

Hairy Vetch and Triticale Cover Crops for N Management in Soils

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How to cite this paper: Wright, C. and Ghezzi-Haefl, J. (2020) Hairy Vetch and Triticale Cover Crops for N Management in Soils. *Open Journal of Soil Science*, 10, 244-256.
<https://doi.org/10.4236/ojss.2020.106013>

Received: March 27, 2020

Accepted: June 27, 2020

Published: June 30, 2020

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Abstract

Over-application of fertilizer to cropland adversely affects both environmental and agricultural ecosystems. This study examined whether planting a legume-based winter cover crop mix offsets fertilizer application via natural nitrogen inputs. The influence of the cover crop mixture on available nutrients was also assessed. Hairy vetch (*Vicia villosa*) and winter triticale (×triticosecale) cover crops were planted in fall and terminated in May. Soil fertility data was collected before and after planting the winter cover crop to determine the effect on fixing nitrogen and soil phosphorus, potassium and organic matter levels. Increases of soil ammonium were observed in plots with cover crop treatments. A triticale-hairy vetch cover crop mix was successful at scavenging P for future crops and appears to hold promise for long-term soil fertility benefits.

Keywords

Hairy Vetch, Triticale, Cover Crop, N Leaching, N Management

1. Introduction

Herbicide and fertilizer use have progressively risen in recent decades, increasing the concern for potential leaching to groundwater and the surrounding environment. In order to address this issue in a sustainable manner, conservation practices which reduce the use of herbicides and fertilizers are encouraged, for example the use of beneficial cover crops. Legume cover crops such as hairy vetch can serve as an effective alternative to application of synthetic herbicides and fertilizers by virtue of nitrogen fixation [1]. Species selection and residue management play significant roles in attaining maximum benefits from cover crops.

A clear benefit of a legume cover crop is its ability to convert atmospheric ni-

trogen (N_2) to plant-available nitrogen in the form of ammonium (NH_4^+). The extra labor required for cultivating cover crops can be a disincentive for farmers, however. Fertilizer application is a simple and convenient method to provide required plant nutrients to the soil. In a 2007 survey conducted on farmers in the Corn Belt (Midwestern U.S.), only 11% of respondents stated they had used cover crops in the last five years. Most farmers that decided against the use cover crops expressed concerns over cost and incomplete understanding of the practice [2]. Some studies found that cover crops decreased available nitrogen for the growing season [3]; however, others have found that soil nitrogen levels can be addressed by use of a legume cover crop [4] [5]. Brainard *et al.* (2011) observed that legumes like hairy vetch supply nitrogen to cash crops such as corn [4]. In addition to nitrogen, legumes can increase levels of other macronutrients like phosphorus and sulfur by increasing soil organic matter content [6].

Previous studies have revealed elevated concentrations of available nitrogen in soil plots with high quantities of above-ground biomass [7]. These studies examined the effects of cover crops on available soil nitrogen [7]. In two out of three project years, available nitrogen levels increased significantly in plots with cover crops. This suggests cover crops are effective at scavenging nitrogen at a soil depth of up to 0.9 meters [7] [8]. These findings also indicate that nitrogen mineralized from cover crop biomass is not available until later in the growing season due to the time required for residue decomposition following tillage [8].

An additional consideration when choosing a cover crop is the effective C:N ratio of the decomposing cover crop tissue. The closer the C:N ratio of the biomass to 25:1, the more rapidly tissue can be mineralized to provide available nutrients for subsequent crops. Various studies [3] [8] [9] [10] evaluated the combination of hairy vetch with popular cover crops such as rye, wheat or oats, indicating a mix with a legume and grass was favorable for rapid decomposition and release of nutrients. These studies also indicated the additional benefit of a grass-legume mix for mining nutrients from deeper portions of the soil profile [3] [8] [9] [10]. A new cover crop option, triticale, is a hybrid produced by crossing wheat and rye; this grass offers a promising yet little-studied option for mixing with a legume like hairy vetch.

The current study seeks to showcase cover crops as useful tools for farmers seeking sustainable cropping methods that enhance soil fertility. *The objectives of this study are to determine if planting a hairy vetch-triticale cover crop mix can offset the application of N fertilizer. Examining soil nutrient levels over the course of the project will demonstrate whether the cover crop adds or removes nutrients from soil. We hypothesize that a hairy vetch-triticale cover crop mix will increase available soil N pools for future cash crops.*

2. Materials and Methods

2.1. Study Site

The study was conducted in northeastern Delaware County in Albany, Indiana

at the Juanita Hulst Environmental Learning Center (85°13'45.1"W, 40°18'40.2"N). The site, measuring 1.54 hectares (3.8 acres), was fallowed for two years prior to the study and historically used in a corn-soybean rotation. The site consists of three soil types (**Figure 1**): Blount silt loam (0% - 2% slopes), Glynwood silt loam (1% - 4% slopes), and Glynwood-Mississinewa clay loam (6% - 12% slopes). The soils range from moderately to poorly drained; there is no subsurface drainage onsite. All soils are subject to surface ponding during heavy rain events.

2.2. Hairy Vetch and Triticale Winter Cover Crop Mix

Following corn harvest in Fall 2017, the field was disked. A cover crop mixture of triticale and hairy vetch was broadcast seeded at 168 kg/ha (150 lb/acre) in mid-September 2017. The mix was chosen based on NRCS planting rates as 20% hairy vetch and 80% triticale [11]. Triticale was seeded at 142 kg/ha (127 lbs/acre), slightly lower than the typical seeding rate, to allow for the hairy vetch to establish better and encourage nitrogen fixation. Hairy vetch was seeded at 39 kg/ha (35 lbs/acre) using an ATV-mounted broadcast seeder. In May 2018 the cover crop was sprayed with the herbicide glyphosate and residue was left on the field.

2.3. Study Site and Plot Design

The 1.54 hectares (3.8 acres) of agricultural land was divided into 16 plots (**Figure 1**). Each plot measured 0.1 hectares (0.23 acres). One control plot for each of the three soil types was included. Control plots were cultivated to corn only during the growing season, with fallow during winter. Treatment plots were cultivated to corn and the hairy vetch-triticale mix for the duration of the study.



Figure 1. Site map showing soil types (text), plots (black lines) and soil sample (black x's) locations.

To ensure that cover crops did not invade control zones, the zones were sprayed with glyphosate. Five plots (**Figure 1**) were eliminated from the study due to water inundation. A 6.1 m-buffer (20-foot buffer) was established between the corn and surrounding tree line on the north, east, and south side of the field to reduce shading of plots.

2.4. Soil Sampling

Soil samples were collected in the control and treatment plots in early fall, after winter cover crop termination and after harvesting corn. Samples were collected from each plot (indicated by “x” on **Figure 1**) with a stainless-steel soil coring tool to a depth of 12 inches. As recommend by the NRCS, soil cores were taken to a depth of 12 inches due to the potential mobility of nitrogen in the soil profile. Soil samples were stored at -4°C until they were brought to the lab for analysis (within 24 hours). Samples were dried at 105°C for 24 hours, sieved through a 2-mm mesh sieve, and aggregated into composite samples.

2.5. Soil Nutrient Analysis

Soil pH was measured in a 50:50 soil:solution slurry using a digital pH meter (Horiba D-52, United Kingdom). The available phosphorus content was determined using the Strong Bray method (FIALab Spectrophotometer). Organic matter was determined using loss on ignition. Soil nitrate and ammonium were determined using a KCl extraction solution with a cadmium reduction column (LACHAT – QuikChem FIA + 8000 series, HACH). All samples were analyzed by A&L Great Lakes Laboratory in Fort Wayne, Indiana. All testing was conducted in compliance with the 2011 Recommended Chemical Soil Test Procedures for the North Central Region No. 221.

2.6. Herbicide Application

The field received a mixture of Round-Up™ and 2-4-D after mowing the winter cover crop. Though not desired, herbicide application was necessary due to weed pressure. The first application was in late June 2018 via ATV equipped with boom arms. Continued weed pressure after no-till planting of corn required an additional application of herbicide around the V-2 stage using Me Too™. The final application used Impact™ at the V-4 stage. Soybean oil was used as a surfactant in all applications.

2.7. Statistical Analysis

Statistical analysis for yield and soil nutrient data from the control (without cover crop) and treatment (with cover crop) plots was analyzed using ANOVA to determine any statistical differences ($p < 0.05$) [12].

3. Results and Discussion

There were no statistically significant differences ($p > 0.05$) between control and

treatment plots. Multiple cover crop studies indicate that statistical differences require years of study due to the influence of various environmental factors [5] [13]. Despite a lack of statistical difference, notable differences in data were observed (Table 1 and Table 2; Figures 2-7).

3.1. Total N

Table 1 shows nutrient levels in year one of the study (2017), while Table 2 shows nutrient levels available in year two (2018). Figure 2 showcases total N, which is nitrate and ammonium data combined for 2017 and 2018. Overall, total N content increased between 2017 and 2018 (Table 1). This implies that the legume cover crop added nitrogen to soil, despite a lack of a statistically significant difference (Figure 2).

The lack of significant difference between the two treatments also indicates that the cover crop did not remove substantial quantities of soil N. This highlights that legume cover crops will not remove excessive nitrogen, and the potential lack of evidence of nitrogen removal in the legume plots indicates that plants fix sufficient nitrogen for their own needs even if the cash crop may not benefit in the short-term. In contrast, other studies have suggested that hairy vetch does not serve as an adequate replacement for N fertilizer, *i.e.*, it does not generate adequate N for subsequent cash crops in short-term studies [10]. Other research indicates that chemically-terminated hairy vetch provides little to no mineralizable N as opposed to non-chemically terminated vetch, even after

Table 1. Average Soil Nutrients 8/22/2017.

Plot	Sampling Date	Organic Matter (%)	Phosphorus (ppm)	Potassium (ppm)	NO ₃ (ppm)	NH ₄ (ppm)
Control 1	8/22/2017	3.2 ± 0.26	26 ± 10.41	91 ± 2.31	5 ± 1.15	3 ± 7.02
Glynwood-Mississinewa Clay Loam Plots	8/22/2017	3.1 ± 0.27	14 ± 4.64	96.2 ± 9.15	8 ± 0.45	3.6 ± 0.89
Control 2	8/22/2017	2.9 ± 0.40	40 ± 13.87	86 ± 10.07	13 ± 3.21	3 ± 4.00
Blount Silt Loam Plots	8/22/2017	3 ± 0.42	19 ± 8.29	99.8 ± 19.03	3 ± 0.82	3.5 ± 1.00
Control 3	8/22/2017	2.7 ± 0.47	46 ± 20.22	65 ± 32.00	5 ± 1.15	4 ± 2.52
Glynwood Silt Loam Plots	8/22/2017	3.3 ± 0.53	20 ± 13.39	81 ± 13.09	3.5 ± 10.03	8 ± 0.58

Table 2. Average Soil Nutrients 7/11/2018.

Plot	Sampling Date	Organic Matter (%)	Phosphorus (ppm)	Potassium (ppm)	NO ₃ (ppm)	NH ₄ (ppm)
Control 1	7/11/2018	2.7 ± 0.26	46 ± 10.41	87 ± 2.31	5 ± 1.15	17 ± 7.02
Glynwood-Mississinewa Clay Loam Plots	7/11/2018	2.3 ± 0.07	13 ± 5.47	104 ± 9.30	4 ± 1.00	5.5 ± 3.46
Control 2	7/11/2018	2.1 ± 0.40	13 ± 13.87	106 ± 10.07	7 ± 3.21	7 ± 4.00
Blount Silt Loam Plots	7/11/2018	2.1 ± 0.13	10.3 ± 2.22	107.5 ± 10.34	2.8 ± 0.50	10.5 ± 0.57
Control 3	7/11/2018	2 ± 0.47	15 ± 20.22	129 ± 32	3 ± 1.15	7 ± 2.52
Glynwood Silt Loam Plots	7/11/2018	2.4 ± 0.21	18 ± 5.35	121.3 ± 18.19	3.8 ± 1.50	13 ± 2.58

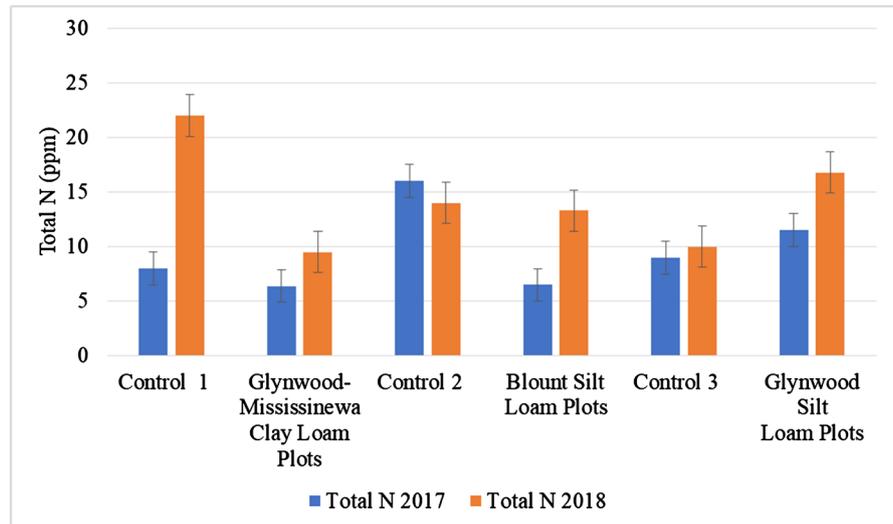


Figure 2. Average 2017 and 2018 Total N (Total N here is measured nitrate and ammonium) by soil type and treatment.

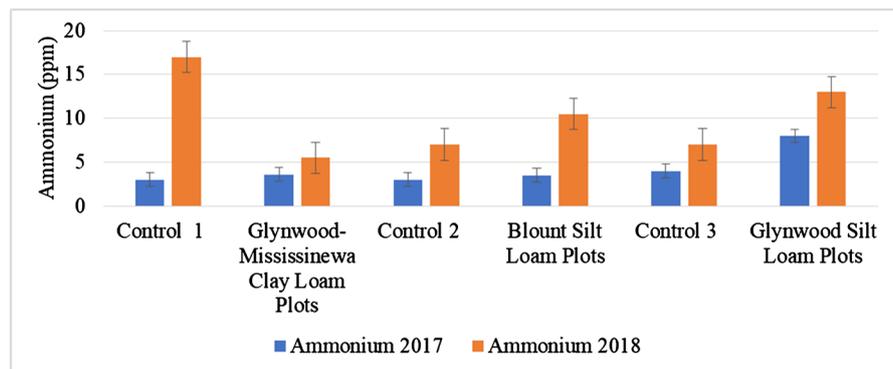


Figure 3. Average 2017 and 2018 ammonium by soil type and treatment.

several years [14].

3.2. Ammonium

Soil ammonium levels increased notably from 2017 to 2018 for most plots (Figure 3). In most cases, increases were greater for treatment plots compared to controls with the exception of Control 1 (Figure 3). The greatest increases were demonstrated by the Blount and Glynwood plots (Figure 3).

The control plots experienced increased ammonium concentrations (Figure 3); these values were greater than expected for bare soil, indicating possible mineralization from residual organic matter [7]. Control plots may also have higher values because no cover crops were extracting nutrients from the soil. However, this likely means those nutrients were lost to leaching/erosion after transformation to nitrate, as shown by lower 2018 nitrate values for control plots (Figure 4). Nitrate is usually lost via leaching when cover crops are not employed to sequester it. Liebig *et al.* had similar experiences with control plot nitrogen values being higher than those for many of the test sites [7].

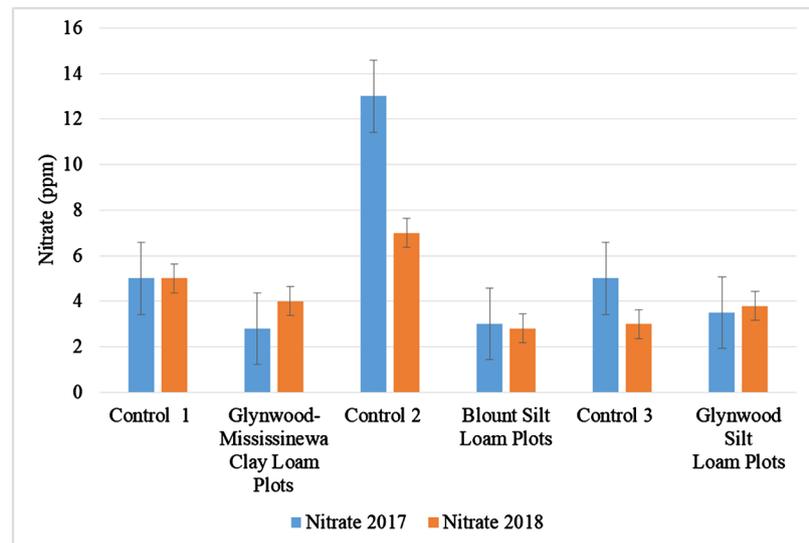


Figure 4. Average 2017 and 2018 nitrate by soil type and treatment.

An alternative explanation is a lack of conversion of soil N to nitrate (**Table 1** and **Table 2, Figure 4**) by nitrifying bacteria [14]. This is evidenced by the substantial concentration of NH_4^+ in the second year data, where nitrate concentrations changed minimally (**Table 2** and **Figure 3** and **Figure 4**). There was no significant difference ($p > 0.05$) between control plots and cover crop treatments for NH_4^+ ; regardless, however, cover crop treatments experienced a greater increase in NH_4^+ concentration when compared to control plots (**Table 2**). On average, the hairy vetch input 16.16 lb N/A of NH_4^+ . Other studies found hairy vetch to release from 40 to 180 lbs/N per acre per year, with some as high as 385 lb N/A [5] [13]. Those studies were conducted over 10 years and used hairy vetch as the sole winter cover crop. The current experiment used a triticale and hairy vetch mix, which might explain why nitrogen input was relatively low. Other studies have indicated that a grass-legume mix was successful at inputting N to soil over longer periods [3] [8] [9].

The lack of statistical difference between control and test plots reveals that plots grown to hairy vetch do not deplete available ammonium when compared to control plots (**Figure 3**). Overall, there was an increase in ammonium concentration between 2017 and 2018 (**Table 1** and **Table 2, Figure 3**). This indicates that hairy vetch was able to fix nitrogen to the soil (**Figure 3**).

3.3. Nitrate

In the plots associated with the Glynwood-Mississinewa soil, nitrate concentrations increased from 2.8 to 4 mg/kg (**Table 1** and **Table 2, Figure 4**, respectively). There was little change in nitrate concentrations in the associated control plot. This suggests that the cover crop helped prevent nitrate losses via leaching and potentially increased nitrate concentrations (**Figure 4**). In the plots associated with the Blount soil, nitrate concentration remained relatively constant (**Table 1** and **Table 2, Figure 4**); however, the initially high concentration for

the associated control plot indicates extensive nitrate leaching between year one and two, thus demonstrating the potential of the cover crops to retain nitrate onsite when compared to the Blount treatment plot (**Figure 4**). In the plots associated with the Glynwood soil and Control 3, nitrate concentration decreased more in the control from year one and two than in the treatment plot (**Figure 4**). This indicates that the presence of the cover crop in the Glynwood plots helped reduce nitrate leaching between 2017 and 2018 (**Figure 4**).

Soil NO_3^- may have been lost to denitrification due to the warm, moist, field conditions [15]. Indiana experienced substantial rain events and had an unusually warm year, especially between the first and second sampling years. This, combined with a water table located within 6 to 24 inches of the surface, left the soil in all plots inundated. The field had no subsurface tile drainage which resulted in surface ponding and field conditions favorable for denitrification. Also, since nitrate is water-soluble and the field is on a gentle slope, some nitrate could have been lost in runoff water. This would explain the high concentration observed in the second sampling date and the low NO_3^- concentrations observed in all plots (**Table 2** and **Figure 4**). The heavy rain events, coupled with aquic soil conditions during the study potentially led to the nitrate losses via denitrification, leaching, and/or runoff [16].

Plots located on the southern half of the field had higher baseline NO_3^- concentrations (**Table 1** and **Table 2**, **Figure 4**). Despite a lack of statistical significance, there appears to be a difference suggested in nitrate values (**Table 1** and **Table 2**, **Figure 4**). This could be attributed to the presence of residual fertilizer from previous years in the control zones, which experience lower biological activity and organic matter decomposition due to limited plant growth during the study. This effect could have resulted in more residual fertilizer in the controls, and skewed results.

3.4. Phosphorus

The soil phosphorus values from 2017 and 2018 were significantly different ($p = 0.039$) (**Table 1** and **Table 2**). In one soil type especially, smaller available pools of P were noted after the cover crop (**Figure 5**). The Blount plots experienced a decrease in P concentration from 2017 and 2018, with values of 19 and 10.3 mg/kg respectively (**Table 1** and **Table 2**, **Figure 5**). The control soil associated with this plot (*i.e.*, no cover crop) had Bray P values of 26 and 46 mg/kg for 2017 and 2018 (**Table 1** and **Table 2**, **Figure 5**). This would indicate that more available P occurs in this soil type when it is not cultivated with this cover crop mix, which has significant implications for the subsequent cash crop (**Figure 5**). This trend did not occur in the other soil types; the Glynwood-Mississinewa had a Bray P value of 14 and 13 mg/kg in 2017 and 2018, respectively (**Table 1** and **Table 2**, **Figure 5**). The Glynwood plots indicated Bray P values of 20 and 18 for 2017 and 2018, respectively (**Table 1** and **Table 2**, **Figure 5**). This might indicate that cover crop mixes with hairy vetch and triticale may not affect phosphorus

levels in these soils; however, when compared to their corresponding control plots a different trend is observed. The control plots for the Glynwood-Mississinewa had P values of 40 and 13 mg/kg, while those for the Glynwood were 46 and 15 mg/kg P for 2017 and 2018, respectively (Table 1 and Table 2, Figure 5). The 2018 values were markedly lower for the control plots, suggesting that in the absence of the hairy vetch-triticale cover crop.

P concentrations decreased by nearly three times (Table 1 and Table 2, Figure 5). This suggests that the hairy vetch and triticale mix increases the availability of P in these soil types, likely due to foraging by triticale roots lower in the soil profile and bringing it up to the rooting zone [17].

In a study conducted from 2004 to 2007, Idaho farmers found that triticale was effective at foraging and removing phosphorus. They found that triticale can remove up to 0.5 lb/acre daily, especially if the plant reaches flowering stage [17]. This could possibly explain why plots with the cover crop had noticeably lower P concentrations. Analysis of plant tissue samples would have helped determine if this were the case. Finally, the additional presence of hairy vetch in this study indicates that a lower population count of triticale in certain soil types may result in greater deposition of P from decomposition of cover crop biomass for the following cash crops.

3.5. Potassium

At first glance, it would appear that the cover crop mix imparted a positive effect on potassium concentration in the treated plots; however, the control findings negate this prospect (Table 1 and Table 2, Figure 6). The Glynwood-Mississinewa plots had K concentrations of 96.2 and 104 mg/kg in 2017 and 2018, respectively (Table 1 and Table 2, Figure 6). The associated control K values ranged from 91 to 86 mg/kg for 2017 and 2018, respectively (Table 1 and Table 2, Figure 6). A similar trend occurred in the Blount plots where K concentrations ranged from

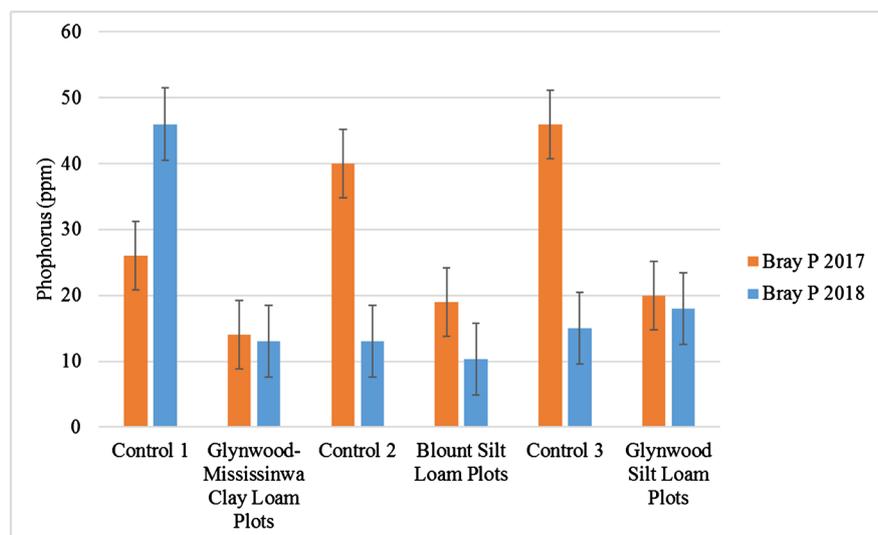


Figure 5. Average 2017 and 2018 phosphorus by soil type and treatment.

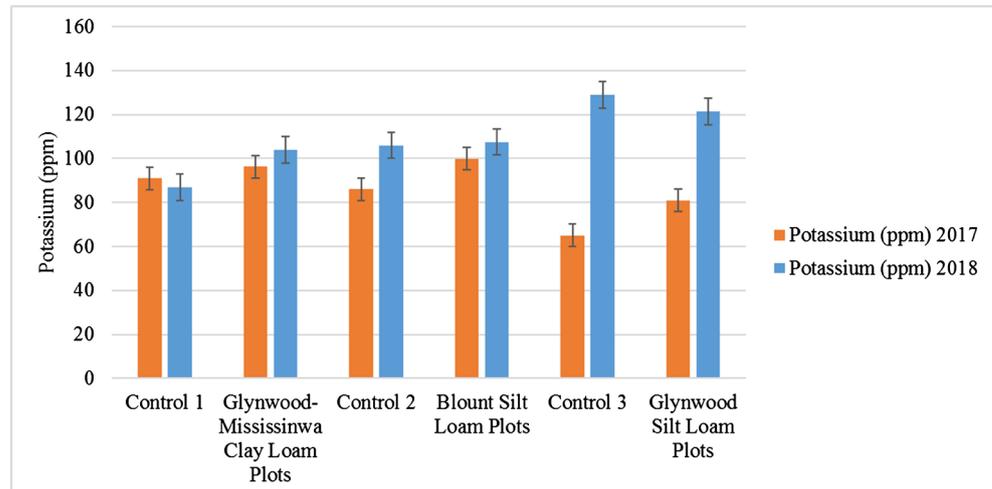


Figure 6. Average 2017 and 2018 potassium by soil type and treatment.

99.8 to 107.5 mg/kg in 2017 and 2018, respectively (Table 1 and Table 2, Figure 6). The associated control plots ranged from 86 to 106 mg/kg K in 2017 and 2018, respectively (Table 1 and Table 2, Figure 6). In the Glynwood plots K concentrations were 81 mg/kg in 2017 and increased to 121.3 mg/kg in 2018 (Table 1 and Table 2, Figure 6). The K concentrations in the associated control plots increased from 65 mg/kg in 2017 to 129 mg/kg in 2018 (Table 1 and Table 2, Figure 6). Many crop plants are known for luxury potassium consumption, which may account for the erratic potassium trends in these soils. Additionally, flooding of the plots could have contributed to potassium leaching, which is usually greater in sandier soils, but can still occur in heavier textures with excessive water inundation [18].

Potassium is an essential plant nutrient; the cash crop would be adversely affected if K was depleted by the cover crop. Hairy vetch can be effective at accumulating potassium for storage in plant tissue [19]. Studies indicate a substantial release of potassium when overwintering hairy vetch was terminated in late spring [19]. The hairy vetch in this study was terminated after May 1st and might explain why cover crop plots had a higher K concentration when compared to control zones. Normally, the low C:N ratio of hairy vetch would provide rapid breakdown and release of nutrients [5]. Another explanation could be that soil samples were collected before complete mineralization of cover crop tissue, and that K additions could occur at later dates when cover crop tissue are further decomposed.

3.6. Organic Matter

There were no significant differences ($p < 0.05$) in organic matter content resulting from the use of the cover crop mix. In the Glynwood-Mississinewa plots organic matter content was 3.1 to 2.3 percent in 2017 and 2018, respectively, with control values at 3.2 and 2.7 percent for 2017 and 2018, respectively (Table 1 and Table 2, Figure 7). While individual values did not increase between years

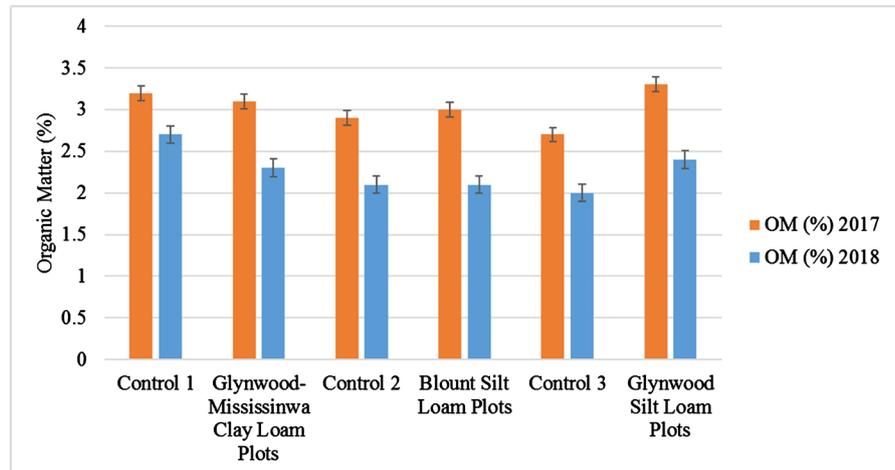


Figure 7. Average 2017 and 2018 organic matter for all soil types and treatments.

of study for individual plots, the test plots are not markedly different from the associated control plots either (Table 1 and Table 2, Figure 7). Similarly, the Blount plots had organic matter contents of 3 and 2.1 percent, with the associated control plot having 2.9 and 2.1 percent for 2017 and 2018, respectively (Table 1 and Table 2, Figure 7). It is possible that additional years of study would be needed to observe the mineralization of C to a significant value.

The Glynwood plots had organic matter contents of 3.3 and 2.4 percent, with control plots having organic matter contents of 2.7 and 2.0 percent for 2017 and 2018, respectively (Table 1 and Table 2, Figure 7). In this soil, increases in organic matter content were not observed between years within the same treatment; however, control organic matter values are notably lower than in the corresponding test plots. This indicates that for the Glynwood treatment, the use of the cover crop may have contributed to organic matter additions (3.3 and 2.4 percent for 2017 and 2018, respectively) compared to plots without cover crops (2.7 and 2 percent for 2017 and 2018, respectively; Table 1 and Table 2, Figure 7).

Organic matter addition to soil is a crucial soil health indicator [18]. Control zone increases in organic matter content can likely be attributed to corn residue remaining after harvest. Organic matter requires substantial time to accumulate and will likely increase with minimal tillage or no-till in conjunction with cover crops. Hairy vetch has a C:N ratio of 8:1-15:1, which results in near-complete decomposition [5]. This results in no long-term soil organic matter buildup. Triticale had a C:N ratio of 13:1 to 21:1 and would take longer to decompose [20]. This may likely be the cause of the increased organic matter levels, as the plant biomass would be more persistent. Long-term cover crop studies indicate more substantial changes [21].

4. Conclusion

Hairy vetch was tested as a winter cover crop to examine its ability to fix nitrogen and affect the availability of macronutrients, with the intention of offsetting fertilizer application. The findings indicate the ability for a cover crop of hairy

vetch and triticale to increase available soil nitrogen, phosphorus and organic matter levels compared to control plots where no cover crops were grown. There was not sufficient, however, to completely substitute for artificial inputs of nitrogen. Except for the case of phosphorus, the cover crop did not significantly deplete nutrients when compared to control zones. This indicates that hairy vetch used in the cover crop mix is a viable option to help offset nitrogen inputs while not depleting available macronutrients for the following cash crop. Future studies must address nutrient contents in plant tissue samples to demonstrate whether the cover crop decreases nitrate leaching. All soil-based studies should be conducted long-term, so continued study on this cover crop is encouraged to assess its contribution to more sustainable agricultural practices.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Hartwig, N. and Ammon, H. (2002) Cover Crops and Living Mulches. *Weed Science Society of America*, **50**, 688-699. [https://doi.org/10.1614/0043-1745\(2002\)050\[0688:AIACCA\]2.0.CO;2](https://doi.org/10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2)
- [2] Singer, J., Nusser, S. and Alf, C. (2007) Are Cover Crops Being Used in the U.S. Corn Belt? *Journal of Soil and Water Conservation*, **62**, 353-358.
- [3] Kuo, S. and Jellum, E. (2000) Long-Term Winter Cover Cropping Effects on Corn (*Zea mays L.*) Production and Soil Nitrogen Availability. *Biology Fertility Soils*, **31**, 470-477. <https://doi.org/10.1007/s003740000193>
- [4] Brainard, D., Bellinder, R. and Kumar, V. (2011) Grass-Legume Mixtures and Soil Fertility Affect Cover Crop Performance and Weed Seed Production. *Weed Science Society of America*, **25**, 473-479. <https://doi.org/10.1614/WT-D-10-00134.1>
- [5] Clark, A. (2007) Hairy Vetch for Cover Cropping in Organic Farming. National SARE Outreach Handbook Series Book 1(1), 9th Ser., 1-10. <https://articles.extension.org/pages/18570/hairy-vetch-for-cover-cropping-in-organic-farming>
- [6] Villiamil, M., Bollero, G., Darmody, R., Simmons, F. and Bullock, D. (2006) No-Till Corn/Soybean Systems Including Winter Cover Crops: Effects on Soil Properties. *Soil Science Society of America Journal*, **70**, 1936-1944. <https://doi.org/10.2136/sssaj2005.0350>
- [7] Liebig, M.A., Hendrickson, J.R., Archer, D.W., Schmer, M.A., Nichols, K.A. and Tanaka, D.L. (2015) Short-Term Soil Responses to Late-Seeded Cover Crops in a Semi-Arid Environment. *American Society of Agronomy*, **107**, 2011-2019. <https://doi.org/10.2134/agronj15.0146>
- [8] Clark, A.J., Morris Decker, A. and Meisinger, J.J. (1994) Seeding Rate and Kill Date Effects on Hairy Vetch-Cereal Rye Cover Crop Mixtures for Corn Production. *Agronomy Journal*, **86**, 1065-1070. <https://doi.org/10.2134/agronj1994.00021962008600060025x>
- [9] Kuo, S. and Sainju, U.M. (1998) Nitrogen Mineralization and Availability of Mixed Leguminous and Non-Leguminous Cover Crop Residues in Soil. *Biology and Fertility of Soils*, **26**, 346-353. <https://doi.org/10.1007/s003740050387>

- [10] Utomo, M., Frye, W.W. and Blevins, R.L. (1990) Sustaining Soil Nitrogen for Corn Using Hairy Vetch Cover Crop. *Agronomy Journal*, **82**, 979-983. <https://doi.org/10.2134/agronj1990.00021962008200050028x>
- [11] NRCS (2011) Cover Crop Planting Specification Guide. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1081555.pdf
- [12] SPSS (2009) Statistical Software. IBM.
- [13] Townshend, W. (1994) No-Tilling Hairy Vetch into Crop Stubble and CRP Acres. SARE Project Report. <https://projects.sare.org/project-reports/fnc93-028/>
- [14] Peoples, M.B., Herridge, D.F. and Ladha, J.K. (1995) Biological Nitrogen Fixation: An Efficient Source of Nitrogen for Sustainable Agricultural Production? *Plant and Soil*, **174**, 3-28. <https://doi.org/10.1007/BF00032239>
- [15] Johnson, C., Albrecht, G., Ketterings, Q., Beckman, J. and Stockin, K. (2005) Nitrogen Basics—The Nitrogen Cycle. <http://cceonondaga.org/resources/nitrogen-basics-the-nitrogen-cycle>
- [16] USDA (2014) Soil Nitrate. <https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=stelprdb1237387>
- [17] Brown, B. (2009) Nitrogen Timing for Boot Stage Triticale Forage Yield and Phosphorus Uptake. *Western Nutrient Management Conference* 2009, Vol. 8, Salt Lake City. <http://www.extension.uidaho.edu>
- [18] Wiel, R.R. and Brady, N.C. (2017) *The Nature and Properties of Soil*. Pearson Education, Columbus.
- [19] Duiker, S. and Curran, W. (2010) Hairy Vetch as a Crop Cover. *Penn State Extension*, 71, 1-4. <https://extension.psu.edu/hairy-vetch-as-a-crop-cover>
- [20] Ketterings, Q., Kingston, J., McIlvennie, S., Long, E., Godwin, G., Gami, S. and Czymmek, K. (2011) Cover Crop Carbon and Nitrogen Content. *What's Cropping Up*, **21**, 2-4.
- [21] Sapkota, T.B., Mazzoncini, M., Barberi, P., Antichi, D. and Silvestri, N. (2012) Fifteen Years of No Till Increase Soil Organic Matter, Microbial Biomass and Arthropod Diversity in Cover Crop-Based Arable Cropping Systems. *Agronomy for Sustainable Development*, **32**, 853-863. <https://doi.org/10.1007/s13593-011-0079-0>