proceedings of the 2012 Canadian Organic Science Conference*