Nutrient Budgeting in Organic Grain Production (2016-2017)

Final Report for OFRF Research Grant

Iris Vaisman, Prairie Organic Grain Initiative
Dr. Martin Entz, Plant Sciences Department, University of Manitoba
Joanne Thiessen Martens, Plant Sciences Department, University of Manitoba

1. Project Summary

The Nutrient Management Program was a collaboration of farmers, agronomists, the University of Manitoba, and the Prairie Organic Grain Initiative. The program was created to address the need for a better understanding of green manure and fertility management. The initial desired outcome was to enable farmers to make better decisions about green manures. However, as the program evolved, other outcomes emerged.

Green manures (GMs) play an essential role in organic grain-based systems on the Canadian prairies by contributing to soil health, cash crop yield, and grain quality. While this is well documented on research farms, a recent scan conducted by the Prairie Organic Grain Initiative (POGI), indicated poor adoption of GMs and lack of proper GM management by farmers. Concurrently, surveys of organic farms across the prairies have revealed nutrient deficiencies, ultimately decreasing yield potential (Knight et al 2010, Entz et al 2001). Farmers need to understand the link between GMs, soil health, nutrients, cash crop grain yield, and grain quality, in the context of a whole farm nutrient budget. Farmers need to have access to knowledge that gives them confidence to make decisions about the diversity of options in GM species, termination method, and termination timing. Furthermore, farmers would benefit from a spreadsheet tool that would allow them to calculate their farm nutrient budget while also allowing them to run alternative crop rotation and nutrient management scenarios.

At the same time, farmers have expressed the need for on-farm visits by knowledgeable agronomists. Each organic farm is unique and having one-on-one extension would be extremely beneficial. Unfortunately, there are few trained organic agronomists on the Prairies. And so this was the context in which the Nutrient Management Program was created.

The Prairie Organic Grain Initiative launched the two-year program in 2016. POGI advertised the program to organic farmers and agronomists across the Canadian Prairies (Manitoba, Saskatchewan, Alberta, and British Columbia). Farmers were then matched with agronomists. Most of the agronomists previously participated in POGI's Organic Agronomy training program in 2016. The agronomists ranged from government extension workers, private agronomists, and university employees.

The agronomists in the program were supported by POGI and received training through the University of Manitoba. This included webinars, emails, shared documents, and phone calls. The webinars covered the methodology of proper plant and soil sampling, how to interpret results, how to establish a nutrient budget, and how to co-design management advice for farmers.

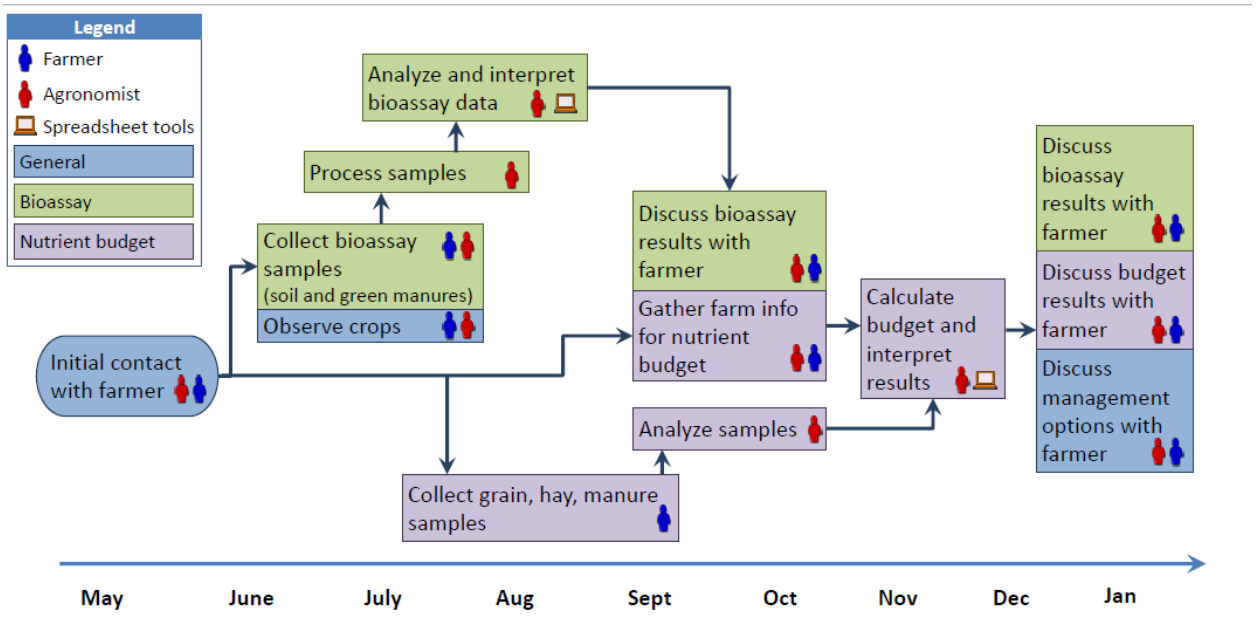

Figure 1: Timeline and participants of the Nutrient Management Program. Diagram provided by Joanne Thiessen Martens.

Figure 1 shows how the program was carried out over the course of the year. To summarize: the agronomists visited the farmers at the time of termination for the green manures, taking plant and soils samples. They also collected field history and discussed management issues and concerns. At the end of the season, famers submitted grain samples. With all the information from the samples and field history, agronomists constructed a nutrient budget. They shared the nutrient budget with the farmers and together came up with a management plan to achieve the farmer's goals.

Agronomists submitted all the soil and plant results, nutrient budgets, and final reports to POGI. A database of all the results was compiled and given to the University of Manitoba.

Over the two years, we worked with fifty-two farmers and fourteen agronomists. Overall, farmers received in-depth information and management advice for their farm, agronomists were trained, information and data were collected from farms, and information flowed back to the University of Manitoba and POGI on how to enhance tools and programming for farmers.

2. Introduction to Topic.

An advisory committee convened by POGI comprising of organic farmers, researchers, government workers, and industry from across the Canadian Prairies identified the top priorities areas for building resilient organic grain production systems on the Canadian Prairies: 1) building soil fertility, 2) designing crop rotations for weed and fertility management, 3) weed management, and 4) increasing grain quality. All four priority areas indicate a need for a better

understanding of nutrient and fertility management on grain-based organic farms. This project aimed to address the need to investigate nutrient management.

Green manures play an essential role in organic grain-based systems on the Canadian Prairies. Typically seeded in the spring, and terminated mid-summer, GMs are key to soil fertility. They supply the soil with carbon and nitrogen, provide ground cover, provide habitat for soil microorganisms, and increase soil organic matter (Fageria 2007, Sarrantino and Gallandt 2003). Subsequent cash crops in the rotation benefit from the improved soil health and soil nutrients, translating into high grain yield and high-quality grain (Fageria 2007, Sarrantino and Gallandt 2003). Multiple studies at universities and research stations across the Canadian Prairies investigated how to manage GMs to achieve maximum rotational benefit. Methods to achieve this include choosing the right species for the right environment (Biederback et al 1998, Bullied at al. 2002), optimizing termination timing (Zentner et al 2004), optimizing termination method (Vaisman et al. 2011, Blackshaw 2010), and livestock integration (Thiessen Martens and Entz 2009).

However, while a good understanding of GM management has been established at the research stations, when it comes to adoption of GMs and best management, there is a significant gap that exists on-farm. The Prairie Organic Grain Initiative compiled and examined a comprehensive scientific and extension literature review for the Canadian Prairies and adjacent USA states, over the last thirty-five years in a document called EnviroScan (see the Resources Section Below). EnviroScan indicates there is "A lack of acceptance of green manuring in the organic farming community". Concurrently, surveys of organic farms across the prairies have revealed nutrient deficiencies, ultimately decreasing yield potential (Knight et al 2010, Entz et al 2001). And while links between green manure management and grain quality have been established (Malhi et al. 2007, Campbell et al 1997), EnviroScan indicates that the research is insufficient, resulting in lack of extension and, "merits further work on both the research and extension fronts".

Moreover, this project was developed to address some of these gaps and challenges. It was recognized that there was a need for appropriate extension and GM nutrient assessment. Farmers need to have access to knowledge that gives them confidence to make decisions about the diversity of options in GM species, termination method, and termination timing. Farmers would also benefit from a tool (spreadsheet) that would allow them to calculate their whole farm nutrient budget while also allowing them to run alternative crop rotation and nutrient management scenarios.

It is important for organic farmers to address these issues because GMs are integral to the financial success and environmental resiliency of the farm. Additionally, learning how to incorporate GMs on the farm in order to provide adequate nutrition to the soil and the rotation will contribute to the overall success of the farm.

The Natural Systems Lab at the University of Manitoba has been working on research for organic grain production on the Prairies for over twenty-five years (http://www.umanitoba.ca/outreach/naturalagriculture/). Researchers Dr. Martin Entz and

Joanne Thiessen Martens recognized the need for tools that farmers can use to increase their understanding of nutrients budgets on the farm. They found that typical soil tests used for conventional farms were not providing the complete picture for organic farmers. This is because on organic farms, nutrients come from plant and animal base materials, which tend to be slow releasing, and do not show up on soil tests. Dr. Martin Entz and Joanne Thiessen Martens developed a green manure bioassay protocol and a spreadsheet-based tool, that would help organic farmers assess and manage crop nutrients.

Joanne Thiessen Martens' training materials notes that "a plant nutrient bioassay works on the principle that a plant will take up as much of each nutrient as it needs from the soil, unless a nutrient is in short supply. If the soil (including soil organic matter, plant residues, and the action of soil biology) cannot adequately supply a particular nutrient, the concentration of that nutrient in the plant biomass (above-ground growth) will likely be lower than normal. With a plant nutrient bioassay, we measure the "functional soil fertility," or the ability of the soil to actually provide nutrients to a growing crop. For information on the soil's ability to supply P, K and S, it is best to conduct the plant nutrient bioassay on a legume green manure. A plant nutrient bioassay on a legume green manure can also provide an estimate of how much N the green manure fixed."

Soil samples were also taken at the same time as the plant sample.

The spreadsheet they developed incorporated this information, plus field history to account for nutrient flow on the farm. After all the information is inputted, the spreadsheet can show whether the farm is deficient, or in surplus, of a nutrient (see below for more detail on how this worked under "Educational Approach"). They piloted these tools in the summer of 2015 with several farms in Manitoba.

The Prairie Organic Grain Initiative is a 4-year, tri-provincial project dedicated to achieving resiliency and stability in the prairie organic sector by focusing on increasing the quantity and quality of organic grains, and developing relationships across the organic market value chains. It is a partnership of the three provincial organic associations (Manitoba Organic Alliance, SaskOrganics, and Organic Alberta) and The Bauta Family Initiative on Canadian Seed Security with funding from the industry-supported Prairie Organic Development Fund, matched federal funding and partnerships with several industry stakeholders. The Prairie Organic Grain Initiative is focussed on improving the quality and quantity of organic grains through the development and distribution of educational research, mobilizing knowledge transfer from the latest organic agriculture research, and working with organic value-chain to build organic grain infrastructure. The Initiative also seeks to support transitioning and new organic farmers by providing an integrated suite of educational and on-farm resources. Lastly, the project works to increase international and domestic markets for Canadian organic grains by working with the organic stakeholders to facilitate sales, address issues related to grain quality and infrastructure, and increase long-term demand for Prairie-branded organic grains.

3. Objectives Statement

Original Research Objective: *The overall objective is to increase information flow, assess on farm nutrient budgeting, and broaden the concept of the co-design model across the Prairies. We are seeking to expand to Saskatchewan and Alberta, to capture more farmers in various ecoregions.*

Increase information flow, measurable outcomes: This program involved several different players, with information being transferred in different directions. In total, fourteen agronomists worked with fifty-two farmers. The Prairie Organic Grain Initiative coordinated the project, and the U of M provided the tools and training to agronomists. What resulted was: the farmers received information about their farm plus advice on future management. Agronomists not only received training from the U of M, but also got valuable hands-on experience on the farm, learning from farmers. Additionally, the U of M received constructive feedback from the agronomists on the tools.

Assess on-farm nutrient budgeting, measurable outcomes: The farmers involved in the program had plant, soil, and harvest samples collected from their farms. This information plus field histories were used to create a nutrient budget using the spreadsheet. All agronomists were required to share spreadsheets with the farmers, POGI, and the U of M.

Broaden the concept of the co-design model, measurable outcomes: Agronomists received training from the U of M to use a co-design method to work with their farmer clients. We worked with from across the Prairies (see Figure 2).

The overall objectives mostly stayed the same, but you will see below that some of the specifics of the two sub-objectives changed:

Original Sub-objective 1: Gain a better understanding of on-farm GM management:

a. *Identify the challenges to the practical application of GMs. (Measurable outcome: conduct short survey of farmers participating in the research project to identify the top 3 challenges. This data will be compiled with data from 1b to find links between challenges and other on-farm variables)*

For this sub-objective we said we would conduct a short survey to identify the top 3 challenges. However, due to time constraints, and since we were already asking the agronomists to do a fair amount of work, we did not conduct an official short survey. All the agronomists were required to submit reports to the farmers and to POGI summarize their findings. Therefore, we

Figure 2. Map of participants in the Nutrient Management Program, fifty-two farms (blue dots) and fourteen agronomists (red dots).

do have some information there, and can find some common themes (which will be discussed in the Results section).

b. *Collect on-farm data to create a database and find correlations and relationships between GM management, soil nutrients, ecoregion/soil type, cash crop grain yield, and grain quality. (Measurable outcome: GM tissue samples and grain samples will be analyzed for nutrients and micronutrients, create database, create baseline for current situation, run statistics to find significant relationships).*

The data from 2016 and 2017 has been compiled and shared with U of M. This data includes farm location, green manure type, crop stage, nodulation, green manure biomass weight, and plant nutrient concentrations. At the moment, these numbers have not been integrated into

the tool, nor have any correlations and relationships been analyzed. The feedback for the tool mostly came in the form of feedback from the agronomist on the use of the tool.

Original sub-objective 2: Create appropriate extension for farmers on GM adoption and management.

a. *On-farm visits will be initial form of extension, as well as follow up conversations on GM and grain analysis results. (measurable outcome: number of farm visits, short exit survey in year 2 to assess if management practices/understanding of GMs have changed, create case study farmer profiles to share with other farmers).*

The measurable outcome in this case was that fifty-two farms were visited with some extension happening alongside the soil and plant sampling (more information below on what happened during the visits). Additionally, there were follow up conversations on the results and a co-design approach to management advice. While not all farmers received an exit survey, the program was part of a final evaluation of the entire Prairie Organic Grain Initiative (I discuss the findings in further detail below). Three farm profiles have been written up and are currently being edited to make them widely available on our website: pivotandgrow.com.

b. *From the database, researchers will be able to provide farmers with knowledge on how to best manage GMs. Since the data is coming from the farm, it will be more applicable to farmers. In addition, the database will allow for the development of a tool (in excel) that allows farmers to calculate their whole farm nutrient budget while also allowing them to run alternative crop rotation and nutrient management scenarios. Plants are used to determine the P, K, S and micronutrient supplying power of the soils. Farmers use this tool and to test their soils using the plant-based soil supply test.*

This objective as it was written before the start of the project evolved as the project went on. Plants indeed were used to determine the N, P, K, S and micronutrient supplying power of the soils, and soils were tested as well. And it was that information (plus field history) that was used to allow farmers to calculate their farm nutrient budget, while also allowing them to run alternative crop rotation and nutrient management scenarios. The focus also shifted away from the whole farm to a few selected fields, as this was a more reasonable approach considering the time and experience of the agronomists.

4. Educational Approach

In this program, individual agronomists were matched with an organic farm. The agronomist went out to the organic farm one time, ideally just before GM termination. The agronomist took plant and soil samples, according to the green manure bioassay protocol developed by the U of M. The samples were sent to A and L Laboratories. The plant samples were analyzed for N, P, K, Mg, Ca, S, Na, Fe, Al, Mn, b, Cu, and Zn. The soil was analyzed for OM, P, K, Mg, Ca, Na, soil pH, Al, H, CEC, % base saturation, K/Mg ratio, S, and N03. At harvest,

farmers were instructed to send harvest samples – these could be grain, manure, or hay samples. The grain and hay were analyzed for N, P, K, Mg, Ca, S, Na, Fe, Al, Mn, b, Cu, Zn, and the manure for N, P, K, moisture and NH4-N. The agronomist then took all the lab results, combined with field history, and used the Rotation Budget spreadsheet to determine a nutrient budget for the sample fields. In the following fall/winter, the agronomist shared this information with the farmer.

There were several points throughout the program that gave opportunity for education. This includes hands-on training opportunity for agronomists, extension for farmers, and access to U of M tools.

Agronomists Training

Most of the agronomists in the Nutrient management program were trained in the Organic Agronomy Training, also delivered by the U of M. In order to train the agronomist for the nutrient management program, a series of webinars and phone calls were planned by Joanne Thiessen Martens of the U of M. The first webinar was held before the agronomists went out to the farms. This webinar covered background information about nutrients on organic farms, as well as how to follow the green manure bioassay protocol. After the agronomists received the results back from the lab, another webinar was delivered that covered how to use the Rotation Budget spreadsheet. And finally, a third webinar was delivered that covered the concept of "co-design" and how to share the information with the farmer. Throughout the program, agronomists were able to contact Joanne through phone calls or emails, as needed.

In addition to receiving training from the U of M, the agronomists learned a great deal from the farmers. For most of them, this was the first time they were advising on organic farms. This hands-on learning is very important, especially in the context of organic farming, where farms can be very heterogeneous. They learned both from the knowledge and experience of the farmer and also by "learning by doing".

Extension for Farmers

The farmers gained knowledge in several ways. The first was simply receiving the results of the soil, plant, and harvest samples. We learned that many farmers did not typically soil sample, so for many this was already valuable information. Second, was when the agronomist visited the farm, the farmers had the opportunity to walk the field with their agronomist. We have heard many times from farmers that one-on-one agronomy support is lacking and is a major hurdle for organic farmers. And finally, a major point of learning for farmers was when the agronomists shared their finding with farmers, going over the nutrient budget of the fields, and giving management options.

The U of M emphasized the concept of "co-design," as opposed to the agronomists just giving advice and have information flow in only one direction. With "co-design," the process is collaborative and interactive, farm systems are developed that meet stakeholder goals, and the evaluation and adaptation process is iterative. The U of M teams encourages this approach,

because, as they explained in a webinar: “organic farming relies heavily on understanding of ecological processes, effects of interaction farming practices, social and economic factors, and local condition and variability.” As well: “agronomists can help to create a framework for making good decisions: diagnostic tools can help to ID root causes of problems. Then you can explain their system back to them – why certain things work or don’t work, providing various options. Ultimately, though it is the farmer’s decision.”

The way “co-design” was applied for this program was that agronomists shared the Nutrient Budget spreadsheets with the farmers and explained what is happening with nutrient flows on the farm. The agronomist would then provide advice based on the findings. For example, if the farm is low on Nitrogen, then the farm could consider ways to improve GM management. The farmer can then describe what seeds they have access to, what legumes grow well on their farm, etc.

Learnings for the University of Manitoba

The agronomists were the first people to use the U of M’s GM bioassay protocol and spreadsheets. This became an opportunity for agronomists to provide constructive feedback to the U of M on the tools. Ultimately, optimizing the tools.

5. Project Results

In terms of quantitative results, we worked with fifty-two farms and trained fourteen agronomists. The quantitative results would be those that were shared with the individual farmers. As well, a database of the results was compiled.

The goal of the program was not only to share the information, but have the information guide management decisions, specifically around GM management. What we learned was that the management advice was not restricted to green manures. While the sampling was occurring in the green manure year, the information gathered also resulted in insights about other management options such as animal manures, rotation planning, and weed control. Through informal conversations with farmers, reviewing the final reports of the agronomists, and a formal evaluation (since POGI is coming to end in December 2018, an evaluation of the entire Initiative was conducted by a third party. Some specific information was gathered which included the nutrient management program) we were able to gather whether the program resulted in changes on the farm.

From the evaluation we learned that farmers found the program to be valuable. They felt that they received information and advice that they would not have received if they had not participated in this program. Some of the thoughts and reaction from farmers include:

- One farmer noted that when they saw the report from the agronomist, it was an eye opener to see the deficit of nutrients occurring on his farm – the amount of nutrients exporting versus importing was high. It enforced his decision to increase the number of

crops that go into the green manure the following season – and source additional seed from off-farm to ensure they get the variety mix they are hoping for.

- For another farmer: the change in cattle management and the decision to import off-farm manure was the biggest change in farm management as a result of the nutrient management tools.

- One farmer said: “The results will affect the length of his rotations in some fields." The nutrient testing this past year was done on a clover plough down field, which showed good results for nitrogen levels. He now thinks he will be able to take a couple grain crops off the field prior to putting a clover plough down back into the rotation due to the soil quality levels being so good.

- Another farmer decided he should diversify green manures and cover crops. The plan is to use a mix of annuals, biennials, and perennials.

While some farmers said they would change practices, it is in fact too early to tell what these changes will actually mean for the farm.Furthermore, some farmers found that the agronomist they were partnered with was not experienced enough to provide valuable information.

Another result of this program was agronomists who are now trained to work with organic. There is a lack of experienced organic agronomists on the prairies, while at the same time farmers have identified the strong need for experienced agronomists. Through this program we were able to train agronomists, who will hopefully use their experience to continue working with organic farmers. We know of at least three agronomists in the program who have done that. That said, we know that some agronomists engaged with the program more than others. Those who actively participated in the webinars, phone calls, and met deadlines got more from this program in comparison to those who engaged on a lower level.

And another result - we are working with two agronomists to develop farm profiles. We would like to share the findings of this program by sharing three specific stories. The profiles will cover the farm background, the findings of the rotation budget, and what management options exist for the farm. Once they are complete, we will post them on our website, www.pivotandgrow.com, and promote the stories through our social media channels and newsletters.

6. Conclusions and Discussion

This project resulted in fifty-two farmer participants and fourteen agronomist participants. Farmers got valuable information about their farm (plant, soil, harvest, nutrient budget), agronomists were trained, and the U of M got valuable feedback on their tools. We feel that we were able to reach our overall objective to increase information flow, assess on

farm nutrient budgeting, and broaden the concept of the co-design model across the Prairies. We learned that having agronomists do on farm visits and work together with farmers on a co-design approach was effective and valuable, and, in some cases, resulted in a change of management. Having the training from the U of M and a framework to work within helped the agronomists work effectively with the farmers.

We certainly encountered challenges throughout this project. Some farmers reported that their assigned agronomist was too unfamiliar with organic farming to be effective. Some agronomists were not timely in returning the information to the farmers, and in a couple of instances felt like they wanted more time to be spent on the assessment. As well, in a few instances the farmers felt like the management advice they received was not practical. For example, one farmer said: "my problem with it was that their sole answer for fixing our nutrient management was manure. And I don't think that is realistic, we have cows, but we don't have enough manure to cover the whole farm. And in most cases, where we are, you're not going to purchase manure from another person because they will be using it on their farm. And so, the manure consultation was not realistically achievable- when you do that intensive of a consultation I was disappointed that that was the only solution. We've decided to concentrate our time energy and money on the regenerative ag poly crops and green manures to try to problem solve around nutrient issues."

As well, agronomists reported that it was sometimes difficult to line up the date for a farm visit, as the sampling method requires sampling right before GM termination. We also had a few situations where the communication was not that great – famers not getting back to agronomists, agronomists not getting back to farmers, and in some cases, both happening at the same time. Effective communication on both sides was important for the effectiveness of the program. While POGI tried to foster good communication, it did not always happen. At times, the coordination of farmers, agronomists, A and L Laboratories (where we sent in our samples) the U of M, and POGI was cumbersome, as there were many "moving parts". We were also learning as we were going in terms of the framework and process to run the program. For example, coordinating all the samples to go to A and L laboratories smoothly took some time to figure out.

And of course, as is always the case with farming, weather was another challenge. We had set out some timelines and guides for farm visits, sampling, and report submission. In 2016, a late harvest resulted in a delay in the process of farmers sending in grain samples, and agronomists finishing their budgets. In 2017, a severe drought in Southern Saskatchewan resulted in many farmers pulling out of the program because their green manures did not germinate or grow.

If we were to redo the project, there are certain things we can do have the project run more smoothly. For instance, advertising to farmers earlier in the season and learning how to communicate with agronomists more effectively so that we do not have situations where farmers are receiving their reports late.

In terms of next steps, we now have a framework which others can copy or build upon. Other activities can be continuing to find ways to bring one-on-one support for farmers.

7. Outreach

The Nutrient Management program is now over, and what remains to distribute is the farm profiles and other POGI resources that relate to fertility management (see below). The U of M is continuing to work on tweaking the spreadsheets. Anyone interested in these spreadsheets and the protocols, please contact Martin Entz : M.Entz@umanitoba.ca
While the program was running, Joanne Thiessen Martens shared some findings at the Organic Alberta conference in 2017.
The Prairie Organic Grain Initiative also organized monthly phone calls for stakeholders, and program updates were provided.
As well, an article was written about the tools : https://organicbiz.ca/new-tool-to-help-organic-farmers-assess-and-manage-nutrients/

8. Financial accounting

Item	Justification	Cost
Agronomist Labour and Travel	**Labour** (farm visit, sampling and processing green manure bioassay, analysis of results, and co-design conversation) **Travel** (Car rental and gas, or mileage)	40583.48
Materials for Sampling	Postage, paper bags for samples, augers	734.79
Analysis Submission	**Sample analysis by A and L Laboratories:** **Plant Tissue Package** (N, P, K, Mg, Ca, S, Na, Fe, Al, Mn, b, Cu, Zn) **Soil Package** (OM, P, K, Mg, Ca, Na, soil pH, Al, H, CEC, % base saturation, K/Mg ratio, S, N03) **Grain Package** (N, P, K, Mg, Ca, S, Na, Fe, Al, Mn, b, Cu, Zn) **Manure Package** (N, P, K, moisture, NH4-N)	8205.56
Outreach	**Extension and Education Material** Farmer Profiles Agronomist Training	3480.3
Total		$ 53004.13 CAD

9. Leveraged resources

POGI is coming to an end for December 2018, and therefore no additional funding would be available to be leveraged, and there will not be people to continue to manage the program. Another Canada-wide grant is being proposed for 2019, and the learnings from this program are being incorporated.

Otherwise, it is our hope that despite a lack of funding, the training provided to the agronomists will allow them to continue to work with farmers. For example, two agronomists that were trained in this program, used their training with farmers in Northern Alberta, as part of an Organic Alberta program.

10. References

Biederbeck, V.O., Bouman, O.T., Campbell, C.A., Bailey, L.D., and Winkleman, G.E. 1996. Nitrogen benefits from four green-manure legumes in dryland cropping systems. Canadian Journal of Plant Science 76:307-315.

Blackshaw, R.E., L.J. Molnar, and J.R. Moyer. 2010. Sweet clover termination effects on weeds, soil water, soil nitrogen, and succeeding wheat yield.Agron. J. 102:634–641.

Bullied W J, Entz M H, Smith S R Jr, Bamford K C. 2002. Grain yield and N benefits to sequential wheat and barley crops from single-year alfalfa, berseem and red clover, chickling vetch and lentil. Can. J. Plant Sci. 82: 53-65

Campbell, C.A., Selles, F., Zentner, R.P., McConkey, B.G., McKenzie, R.C., and Brandt, S.A. 1997. Factors influencing grain N concentration of hard red spring wheat in the semiarid prairie. Canadian Journal of Plant Science 77:53-62.

Entz, M. H., Guilford, R. and Gulden, R. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern great plains. Can. J. Plant Sci. 81: 351-354.
Fageria, N.K., and V.C. Baligar. 2005. Enhancing nitrogen use efficiency in crop plants. p. 97–185. *In* A.G. Norman (ed.) Advances in agronomy.Vol. 88. Elsevier Academic Press, San Diego.

Knight, J.D., Buhler, R., J.Y. Leeson et al. 2010. Classification and fertility status of organically managed fields across Saskatchewan, Canada. Can. J. Soil Sci. 90: 667-678.
Malhi, S.S., Johnston, A.M., Loeppky, H., Vera, C.L., Beckie, H.J., and Bandara, P.M.S. 2007. Immediate effects of time and method of alfalfa termination on soil mineral nitrogen, moisture, weed control, and seed yield, quality, and nitrogen uptake. Journal of Plant Nutrition 30:1059-1081.
Sarrantonio, M. and Gallandt, E. 2003. The role of cover crops in North American cropping systems. Pages 210-256 *in* Shrestha, A. ed. Cropping Systems: Trends and Advances. Food Products press.

Thiessen Martens, J.R. and Entz, M.H. 2011. Integrating green manure and grazing systems: A review. Can. J. Plant Sci. 91: 811 – 824.
Vaisman, I., Entz, M.H., Flaten, D.N. and Gulden, R.H. 2011. Blade Roller–Green Manure Interactions on Nitrogen Dynamics, Weeds, and Organic Wheat. Agron. J. 103:879–889.

Zentner R P, Campbell C A, Biederbeck V O, Selles F, Lemke R, Jefferson P G, Gan Y. 2004. Long-term assessment of management of an annual legume green manure crop for fallow replacement in the Brown soil zone. Can. J. Plant Sci. 84: 11-22.

11. Photos and other addenda

Resources:

Natural Systems Agriculture
http://www.umanitoba.ca/outreach/naturalagriculture/index.html

New tool helps organic farmers assess and manage nutrients. September 8, 2016.Organic Biz: https://organicbiz.ca/new-tool-to-help-organic-farmers-assess-and-manage-nutrients/

Enviro-Scan – A summary and overview of organic research and extension on the Prairies
http://www.pivotandgrow.com/wp-content/uploads/2016/09/EnviroScan_FINAL.pdf

Organic Agronomy Research and Extension Database – A comprehensive searchable database of research and extension on the Prairies
http://www.pivotandgrow.com/resources/research-projects/

Green Manure Toolkit
http://www.pivotandgrow.com/resources/production/green-manures/green-manure-tool-kit/

Pictures on the following page …..

A field of sweet clover being terminated with a disc in Southern Saskatchewan, summer 2017.

Photo credit: Michael Thiele

Demonstrating the Green Manure Bioassay to farmers at a field day in Northern Alberta in July 2016.

Photo credit: Tierra Stokes

Farmers at a field day in Central Alberta in July 2016. Organic farmers on the Prairies are exploring the use of the roller crimper for managing green manures.

Photo credit: Melisa Zapisocky

Pea and oat green manure intercrop is a popular choice for organic farmers on the Prairies.

Photo credit: Joanne Thiessen Martens