Assessing Nitrogen Contribution and Soil Biological Effects of Promising Winter Annual Legume Cover Crops for Minnesota

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Photo: 1 from left to right: Sharon Perrone (MS Student), Alex Liebman (MS student), Anne Pfeiffer (field technician), Julie Grossman (PI) and Fucui Li (post-doc) in Forever Green field site Lamberton, MN.

Photo 2: Alex Liebman in Forever Green plots at Lamberton, MN

Abstract:

Cover crops are non-harvested crops that provide important benefits including erosion control, landscape diversification, nutrient addition and soil quality improvement. Leguminous cover crops in particular can increase soil nitrogen (N) by converting atmospheric N into a form that can be used by the legume plant for growth via the process of nitrogen fixation, and may also increase soil organic matter. This project addressed the lack of winter hardy legume cover crop species options that can contribute to soil quality, fertility and active microbial functioning in northern climates. The purpose was to provide legume cover crop options to growers in the upper Midwest to help increase soil quality and nutrient availability to cash crops. We did this by examining key soil microbial processes that regulate nitrogen (N) cycling in select winter-hardy legumes, with an emphasis on hairy vetch and red clover. Together with our project team, we first identified promising commercially-available species of winter annual legumes that had potential to survive and contribute N to soils in our variable Minnesota climates. We were interested in such crops as they could potentially replace a portion of purchased fertilizer inputs with N provided via nitrogen fixation. As well, soil organic matter is an important soil component due to its role in stabilizing nutrients against loss. Organic matter can be measured via assays that fractionate it into pools that are considered to be stable, and those that are

labile and thus accessible to microbes for immediate nitrogen cycling. We were interested in the degree to which these legumes could contribute to labile organic matter pools. Objectives of this Forever Green project included 1) Quantification of amount of the nitrogen that is contributed to soils following the growth and incorporation of legume cover crops, and 2) assessment of the impact of legume cover crops on labile organic matter pools that are related to decomposition and nutrient release of the legume residue in the spring. We carried out two replicated field trials on Minnesota Research and Outreach Centers (Lamberton in SW MN, and Grand Rapids in northern MN). We learned through this project that on a good year when legumes survived the winter (2 of the 3 project years), legumes could provide 50-75 lbs of N to the soil via their biomass, effectively replacing a portion of purchased inputs of commercial fertilizer. We also learned that of this nitrogen contained in the plant tissue, 52-67% of it was derived via the biological process of nitrogen fixation. At one of our two sites (Lamberton, MN) in Y2, extractable N increased in cover cropped plots following termination relative to the control plots, indicating this nitrogen in the legume tissue was mineralizing and becoming available for uptake by cash crops such as corn, with data from Y3 still being analyzed. Potentially mineralizable nitrogen (PMN) is the amount of nitrogen converted from organic to mineral forms during a laboratory incubation and is important measure of labile organic matter pools. At Grand Rapids, PMN increased following termination in all treatments, including the bare-ground control plots. However, in Lamberton, potentially mineralizable nitrogen decreased compared to pre-termination levels. We presented the data to over 375 farmers and farmer advocates, trained three graduate students in advanced techniques in soil/plant nitrogen analysis and trained six undergraduate students, two of whom were from historically underrepresented groups in science.

Background: Agroecosystem challenges facing northern regions of the United States include short growing seasons and climate variability. Cover cropping, or the planting of non-harvested crops grown between cash crop production, is an agroecological approach that can increase ecosystem service provisioning, with benefits of erosion reduction, spatial and temporal biotic diversification, nutrient additions, and increased soil organic matter (Parr et al., 2011). Soil organic matter influences soil structure, water retention, and plant available nitrogen (N) made available through microbial mineralization processes (Giacometti et al., 2013). Leguminous cover crops increase soil N by converting atmospheric N into plant soluble nitrogen, and may also increase organic carbon (C; Marriot and Wander, 2006). Soil C can be measured via assays that fractionate organic matter into pools that are considered to be stable, and those that are labile and thus accessible to microbes for nitrogen cycling. Objectives if this Forever Green project included 1) Quantification of amount of the critical plant nutrient nitrogen that is contributed to soils following the growth and incorporation of legume cover crops, and 2) assessment of the impact of legume cover crops on biological soil quality parameters that are related to decomposition and nutrient release of the legume residue in the spring. We carried out two replicated field trials on Minnesota Research and Outreach Centers (Lamberton and Grand Rapids, MN) and evaluated three hairy vetch ecotypes, as well as two additional legumes or legume mixes of interest to growers.

Progress made toward the original goals of the project:
Treatments in 2016 (Y2) and 2017 (Y3) included: Vetch 1 (*Vicia villosa,* V1, Albert Lea Seed variety, MN 2014 #23), Vetch 2 (V2, Buckwheat Growers variety, MN 2014 #25), Red clover (*Trifolium pretense L*., CLO, Albert Lea 2014), Vetch 2 + rye (V2 Mix), Rye (*Secale cereal,* RYE), and bare ground control. Poorly performing vetch variety #3 (Welter Seed) was evaluated in 2015 (Y1), but was eliminated in Y2 and Y3 due to poor biomass production. Similarly, Austrian winter pea was eliminated as it performed poorly in Y1. We also included a rye/vetch mix (rye and vetch variety 2) to account for commonly used integration of legume cover crops. Additional treatments of with-rhizobia inoculation and without-rhizobia inoculation were imposed to determine the need for inoculation. Results showed that cover crop legumes contributed from 30-75 kg N ha yr^{-1}, with 50-70% of plant biomass N derived from the atmosphere via biological nitrogen fixation. An increase in available soil N was observed following spring cover crop termination. No differences were observed in nitrogen fixation or nodulation parameters when inoculated plants were compared to those without inoculant, suggesting that sufficient native soil rhizobia populations were present to carry out nitrogen fixation.

Treatment	**% Ndfa (se)**
Trifolium pretense L., (CLO)	60.4 (3.2)
Vicia villosa (V1)	60.7 (5.4)
Vicia villosa (V2)	52.8 (4.3)
Vicia villosa – rye (*Secale cereal*) bi-culture (V2 MIX)	67.9 (2.4)

Table 1. Mean percent of total legume plant biomass Nitrogen derived from the atmosphere (Ndfa) measured via Natural abundance isotopic analysis.

We have become increasingly interested in the potential contributions of legume cover cropping systems to increase soil organic matter (SOM) in agricultural soils of the upper Midwest, as such active fractions of SOM contribute to microbial functioning and continued cycling of soil nutrients, including N, from the decomposing cover crop residue. Potentially mineralizable nitrogen (PMN) is the amount of nitrogen converted from organic to mineral forms during a 7-day, anaerobic, laboratory incubation and subsequent KCl soil N extraction. This is an important proxy for determining the capacity of the soil to provide nitrogen in forms available to plants, especially when employing organic inputs. At Grand Rapids, both PMN and extractable soil N increased following termination in all treatments, including the bare-ground control plots. However, in Lamberton, extractable N only increased in cover cropped plots following termination relative to the control plots, and potentially mineralizable nitrogen decreased compared to pre-termination levels. The increase in extractable N across legume, non-legume, and control plots at both sites suggests a complex relationship governing N contribution to soil pools following cover crop termination, likely due to factors including tillage intensity, plant inputs, and soil moisture. The increase in soil N on legume and rye cover cropped plots relative to bare-ground plots in Lamberton suggest that this increase was due to the addition of N-rich legume and substantial residue at termination. However, at Grand

Rapids, all plots including the bare-ground control showed increased soil N following cover crop termination. Tillage required to terminate and incorporate legume residue, which occurred across all treatments, may have been responsible for soil N increases and not cover crop residue additions, as no legume biomass was contributed on control plots, yet increases were still observed. Previous research indicates tillage can serve to mineralize N protected in SOM rich soil aggregates and thus protected organic N may accumulate in the absence of tillage (Larsen et al., 2014; Six et al., 2002). The Grand Rapids site had been perennially-cropped in orchard grasses for over ten years prior to our trial, and thus may had significant organic N sequestered in protected organic matter pools. This is supported by overall greater PMN and available N at Grand Rapids compared to the Lamberton site.

Long-term sustainability and impact of the project:

- Presented to Southern Sustainable Agriculture Working Group (over 200 farmers reached and 150 surveyed) on January 29 and 30th, 2016
- Presented to Midwest Organic and Sustainable Education Service (MOSES) organic farming conference February 26, 2016 (over 150 farmers reached)
- A field day held at the Batalden Farm in April 2016 was attended by 25 growers and extension staff, despite inclement weather.
- Farmers at all events were presented the data in easy-to-understand language. Evaluations showed that farmers increased knowledge about 1) the potential of hairy vetch and red clover to increase available soil N and their N fertilizer replacement value, 2) the importance of soil organic matter in helping to cycle nutrients, and 3) the relative value of vetch, red clover and rye to contribute to soil organic matter.

Additional funds secured to continue the project:

This project provided seed data important to support a $1.5M USDA Organic Research and Extension Initiative (OREI) grant awarded to Dr. Steven Mirsky at USDA-ARS in Beltsville, MD. Our lab is a key collaborator and sub-award on this grant. Primarily a grant involving plant breeders and breeding efforts, one key project goal is to develop cold hardy varieties of vetch for Minnesota and other northern regions. Funds were given to the Grossman lab at UMN to support a graduate student to investigate the effects of cold temperatures on nitrogen fixation of newly developed vetch varieties. Our Forever Green grant provided critical seed funding to allow us to determine baseline nitrogen fixation rates over three years of field data in two regions of MN for current commercially available vetch varieties. Forever Green funding was instrumental to assess existing varieties for their N-fertilizer replacement value and nitrogen fixation capacity.

Undergraduate, graduate student and post-doc education and opportunities provided:

Three graduate students were partially supported on this Forever Green grant:

- Alex Liebman, M.S.
- Sharon Perrone, M.S.
- Daniel Raskin, M.S.

One post-doc was supported on this Forever Green grant:

- JiJY Sooksa-nguan

Six undergraduate students were trained as a part of this Forever Green grant:

- Yordanose Solomone (first generation college student, and student of color)
- Kalei Holt (student of color)
- Victoria Hoffman
- Lindsey Countryman
- Emily Swanson
- Kathleen Hobert