Precision Agriculture Applied to Organic Systems

Progress report for GW19-198

Project Type: Graduate Student
Funds awarded in 2019: $22,499.64
Projected End Date: 12/31/2021
Host Institution Award ID: 4W8089
Grant Recipient: Montana State University
Region: Western
State: Montana
Graduate Student:

Royden Loewen

Major Professor:

Bruce Maxwell
MSU

Project Information

Summary:

The world population is growing and food needs continue to rise. All the while agricultural practices of high inputs and vast continuous monocultures are degrading land, waterways, and reducing ecological services worldwide. Organic agriculture proposes partial solutions to these problems by reducing inputs and emphasizing soil health, but it is unable to match conventional agriculture yields. Conventional systems have been able to increase yields with the adoption of precision agricultural (PA) techniques; techniques that allow variable rates of nitrogen to be applied to specific field points to maximize yield and reduce nitrogen runoff. A similar approach could be adopted in organic systems by mapping yields and optimizing seed rates of both nitrogen-fixing green manures, and cash crops that follow, to maximize yields of the cash crops. By optimizing seeding rates to meet the variability within each of their fields, organic farmers could reduce their costs, increase their plant-available nitrogen levels, and see improved crop output both in yield and quality. Thus, I propose to use newly developed PA tools and adapt them to organic production systems much the same way as synthetic fertilizer applications have been optimized. Organic systems have unique variables relative to conventional systems such as plant nutrient availability and weed density. To explore these sources of variability in cash crop responses, the field trials will be used to develop crop yield predictive models to examine long-term resilience in organic grain rotations. Findings will be shared with both the organic and conventional communities who see benefits to using green manures and varying seeding rates in both cover and cash crops. This research will provide farmers with new on-farm experimentation methodologies and access to modern data sources to increase understanding of what variables cause variation in crop response across their fields and can be managed to increase their sustainability.

Project Objectives:

Overall my objectives seek to increase resilience and thereby sustainability and profitability of organic farms by gaining an understanding of within-field spatial variability in factors driving crop response and providing algorithms that will allow optimized site-specific best organic management practices.

1. Determine the first-principle relationship between green manure (GM) crop seeding rate nitrogen left in the soil and following kamut crop growth over a range of kamut seeding rates.

2. Establish OFPEs on three farms with one or two fields each, where GM seeding rate will be site-specifically varied and subsequent year cereal crop seeding rate factorially varied to determine the influence of seeding rates of successive crops on cereal crop yield and grain protein content. Simultaneously monitor weed densities and determine their influence on crop response. One additional farm with two fields will vary bloodmeal rates, an organic nitrogen input, as they do not use green manure as a nitrogen source.

3. Develop models to predict optimal site-specific GM seeding rates and following year cereal crop seeding rates to maximize producer profitability in the organic fields where OFPE is applied.

4. Share the results of the research in a range of venues.

Timeline:

Table 1 – Gantt Chart – Project Timeline

Table 1 shows the projected timeline for each objective of the project. The Greenhouse study (Obj. 1) will be conducted first to provide information for the field experiments. The model (Obj. 3) will be built simultaneously and updated as new information from the field experiments (Obj. 2) becomes available. The two field growing seasons, the cornerstone experiments of the project, are highlighted under objective 2.

Cooperators

- Bob Quinn - Producer

bob@quinnorganic.com
Farmer
Quinn Farm & Ranch (Commercial (farm/ranch/business))
333 Kamut Lane

Big Sandy, MT 59520
(406) 378-3105 (office)

- Casey Bailey

  caseybail@gmail.com
  farmer / rancher
  farm and ranch (Other)
  Big Sandy, MT
  (406) 240-2389 (office)

- Ole Norgaard

  olenorgaard@hotmail.com
  farmer
  farm (Other)
  Shonkin, MT
  (406) 403-4600 (office)

- Ty OConnor

  oconnorranch@yahoo.com
  farmer
  OConnor Ranch (Other)
  Ekalaka, MT
  (406) 853-1190 (office)

Research

Materials and methods:

Objective 1) Greenhouse Experiment

The goal of this experiment was to determine optimum green manure (GM) seeding rates to maximize biomass production and following kamut yield as a result of nitrogen fixed by the GM and made available to kamut. Kamut is an ancient grain similar to wheat and popular among organic growers. Garden boxes measuring 50cm by 50cm and 25cm deep were filled with sterilized soil mixed with 50% sand in order to better emulate low nitrogen and sandy conditions typical of agricultural settings in north central Montana. The green manure tested was Arvika peas, a common Montana crop and variety. Inoculated seeds were planted 3cm deep in rows 16cm apart similar to how they would be planted in field conditions. Seeding rates encompassed a range well below and above typical farmer chosen rates and included 0, 7, 13, 34, and 81 seeds per box (0, 45, 90, 225, and 550 kg/ha). Plants were measured for height and length and width at three separate growth stages to estimate their biomass in order to understand the intraspecific plant competition occurring between plants at varied seeding rates (Bussler et al., 1995). Pea plants were grown for approximately eight weeks at optimal light and temperature growth conditions. Plants were terminated at first flowering stage, when roughly half the plants were flowering, which is the recommended termination stage to maximize N production and minimize water loss, (Mccauley et al., 2012; McCauley et al., 2012). At termination a subset of plants was collected, dried, and weighed to estimate biomass of the remaining plants which were incorporated into the soil. Pea plants were mixed into the soil and allowed to decompose over six weeks; soil was kept moist and occasionally stirred with a shovel.

Kamut seed was planted into the boxes at four different rates: 25, 50, 75, 100 seeds/box (30, 60, 90, 120 kg/ha). Each kamut rate was planted across each pea rate to create a full factorial design. Two weeks after seeding the kamut was counted to determine germination rate. Each plant was located within the box to determine physical position of the plant relative to its neighbors, and finally plant height and diameter were collected to estimate biomass. Kamut was grown until maturity, which took approximately twelve weeks, then each head was harvested and weighed individually to determine crop yield by plant and by box. Soil was sampled to track nitrogen gain and loss in the soil at multiple time points: at pea planting, pea termination, kamut planting, and again following kamut harvest.

Data was analyzed with regression analysis using generalized linear models to determine the relationship between GM seeding rate and kamut seeding rate and final kamut biomass and yield response.

Objective 2) On Farm Precision Experimentation of Seeding Rates and Harvest Yield

On farm precision experimentation (OFPE) is being used to adaptively manage inputs on organic farms. In practice, OFPE will be used to optimize seeding rates of nitrogen-fixing GM crops, and non-GM cash crops such as wheat, barley, or kamut, and on one farm bloodmeal is being varied to determine its optimum input rate. Rates are being varied randomly across the field in order to understand within field spatial variation based on continuous georeferenced yield and protein monitor combine data. As all organic farmers face weed challenges, variation in weed density is being mapped using a range of methods (Maxwell et al., 2005).

A total of four separate Montana certified organic farms are collaborating on this project, and each farm is conducting experiments on at least one field. Those farms include the Bob Quinn farm (currently run by Seth Goodman) near Big Sandy, Casey Bailey's farm near Fort Benton, Ole Norgaard's farm near Shonkin, and finally Ty O'Connor's farm near Ekalaka. The first three farms are conducting OFPE with seeding rates of GMs and cash crops, and the O'Connor farm is experimenting with varied rates of bloodmeal, an organically approved source of nitrogen, on wheat cash crops. The acreages of the fields vary from 32 to 93 hectares.

Initially, one field per farm was extensively soil sampled (approximately one sample for every two acres). Bailey and O'Connor added a second field to the experimentation and these fields were not soil sampled due to cost restrictions. The samples have been or are in the process of being analyzed for nitrogen content in Montana State University's Environmental Analytics Laboratory (EAL) and are being used to build a fertility map of each field. Wherever possible, the fertility map, previous yields, and other geographic variables are used to stratify GM seeding rate strips across the field to maximize variability within each randomized replicated strip.

Second, five rates of pea at 0X, 1.5X, 1.0X, 0.75X, and 0.5X farmer selected rates were to be planted with standard planters owned by each farmer. Given differences in equipment and ever-changing field and weather conditions the exact number and level of different rates was not followed precisely. In year two, differing seed rates of cereal crop will be planted on top of the GM variable strips such that each GM rate will have every level of the cereal crop overlaid. Cereal seed rates will similarly be 1.25X, 1.0X, 0.75X, and 0.5X of recommended organic rates. These are guidelines, and in practice rates are being adjusted by farmers' specific needs as seen below.

The farms are in various states of experimentation as they joined the project at different times. In 2019 Goodman planted peas on a 32 hectare field (soil sampled) at rates of 0, 60, 90, and 120kg/ha, and tilled them in after approximately eight weeks. In 2020 Goodman planted barley over the same field at 60, 90, and 120 kg/ha, unfortunately a storm caused hail damage that wiped out 90% of the crop, and the remaining plant matter was removed as hay bales. Barley was again planted at the same rates as in 2020 in the spring of 2021, and harvested at the end of July 2021. In 2019 Bailey planted winter wheat at 60, 90, and 120 kg/ha across a 40 hectare field site (soil sampled); this field was severely wind damaged to the point where spring wheat was reseeded in a patchwork that made yield data collection based on seeding rate variation meaningless. In spring 2020 Bailey also planted peas at 70, 90, 110, 130 kg/ha on a different 32 hectare field (not soil sampled), and planted winter wheat in fall 2020. The farmer chose not to vary the winter wheat seeding rates, but the experiment will still provide important data on the effects of the varied pea rates. In spring 2020 Norgaard planted peas at rates of 80, 100, 120, and 140 kg/ha across a 93 hectare field (soil sampled) and tilled them in approximately eight weeks later. Winter wheat was planted in fall 2020 across the field at varied rates of 55, 70, 85, and 100 kg/ha. O'Connor planted spring wheat at a uniform rate across a 32 hectare field (soil sampled) and a 67 hectare field (not soil sampled). Bloodmeal was applied across both fields at nitrogen rates of 0, 10, 20, 45, and 65 kg/ha. Yield and protein data will be collected from the combine monitors for the O'Connor fields for analysis this fall (2020). O'Connor was set to repeat this experiment in 2021 however suffered severe crop loss across their farm due to drought. The other three farms will report harvest data from cereal crops after harvest in late summer 2021.

Crop and weed data are being collected during the growing season to track how the different seeding rates are affecting crop and weed growth. 60 points are chosen at random across each field, and stratified on seeding rate, in order to non-destructively survey plant growth. A wire frame with an area of $0.25m^2$ is placed on the ground at the point and two researchers view its contents to estimate crop and weed cover. Each researcher estimates the amount of crop canopy coverage in the circle from 0 to 100 percent. To reduce bias the researchers then share their numbers and record the average. The height of an average looking crop plant is then also recorded, and the percent cover and height can be multiplied in order to estimate the volume that the crop occupies. Finally, several crop plants are measured, then collected and dried to create a regression of plant volume to biomass in order to convert plant volumes into estimates of plant biomass. This method is additionally conducted for the three most dominant weed species within the wire frame at each of the points across the field. Each species can have up to a total of 100% canopy cover. To further verify seeding rate affect across the field, crop counts are collected from across the field to determine germination rate and actual plant number within each seeding rate across the field.

Perennial weed patches are being tracked on the Goodman field where Canadian thistle (*Cirsium arvense*), and field bindweed (*Convolvulus arvensis*) are significant pests. Each year a sample of the perennial weed patches are measured by tracking their outside edge using a GPS unit. The surveyor walks around the patch, including plants in the patch if they are within 2m of another plant. In this way Canadian thistle and field bindweed are being analyzed for how they respond to the various crop densities applied in their field area.

Each farmer is using their own field equipment, thus dimensions of experimental strips for each farm are slightly different depending on width of seeder and combine. GPS units on tractors and combines, and geospatially referenced yield monitors on the combines are already in place on the farmer's equipment. Two of the farmers (Bailey and O'Connor) have protein monitors on their combines as well which will enable further crop quality analysis.

Automatically aggregated data for each field includes as-applied maps of variable seeding rates, yield points, NDVI, and topographic information (elevation, slope, aspect). As-applied maps are collected from the seeder computer, yield points are collected from combine mounted yield monitors, and NDVI and topographic information are compiled via google earth engine of satellite information from NASA's Modis and Landsat 8 instruments (He et al., 2018). As this project develops these data collection processes will be automated to the point where a farmer can input a field boundary box, and all other information is automatically gathered to produce an experimental rate trial and optimized seeding rates once yield information is gathered. Data will be analyzed using linear and non-linear regression and random forest with R statistics packages in R Studio (Version 1.1.453 – © 2009-2018 RStudio, Inc.). Maps for producers will be produced in ArcGIS Pro, QGIS, and R Studio.

Objective 3) Computer Model and App

A data framework, already functioning in our lab for nitrogen fertilizer optimization across whole fields in conventional systems, will be adjusted and updated for organic agriculture . The current R package that our lab has developed to produce an economic comparison among different nitrogen fertilizer management strategies (e.g. site-specific variable rate, no fertilizer, uniform farmer selected rate, uniform optimum rate, and organic with no fertilizer) will be updated to compare site-specific variable GM seeding rate, no GM (tillage based fallow), uniform farmer selected GM seeding rate, and optimum uniform GM seeding rate based on farmer net return (https://paulhegedus.github.io/OFPE-Website/). The app will also compare different wheat seeding rates on top of each of the GM seeding rate strategies. A final output of the app will be a recommended profit maximizing site-specific GM seeding rate and wheat seeding rate map. This proposed study will initiate a much longer study, as the predictive power of an OFPE based model increases over time. Crucial to the long term implementation of this methodology is automation of OFPE and minimizing farmer knowledgebase and time commitment required to apply OFPE results (https://sites.google.com/site/ofpeframework/home). The longer study will maintain GM and wheat seeding rate experimentation.

The code for this objective is being adapted to increase ease of use and to update it for seeding rate inputs. All code is part of a package built in the R language and environment. The first step in producing experimental maps for farmers is to access a communal lab database. Within this database historical spatial data is stored including: farm boundaries and field boundaries, yield and protein data from combine monitors, and any experimental input rates from sprayers, spreaders, and seeders. Many other data types for each field are also freely collected via Google Earth Engine comprising topographical information including slope, aspect, and topographic position index, weather data including precipitation, and growing degree days, vegetation indices including NDVI, NDRE, and CIRE, and soil moisture from SSURGO. A script built in R is used to aggregate data from the database for a particular field. The aggregated data include: field name, farmer name, spatial coordinates, previous experimental year yield, previous experimental year seeding rate, topographic information, current year precipitation up to March 1 (point of decision making), precipitation of the previous year, growing degree days of the current year up to March 1, vegetation index of the current year up to March 1, vegetation index of the previous year, and vegetation index of two years previous.

This aggregated data file is then used to generate field prescriptions based on the desired type of experiment. Optimum rates are chosen at each point on the field based on maximized net returns, and experimental rates are organized in random blocks over portions of the field to increase optimization power in the future. For the current version of the model visit: https://github.com/paulhegedus/OFPE. The next steps in building this software include making it more flexible and more useable, and also adding a function specifically for green manure seeding rates. This will be especially pertinent next year when we collect the first full sets of green manure followed by cash crop results. From this, new experiments can be generated that use the previous two years of seeding rate experiments to find optimum field rates.

Objective 4) Educational Outreach

Progress and results of this project have been presented at multiple meetings and conferences, and as a guest lecture in classroom settings to students, farmers, and agriculture professionals, and will continue to be presented electronically and at meetings as appropriate. Research was shared through an oral presentation at the Precision Ag Research Association (PARA) annual meeting in Great Falls December 3, 2019 and again Novemeber 30 2020 to interested farm professionals and the collaborator farmers themselves. Research was presented at a talk at the Montana Organic Association's (MOA) annual meeting in Bozeman on December 7, 2019, and again on December 2, 2020. Research was presented through an oral presentation at the crop management school hosted by Montana State University to agriculture professionals on January 7, 2019. Research was presented as part of a broader lecture on precision agriculture applications to agriculture graduate students at Montana State University in a guest lecture of a sustainable agriculture class (February 18, 2020) and similarly in an agroecology class (March 3, 2020). Research was also shared on a poster at the Prairie Organics Conference on March 5, 2020 in Brandon, MB, Canada to organic farmers and organic farm professionals. Research was presented as an invited talk to farmers, agriculture professionals, and agriculture students at the Soils and Crops agriculture conference in Saskatoon, SK, Canada March 10, 2020, and again in March 16, 2021. Focusing on the GIS and mapping aspect of the research, preliminary findings were shared at the Big Sky GeoCon Conference, hosted by the Montana Association of GIS Professionals on April 8, 2021. Finally, the research has also been shared at the department of Land Resources and Environmental Sciences graduate student colloquium hosted virtually at MSU on April 29, 2020, and again the following year on April 15, 2021. Results will continue to be shared with farmers, researchers, and other agriculture professionals through meetings and papers.

Results are targeted to be published in Agriculture Ecosystems and the

Environment, Nutrient Cycling in Agro Ecosystems, Agriculture, and Precision Agriculture. Proposed manuscript titles include:
1. Variable seeding rate of green manures to affect nitrogen production
2. Variable application of wheat seed to maximize yield in an organic rotation
3. Precision agriculture as a method to increase quality and quantity of organically produced wheat

Research results and discussion:

i) Greenhouse Study

Results from the greenhouse study confirmed the first principle relationship showing that seeding rates of green manure affected nitrogen availability for the following cash crop. When the peas were terminated at first flower stage, the roots were observed to have nodules on them, verifying that they were fixing nitrogen. As can be seen in figure 1, the nitrogen levels in the soil increased from pea termination to the point of kamut planting two months later. This verifies that bacteria in the root nodules of the pea were fixing nitrogen, and that the pea plant decomposed enough to provide plant available nitrogen for the following crop. The harvested rates from the kamut, seen in figure 2, showed that there was an ideal rate of pea seed to maximize kamut yield. This was an important step in validating our field experiments with varied pea and cereal crop seeding rates. These results are preliminary and further statistics will be provided in the final report.

Figure 1

Figure 2

ii) On Farm Precision Experimentation of Seeding Rates and Harvest Yield

Field data are in the process of collection and analysis.

Participation Summary

4 Farmers participating in research

Educational & Outreach Activities

5 Consultations

2 Curricula, factsheets or educational tools

14 Webinars / talks / presentations

PARTICIPATION SUMMARY:

75 Farmers

115 Ag professionals participated

Education/outreach description:

My ongoing research has been presented at multiple farmer meetings and conferences, and in classroom settings through oral presentation and poster presentations.

PARA - Precision Ag Research Association - Dec. 3rd 2019 Great Falls MT, USA
-oral presentation
MOA - Montana Organic Association - Dec. 7th 2019 Bozeman MT, USA
-oral presentation
Crop Management School – January 7th 2020, Bozeman, MT, USA
-oral presentation
Sustainable Agriculture Guest Lecture – February 18th 2020 MSU, MT, USA
-oral presentation
Agroecology Class Guest Lecture – March 3rd 2020, MSU, MT, USA
-oral presentation
Prairie Organics Conference - March 5th 2020 Brandon, MB, Canada
-poster presentation
Soils n Crops Ag Conference - March 10th 2020 Saskatoon SK, Canada
-oral presentation
Department of Land Resources and Environmental Sciences student colloquium – April 29th 2020, online hosted by MSU
-oral presentation

Ecological Society of America – August 4th 2020 – online
-oral presentation

Precision Agriculture Research Association – November 30th 2020 - online
-oral presentation

Montana Organic Association – December 2nd 2020 - online
-oral presentation

Soils and Crops at University of Saskatchewan – March 16th 2021 – online
-oral presentation

Big Sky GeoCon by Montana Association of GIS Professionals – April 8th 2021 - online
-oral presentation
Montana State University Department of Land Resources and Environmental

Sciences Colloquium – April 15th 2021 - online
-poster presentation

Project Outcomes

4 Farmers reporting change in knowledge, attitudes, skills and/or awareness

4 Farmers changed or adopted a practice

4 Farmers intend/plan to change their practice(s)

3 Grants received that built upon this project

Did this project contribute to a larger project?:

Yes

Project outcomes:

The outcomes of this project will be seen this fall after harvest data is collected. However, the power of big data in farming should enable much greater efficiency of inputs into farm systems. Currently we are directing our efforts towards seed inputs, but the methods of on farm precision experimentation can easily be geared towards manure or other organically approved inputs. There is a large degree of over-nitrification of the landscape and so reducing these inputs could go a long way to reducing pollutants from farming. The findings can be applied to seeding rates in non-organic systems too, to employ integrated weed management techniques and reduce chemical use and increase yields where appropriate. As well, these methods should improve efficiencies on organic farms, thereby improving economic returns and yields which would further encourage organic development overall over its less sustainable conventional counterpart.

Knowledge Gained:

While most of our lessons remain to be learned with the following year's harvest data, we have learned a lot through the process. Through working with farmers, researchers, and industry professionals I have become aware of how exciting this field is. Farmers are very keen to begin using the data to their advantage. Industry professionals are seeing quick expansion of the tools available to them, and increases in the market whereby sales in PA technology is expanding in every way. And more and more researchers are getting in involved in precision ag as can be seen by the new positions at universities in the field, and growing number of conferences dedicated to the subject.

Another thing I have learned is the amount of variability between farms, fields, and even within fields is very real and very large, and the ability to understand and use that variability to the farmers’ advantage is underutilized. Most farmers use general seeding rates across their farms, across years and within fields. However even from the simple soil survey data I have collected, it is clear that within field variability is large and farmers could do much more to apply their inputs precisely and so reduce waste in some areas, and increase yield in others, thereby improving their bottom line.

Finally I have learned about the need for flexibility when working with farmers as variables such as weather and breakdowns can affect experimental layouts and outcomes considerably. Many experimental prescription maps have been adjusted on the fly as farmers change their needs due to on the ground considerations. For this reason having maps that can be changed quickly, and reduced from complex to more simple layouts has been a key element in working with farmers and the real world conditions they face.

I have learned about how big data can be employed in organic farm settings to enable better decision making by farmers. Farmers are excited about mapping and precision agriculture tools and using them to understand within field variation on their fields and farms. By harnessing this power and coupling it with farmer's traditional knowledge of their land, we aim to reduce uncertainty in farmer's management decisions. There is a large amount of unused agricultural data. Finding, collecting, and working with farmers to explore ways to use it towards greater economic returns for farms and overall farm sustainability has been the area in which I have expanded my own knowledge the most.

Information Products

and do not necessarily reflect the view of the U.S. Department of Agriculture or SARE.

US Department of Agriculture

This site is maintained by SARE Outreach for the SARE program and is based upon work supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award No. 2019-38640-29881. SARE Outreach operates under cooperative agreements with the University of Maryland to develop and disseminate information about sustainable agriculture. USDA is an equal opportunity provider and employer.
