Best Management Practices (BMP) Verification and Demonstration 2015-2017 Project _2803:
4R Approach for Utilizing Soil Amendments

Final Report

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1.0 Introduction

4R nutrient stewardship practices promote the use of the right nutrient source at the right rate, time and placement to improve nutrient use efficiency and protect water quality. Municipal organic amendments are a source of nutrients for crop growth. Management of the nitrogen (N) and phosphorus (P) nutrients from municipal organic amendments was investigated to help reduce nutrient losses and direct BMPs.

The objective of this project was to assess the use of 4R nutrient stewardship practices (the use of the right nutrient source at the right rate, time and placement to improve nutrient use efficiency and protect water quality) in the growing and non-growing seasons to improve the use efficiency and fate of N and P from applied municipal organic amendments. Furthermore, the project investigated soil organic matter and soil health changes in response to the use of municipal organic amendments combined with cover crops.

2.0 Methods

An on-farm field study approach investigated the utilization of two sources of non-manure organic amendments. A biosolid was a LysteGro CFIA registered fertilizer product (processed biosolid) and a digestate was a Bio-En Power Inc. CFIA registered fertilizer from aerobically digested food wastes. Field trials were established at 3 locations in North Wellington, all within 4km of each other near Arthur, ON. The experimental design was a side-by-side strip trial plot with three replicated subplots of 10m length. Plot width was established based on the application equipment width. Application of the organic amendments was done with a liquid tanker with an injector bar and 5 injectors spaced 30cm apart (Fig. 1-4). The plot width at the sites was therefore 7.2m (6 corn rows x 75cm row spacing).

Organic amendment utilization was evaluated at two application timings: in-season side-dress application into V4-6 leaf stage corn in year 1 (2016) and year 2 (2017) and during the non-growing season post winter wheat harvest into a cover crop (fall 2016). The rate of application of treatments was based on the equivalent available nitrogen recommendation for the site conditions and yield goal using the OMAFRA NMAN3 software program. The N fertilizer was an incorporated side-dress application. Study treatments were associated with the timing of amendment application.
Growing season treatments:

1. Digestate + nitrification inhibitor (Dni)
2. Biosolid + nitrification inhibitor (Bni)
3. Digestate only (D0)
4. Biosolid only (B0)
5. No in-season Nitrogen addition (Check)
6. Digestate + N fertilizer (D+N)
7. Biosolid + N fertilizer (B+N)
8. N fertilizer only (0+N)

Non-growing season treatments:

1. Digestate + nitrification inhibitor (Dni)
2. Biosolid + nitrification inhibitor (Bni)
3. Digestate only (D0)
4. Biosolid only (B0)
5. No organic amendment + cover crop 1 (0cc1)
6. Digestate + cover crop 1 (Dcc1)
7. Biosolid + cover crop 1 (Bcc1)
8. No organic amendment + cover crop 2 (0cc2)
9. Digestate + cover crop 2 (Dcc2)
10. Biosolid + cover crop 2 (Bcc2)

The application tanker was calibrated before the plot application using swine manure. A flow meter was used during the application of the materials to record actual application rates. For the inhibitor treatments, the product was added to the tanker and agitated after the other amendment applications.

Figures 1-4: 1. Side-dress application of amendment Site 2, 2. Transfer of digestate to tanker applicator, 3. post application plot strips Site 1, 4. application into cover crops and winter wheat stubble.

Sampling of each amendment was completed on the day of application from the tanker once agitated. Samples were delivered to the lab within 24 hours for standard manure analysis parameters (dry matter, nutrients, organic matter, pH, EC).

Composite soil samples were taken regularly after application using subsamples from across the full inter-row (Fig. 5) for each sub-plot and at 3 different locations per sub-plot (18 cores total per sub-plot). Core samples to 15cm were analyzed for standard nutrients and water extractable phosphorus (WEP). Additional cores were taken to a 30cm depth for soil nitrogen analysis. The soil samples were kept cool until delivery to the lab within 24 hours.

Figure 5: Soil sampling transect of a corn inter-row

Soil sampling of the plots was carried out to deliberately avoid the centre of the treatment application trench lines where the amendments were incorporated in order to be representative of the majority of the soil.

Tissue samples were taken from the corn plots at time of tasseling each year for lab nutrient analysis. The ear leaf was removed from 10 plants within the middle 2 rows of the plot.

Yield comparisons were done of the corn plots by hand harvesting cobs from each subplot. Cobs from 6m of the centre 2 rows were removed and weights taken from 10 randomly selected cobs before and after oven drying and from shelled grain to determine moisture and standard yield. Combine harvest and weigh wagon of treatment strips were also completed to confirm differences (Fig. 6, 7)

Figure 6: Combine harvest of corn plots 2017

Figure 7: Weigh wagon use for corn grain yield 2016

Biomass measurements were taken from the cover crops by removing the above ground plants from a $1m^2$ square area in each subplot (Fig 8, 9). Harvests were conducted in October 2016 and again in November 2016. Plant samples were weighed, dried and reweighed before submission to the lab for analysis of the standard forage parameters: crude protein, nutrients, dry matter, etc.
Replicated treatment differences were statistically analyzed using ANOVA at $p<0.05$.

Figure 8: Cover crop biomass fall harvest 2016

Figure 9: Cover crop 1m^2 harvest area

Temperature and precipitation data were monitored on-site continuously from spring to fall using a HOBO temperature sensor, tipping bucket rainfall monitor and data logger.

3.0 Observations and Results

3.1 Growing Season Use – Year 1

3.1.1 Site 1 Observations

The location of Site 1 (Fig 10) was a corn field with uniform Listowel Silt Loam soil and nearly flat topography of 1% slope.

Figure 10: 2016 Site 1 corn plot approximate location 2016

Year 1 Growing Season Activities

1. Corn planted: early May 2016
2. Treatment application: *June 9, 2016* at the V6 stage; samples taken of amendments for laboratory analysis (Table 1). Treatment details and nutrient additions are shown in Table 2.
3. Soil sampling 2016:
   a. *June 8* (pre application) and *June 15* (1 week post application): basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N and NH_4-N (12in:lab analysis and scanner), water extractable P (WEP; 6in), soil moisture (6in)
   b. *June 22, July 14, July 11, July 18*: NO_3-N and NH_4-N (12inin:lab analysis and scanner), water extractable P (WEP; 6in), soil moisture (6")
   c. *August 30*: NO_3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)
   d. *November 10*, post harvest: basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N (12in:lab analysis and scanner), water extractable P (WEP; 6in), soil moisture (6in)
4. Tissue analysis:
   a. *July 29* (at silking; % N, P, K, Mg, Ca)
5. Sub-plot hand sampling for yield and grain analysis
   a. *October 19* (grain weights)
6. Combine harvesting
   a. *November 4*; harvested corn weights from all plots and grain analyses (moisture, crude protein, Ca, P, K, Mg, Na)

Site 1 Nutrient Amendment Information

Table 1: Amendment analysis			
Date: June 9, 2016	**Amendment**		
Sample ID:	Digestate	Biosolid	Swine
Dry Matter %	3.19	12.25	2.97
EC (ms/cm)	20.1	15.58	16.48
Nitrogen (%)	0.4	0.55	0.48
Ammonium - N (ppm)	3230	5390	2720
Phosphorus (%)	0.07	0.39	0.09
Potassium (%)	0.08	0.19	0.14

Table 2: 2016 Corn Plot Application Treatment Details

	Dni	Bni	D0	B0	Check	D+N	B+N	0+N
Product	digestate	biosolid	digestate	biosolid	0	digestate	biosolid	0
N inhibitor	yes	yes	0	0	0	0	0	0
Rate (imp gal)	2500	2000	2500	2000	0	1600	1000	0
Number of rows	6	6	6	6	6	6	6	6

Product N applied (lb/ac)	84.8	108.4	84.8	108.4	0	54.2	33.9	0
Starter N rate (lb/ac)	18	18	18	18	18	18	18	18
Broadcast N rate (lb/ac)	0	0	0	0	30.6	30.6	30.6	92
Total N rate (lb/ac)	102.8	126.4	102.8	126.4	48.6	102.8	82.5	110
Product P applied (lb/ac)	15	127	15	127	0	9.6	36	0
Starter P rate (lb/ac)	20	20	20	20	20	20	20	20
Total P rate (lb/ac)	35	147	35	147	20	29.6	56	20
Product K applied (lb/ac)	21	41	21	41	0	13	20.5	0
Starter K rate (lb/ac)	20	20	20	20	20	20	20	20
Total K Rate (lb/ac)	41	61	40	61	20	33	40.5	20

Weather Data

Weather in 2016 (Fig. 11) became droughty during the middle of the growing season. Precipitation accumulation levels were below normal in the 2 months after application of 50.4mm. Long-term average normals for June and July are 83.8mm and 89.2mm, respectively for Fergus, Ontario.
Soil diffusion of soluble nutrients would have been low and treatment effects were possibly muted, especially for nitrogen which relies on soil water for conversion to plant available nitrogen and movement to plant roots.

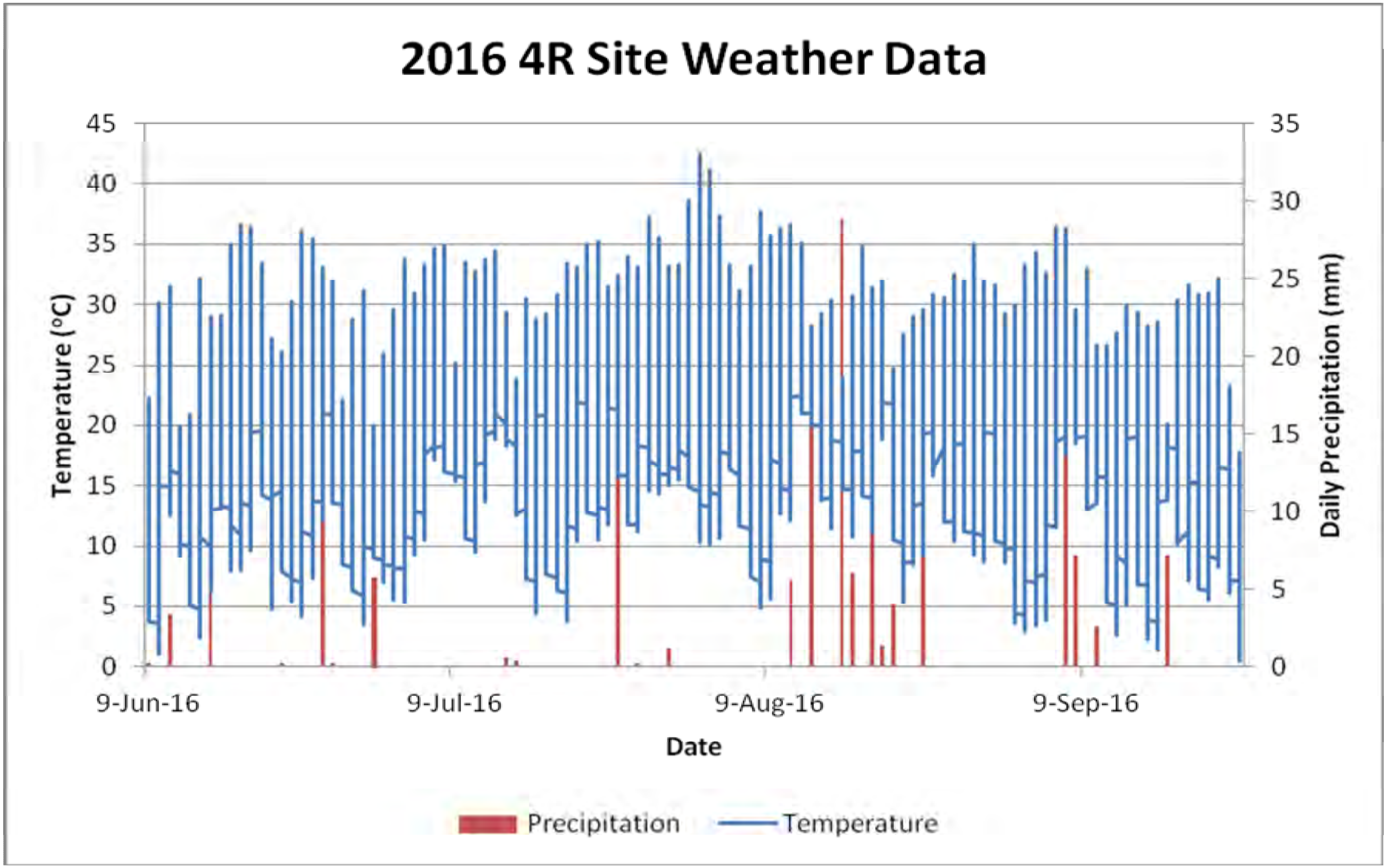

Figure 11: 2016 Site 1 corn plot weather station data

3.1.2 Soil Observations

Soil Moisture

The 2016 soil moisture levels were low initially with a slight increase after August (Fig. 12) as conditions were droughty in 2016. Low moisture conditions may have influenced soil nutrient dynamics and plant nutrient uptake and as a result yield potential. Soil pH remained consistent at Site 1 at around 7.4.

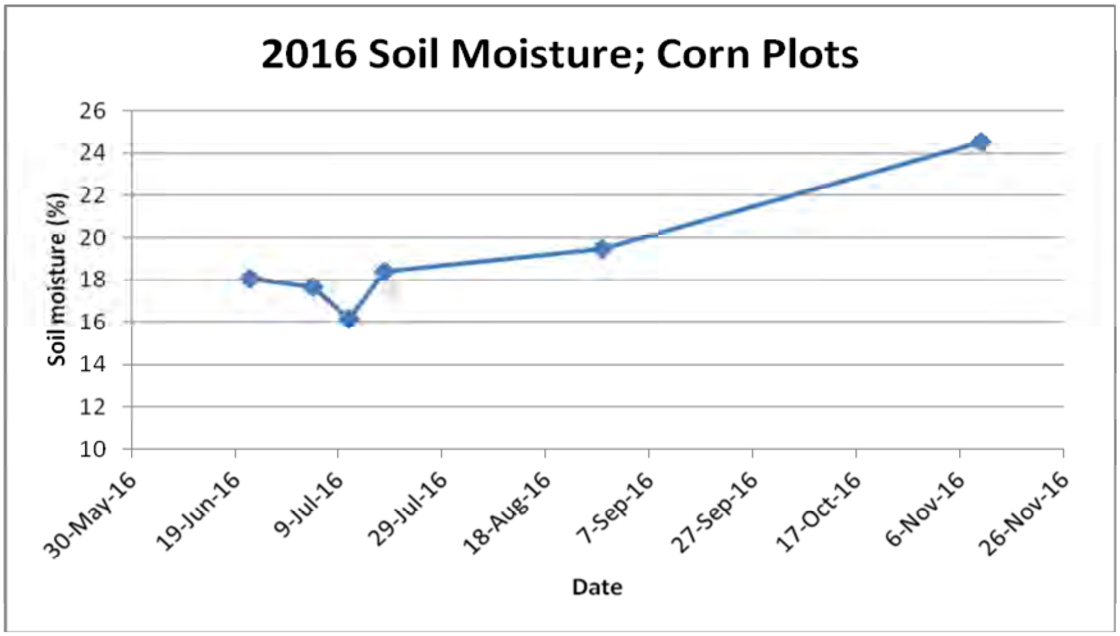

Figure 12: Soil moisture over season of Site 1 corn plots

Soil Nitrogen

Soil nitrate nitrogen increased in all treatments from between 8-18ppm with peak levels occurring around June 15 to July 4 (Fig. 13). Nitrate nitrogen was highest by July 4 in the digestate (DO) and biosolid (BO) amended plots of close to 30ppm; however, those treatments with nitrogen inhibitor added (Dni, Bni) were not delayed and were of similar level earlier by June 22. The inhibitor was expected to delay nitrate release but the opposite was observed. By the end of August, nitrate levels were below 7ppm in all treatments. The ammonium nitrogen (NH_4-N) levels were considerably lower than nitrate levels. In the Dni and Bni plots, the levels of NH_4-N were higher for the inhibitor treated plots than the amendments by themselves between June 15 and July 4 (Fig. 14) which may indicate the inhibitor helped keep nitrogen in the NH_4-N form during that time. By the end of the season, the NH_4-N levels were below 2ppm. The influence of treatment on soil nitrogen dynamics or the influence of an inhibitor was not conclusive in 2016, possibly due to the dry soil conditions experienced.

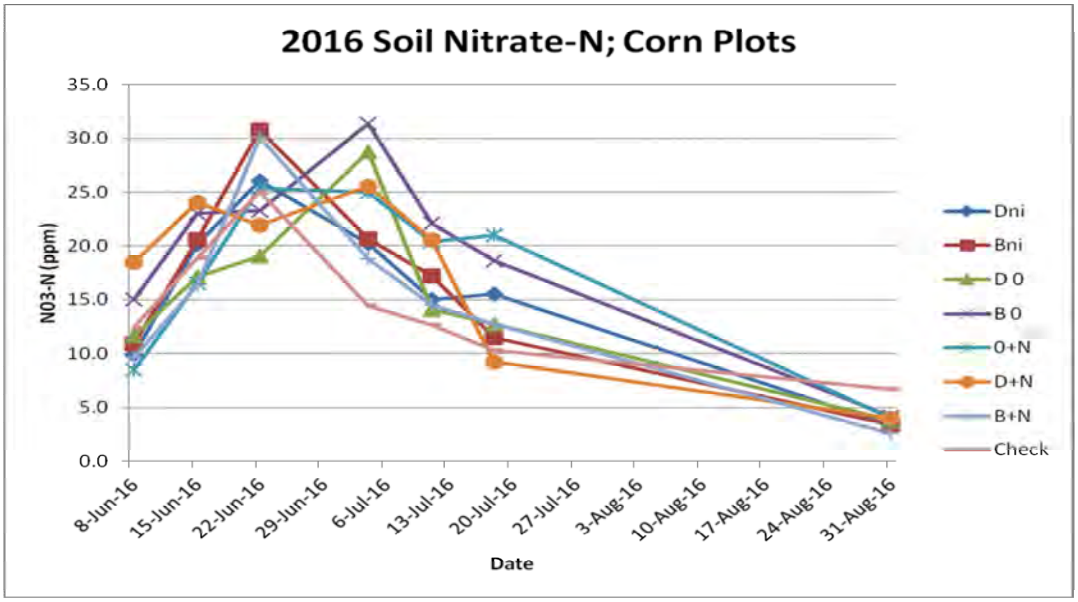

Figure 13: Soil nitrate-N of Site 1 corn plots

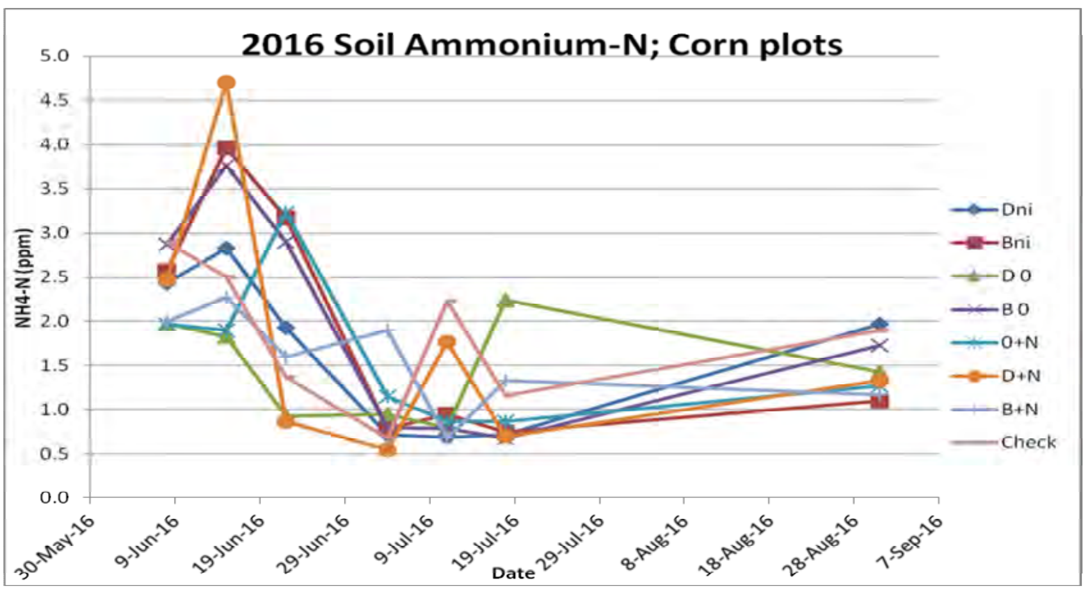

Figure 14. Soil ammonium-N of Site 1 corn plots

Soil Water Extractable Phosphorus

Soil water extractable phosphorus (WEP), i.e. P available for loss with precipitation, was measured as a possible indicator of potential P loss below the root zone and to tiles. WEP measurement was typically below 3.5ppm (Fig. 15) and near the detection limit of the lab procedure, limiting the confidence in comparing treatments. WEP was highest in samples taken from the application day and declined rapidly thereafter which is expected as the plants use this highly available P and as it becomes bound to soil. There was a marked increase in WEP measured at July 12th for some plots which was unrelated to any rainfall event since the last rain event was 12 days previous. The three biosolid based treatments and one digestate treatment increased and in November, WEP levels were again higher for the 3 biosolid treatments than the other treatments. Overall, the higher water extractable P levels observed in the biosolid treatment through the season may be associated with the higher levels and form of P added in this treatment (Fig. 16).

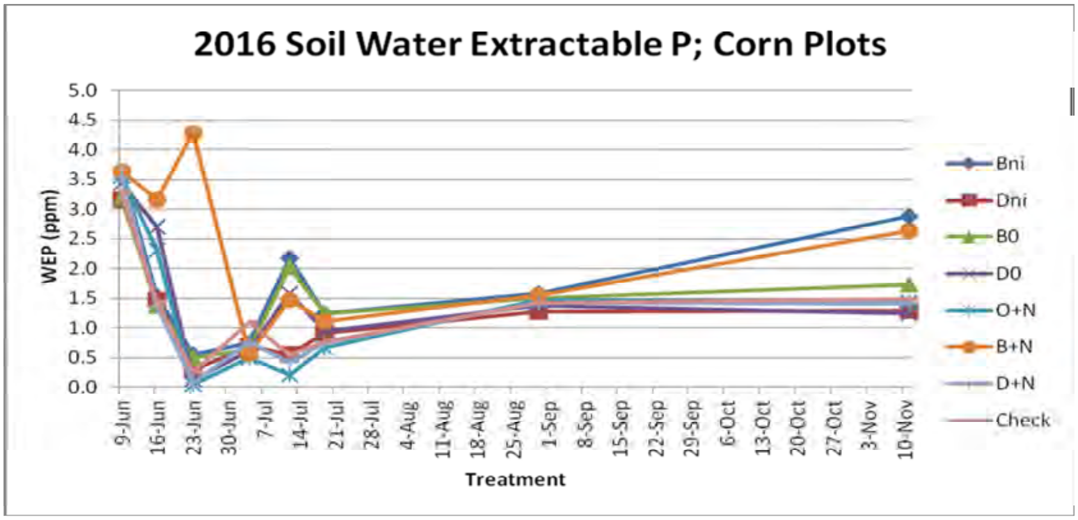

Figure 15: Soil water extractable P (WEP) of Site 1 corn plots

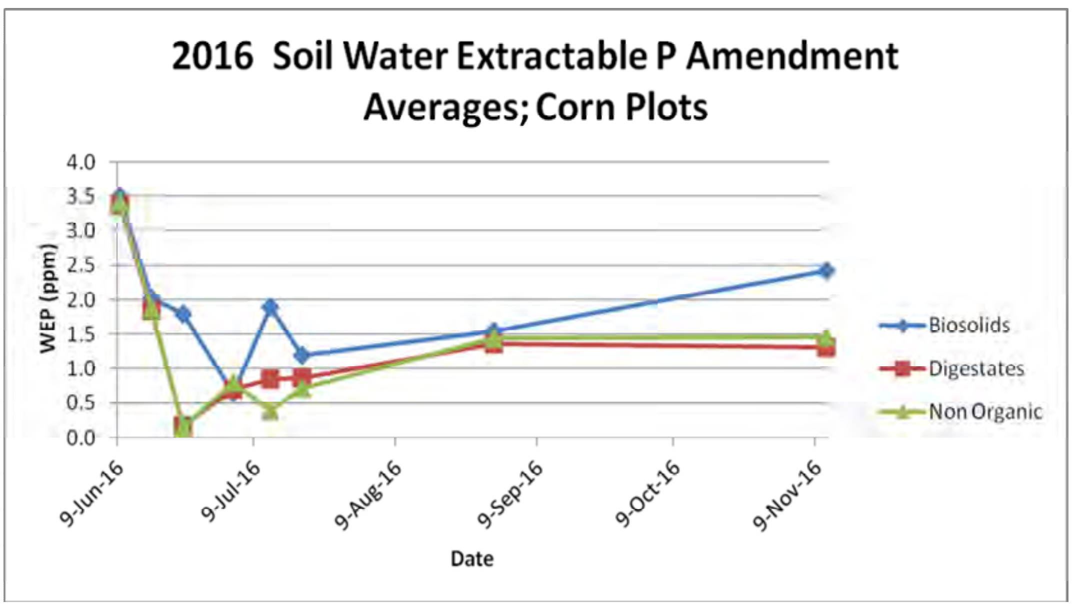

Figure 16: Soil water extractable P (WEP) for amendments only of Site 1 corn plots

Soil Phosphorus and Potassium

Soil P and K concentrations sampled initially indicated low levels at Field Site 1 (11ppm P and 65ppm K on average; Figs. 17 and 18). With the treatment applications, the soil test results over the course of the growing season continued to be low and did not change significantly by treatment. A limited change in soil test P (STP) did not reflect the significant amount of P added in the biosolid treatments over the other treatments. A general increase was measured in most plots at harvest as may be expected to see in all the treatments that received organic amendments even in a dry year, since P is not affected by soil moisture conditions. However, it may be that because the application band was avoided during soil sampling, a significant increase in level was not measured in the organic amendment plots due to the immobility of P in the soil. The observation that the check plot and N fertilizer plot had an increase in STP also indicates the inherent field variability that can exist especially at these low levels.

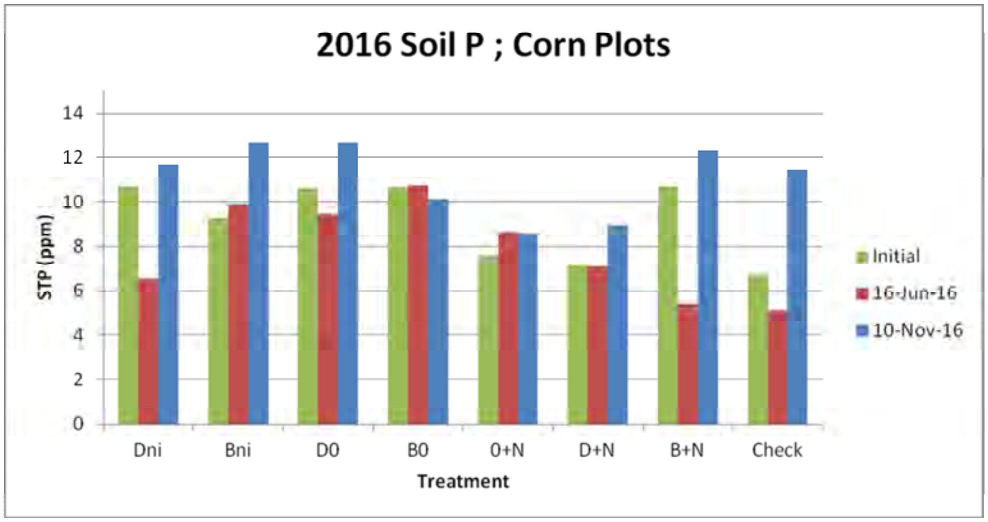

Figure 17: Soil phosphorus of Site 1 corn plots

Soil test potassium (STK) levels indicated a general increase over the season in all the plots that had product applied but not by a significant amount. The field soil K was below recommended sufficiency levels for a corn crop which was evident in the additional tissue sample analysis and yield described in the following sections. As with the soil P results, field variability and plot strip location may have been a factor in the treatment averages observed. The D+ N treatment had STK levels initially and after treatment that were nearly 10ppm higher than the other digestate treatments.

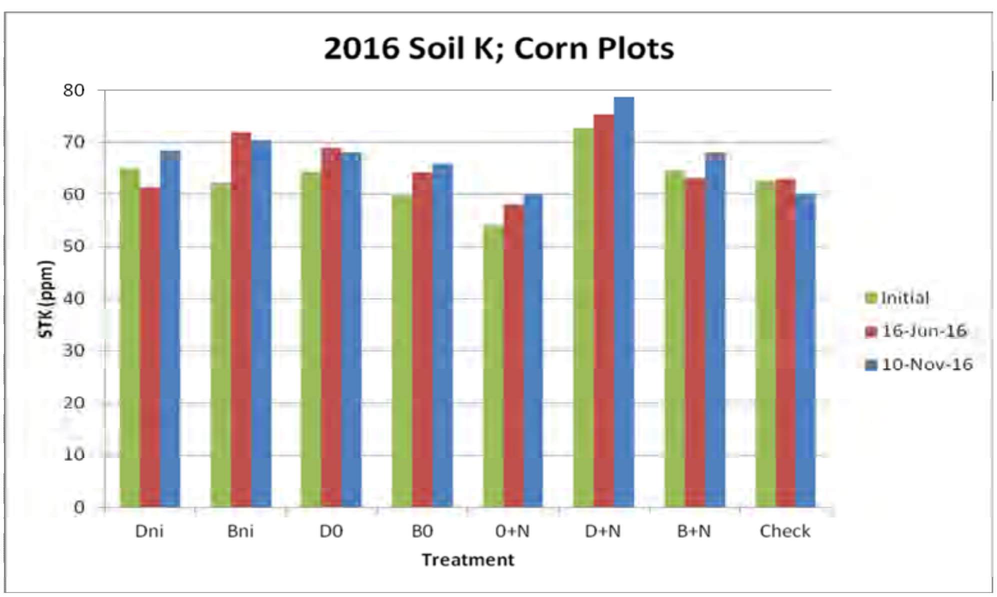

Figure 18: Soil potassium of Site 1 corn plots

Soil Organic Matter

Soil organic matter (OM) levels measured across the treatments varied slightly initially. The same relative variation continued at the post application sampling but was also greater overall than from initial levels (Fig. 19). The increase also occurs in plots where no organic material was applied indicating the likelihood the increase was not related to treatment but rather field or analytical variability. Increased OM levels within a season after just one application of organic amendments would not be expected since it typically requires many years and numerous applications of organic amendments to detect changes in the organic matter level of a soil.

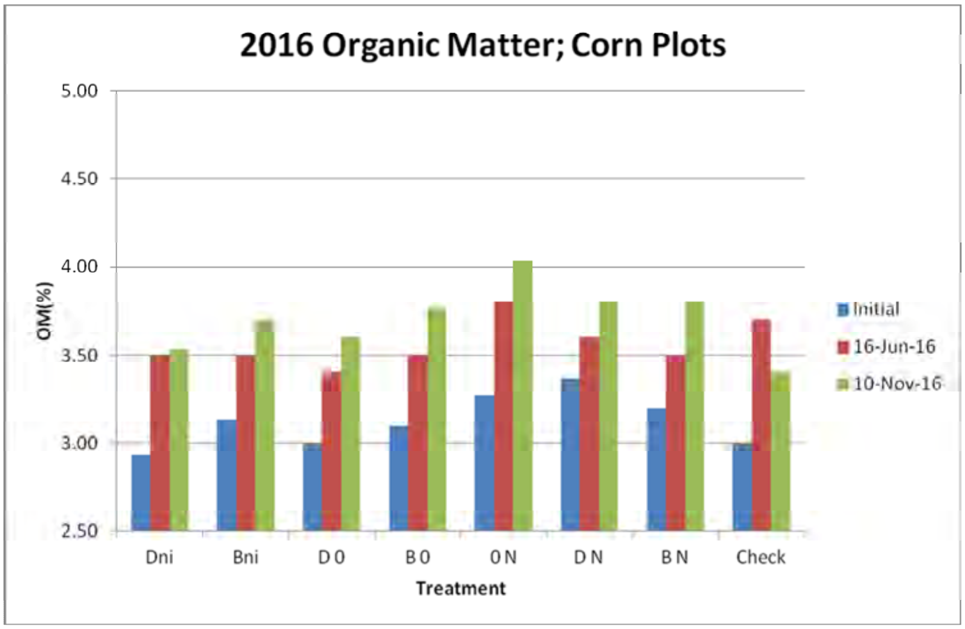

Figure 19: Soil organic matter of Site 1 corn plots

3.1.3 Plant Tissue Observations

Plant tissue analysis, carried out at corn silking time showed some limitations of nutrient concentrations related to the plant critical limit (red lines in graphs Figs. 20-22). Nitrogen levels were all above the critical limit and phosphorus levels were very close in meeting the limit where the organic amendments were added but were slightly below for the fertilizer nitrogen only and check treatments. Potassium levels of the corn crop indicated a potential deficiency in some treatments. Corn leaf tissue results from plots without added biosolid or digestate (check plot or N fertilizer only) were well below potassium sufficiency levels. Correlation analysis between STK and tissue K (R^2=0.84) indicated a significant response in the plant tissue with added K. In addition, the relationship between increased tissue K and greater yield was well correlated (R^2=0.76) though there was no clear relationship between the tissue nutrient concentrations and type of organic amendment. Another observation from the tissue analysis was that the tissue Mg was highest in the plots without organic amendment additions (Fig. 23). This may indicate that Mg uptake was antagonised by the high amount of calcium (Ca) added in the amended plots as high soil calcium is known to inhibit plant uptake of magnesium and calcium. Calcium levels were similarly lower in the organic amendment treatments (Fig. 24). The tissue Ca levels in the treatments receiving the applied materials, particularly biosolid, when compared to liquid manure were significantly higher. Levels of Mg in the corn tissue were above sufficiency levels.

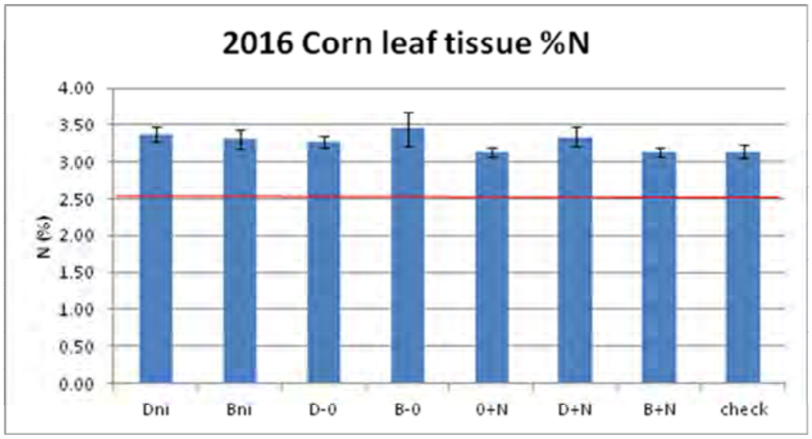

Figure 20: Leaf tissue %N of Site 1 corn plots

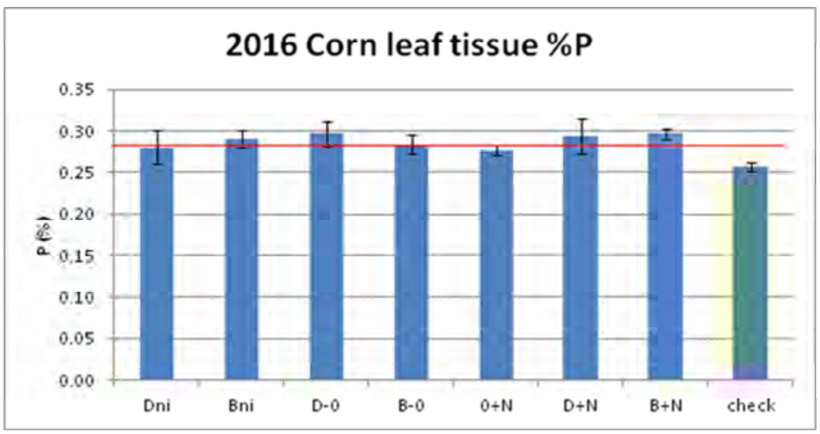

Figure 21: Leaf tissue %P of Site 1 corn plots

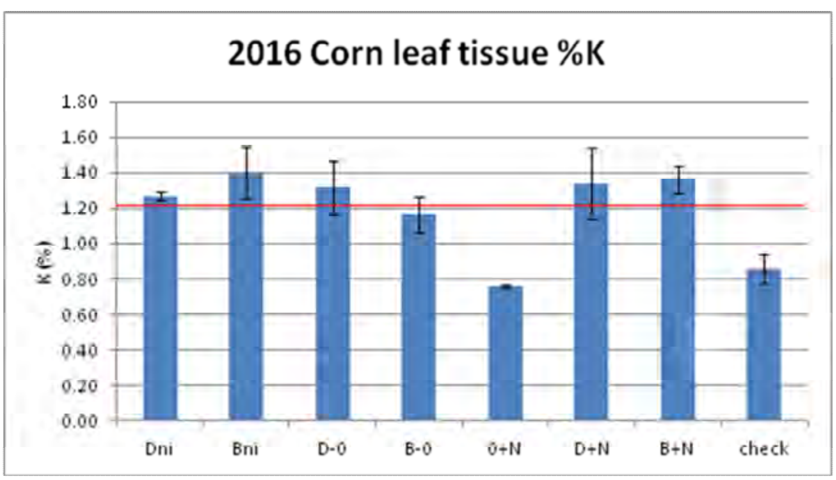

Figure 22: Leaf tissue %K of Site 1 corn plots

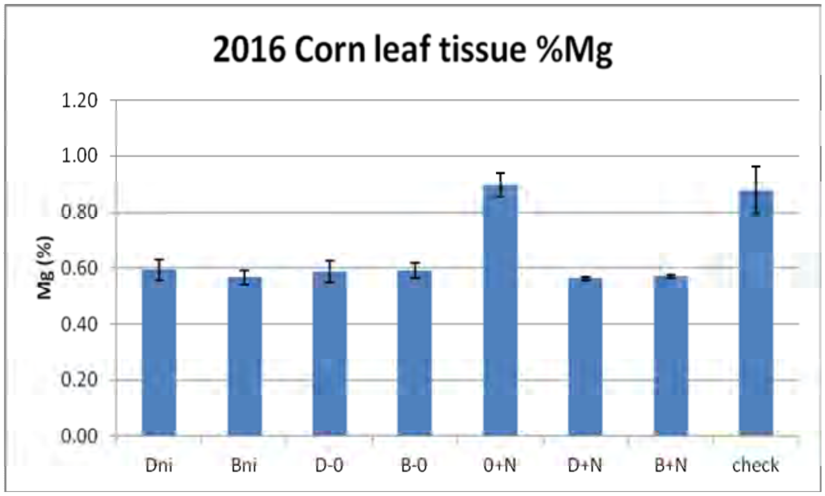

Figure 23: Leaf tissue %Mg of Site 1 corn plots

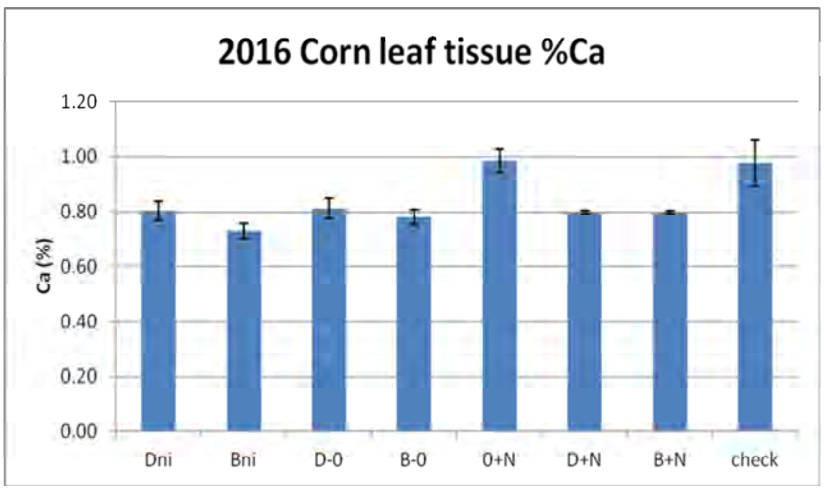

Figure 24: Leaf tissue %Ca of Site 1 corn plots

3.1.4 Crop Yield

Harvest results for the corn crop compared grain protein levels and grain yield between treatments. Crude protein measurement of the corn grain did not indicate significant differences between types of amendment or with the fertilizer nitrogen only treatment (Fig. 25). Grain protein did show an increase in all application treatments over the check treatment.

The Year 1 yield results indicated that the organic amendment treatments yielded as well or better than the fertilizer nitrogen only treatment and the check (Fig. 26). An influence of a nitrogen inhibitor on yield was not observed. A number of factors may have contributed in part to the increased yield of the amendments such as the addition of liquid material in droughty conditions; added P, K, micronutrients, organic carbon, and the benefits of the associated microbial populations. These additions can accumulate over time to help improve soil health and agricultural sustainability. Specific soil health parameters were not measured in this part of the study but were considered for application during the non-growing season trial.

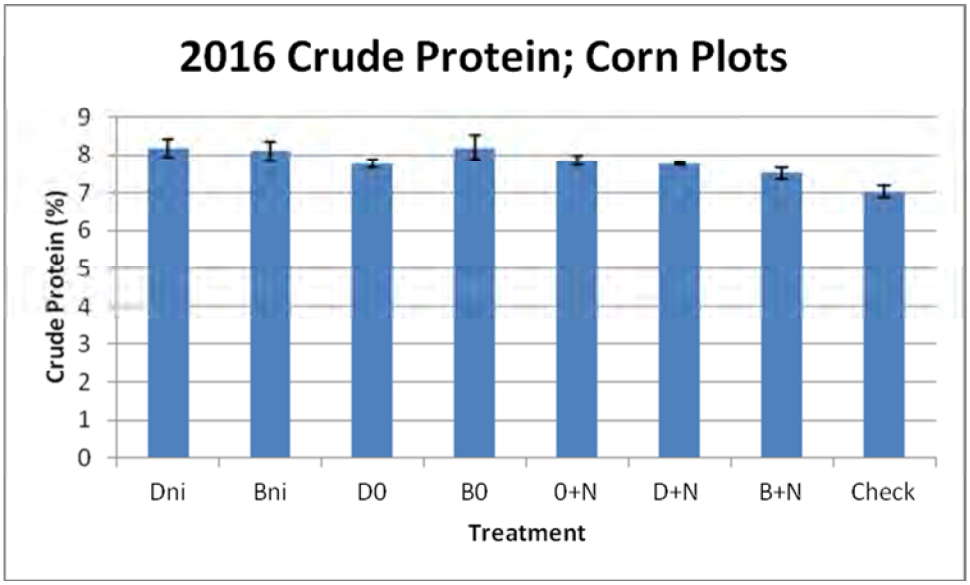

Figure 25: Grain %crude protein of Site 1 corn plots

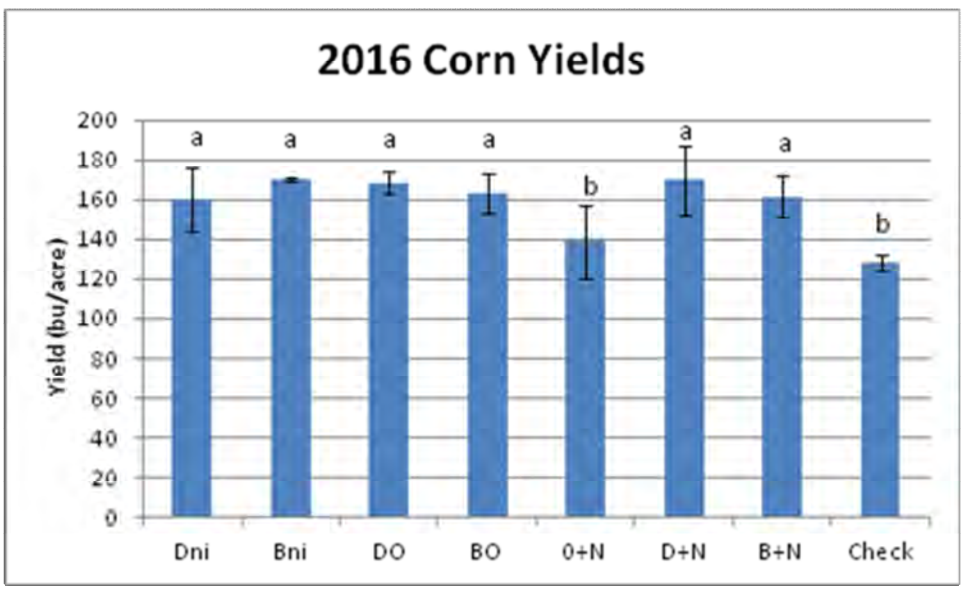

Figure 26: Yield of Site 1 corn plots

3.2 Growing Season Use – Year 2

3.2.1 Site 2 Observations

The location of Site 2 (Fig 27) was a corn field on a uniform gentle 3% slope downslope of a moderate hillslope. Soil type was a Perth Silt Loam.

Figure 27: 2017 Site 2 corn plot field site approximate location

Year 2 Growing Season Activities

1. Corn planted: *May 13, 2017*
2. Treatments applied: *June 14, 2017* (at V6 corn leaf over stage).
3. Soil sampling 2017: (composite across row width and location by subplot)
    a. *June 14* (pre application) and *June 21* (1 week post application), *June 27, July 5, July 12*: basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N and NH_4-N (12in:lab analysis), moisture (6in)
    b. *July 19, August 2, September 13, October 4*, : NO3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)
    c. *November 14*, post harvest: basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)
4. Tissue analysis: (composite by subplot)
    a. *July 30* (at silking; % N, P, K, Mg, Ca)
5. Yield and grain analysis (hand harvest by subplot)
    a. *November 9* (grain weights, plant and cob counts)
6. Harvesting (machine harvest by treatment)
    a. *November 9*; Harvested corn weights from all plots and grain analyses (moisture, test weight)

Site 2 Nutrient Amendment Information

Table 3: Amendment analysis			
Date: June 14, 2017	**Amendment**		
Sample ID:	Digestate	Biosolid	Swine Manure
Dry Matter %	4.7	12	4.2
pH	7.8	8.1	7.2
EC (mS/cm)	16.1	14.2	28.5
Nitrogen (%)	0.34	0.67	0.66
Ammonium - N (ppm)	1790	3470	4821
Phosphorus (%)	0.06	0.34	0.09
Potassium (%)	0.16	.025	0.33

Table 4: 2017 Corn Plot Layout and Treatment Details								
	Dni	**Bni**	**D0**	**B0**	**Check**	**D+N**	**B+N**	**0+N**
Product	digestate	biosolid	digestate	biosolid	0	digestate	biosolid	0
N inhibitor	yes	yes	0	0	0	0	0	0
Rate (imp gal)	4500	2500	4500	2500	0	3000	1700	0
Number of rows	6	6	6	6	6	6	6	6
Product N applied (lb/ac)	111	109	111	109	0	74	74	0
Starter N rate (lb/ac)	43	43	43	43	43	43	43	43
Broadcast N rate (lb/ac)	0	0	0	0	0	38	38	115
Total N rate (lb/ac)	154	152	154	152	43	155	155	158
Product P applied (lb/ac)	65	196	65	196	0	43	133	0
Starter P rate (lb/ac)	46	46	46	46	46	46	46	46
Total P rate (lb/ac)	111	242	111	242	46	89	179	46
Product K applied (lb/ac)	84	76	84	76	0	56	52	0
Starter K rate (lb/ac)	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5
Total K Rate (lb/ac)	144.5	136.5	144.5	136.5	60.5	116.5	112.5	60.5

Weather Data

Weather in 2017 (Fig. 28) was wetter during the middle of the growing season. Precipitation accumulation levels were above normal in the 2 months after application of 314.2mm. Long-term average normals for June and July are 83.8mm and 89.2mm, respectively for Fergus, Ontario.

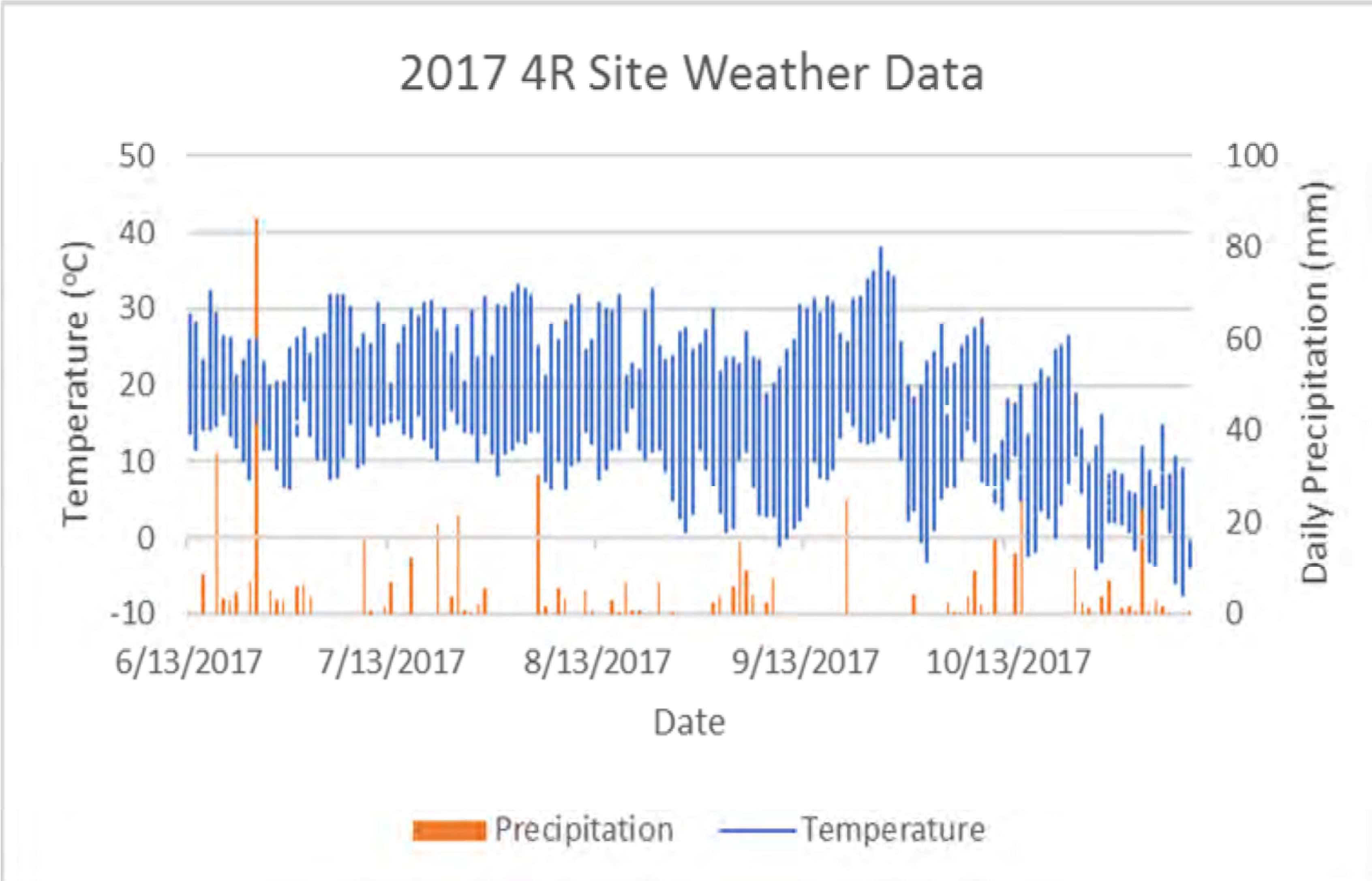

Figure 28: 2017 Temperature and precipitation of Site 2 corn plots

3.2.2 Soil Observations

Soil Moisture

As a result of several major precipitation events during the 2017 growing season, the soil moisture levels were much higher (between 25% and 30%) (Fig. 29) compared to 2016 (<20% throughout the growing season). Soil pH remained consistent at Site 2 at around 7.4.

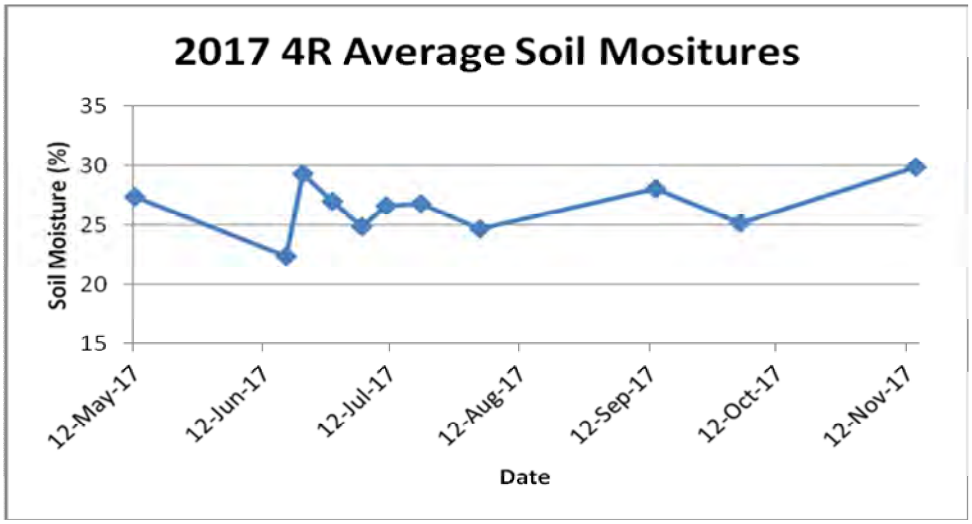

Figure 29: Soil moisture over season of Site 2 corn plots

Soil Nitrogen

Soil nitrate levels rose quickly from time of application (<30ppm,) peaking around June 27 to July 12 (Fig. 30). The greatest levels were observed in the biosolid treatments at >60ppm. By early August nitrates were near or below 20ppm in all plots. The full rate biosolid treatment plots with and without inhibitor maintained higher soil nitrate levels than other treatments throughout the season with the addition of the inhibitor acting to reduce the overall level. When comparing the two amendment products by themselves, the biosolid treatment was more than double the digestate treatment, which in turn was very similar to the fertilizer nitrogen treatment over the entire growing season (Fig. 31). The difference in amendment results may be due to the forms of organic nitrogen in the materials and how quickly organic N may be converted to nitrate N. A detailed N analysis would need to be conducted on both materials to clarify this observation.

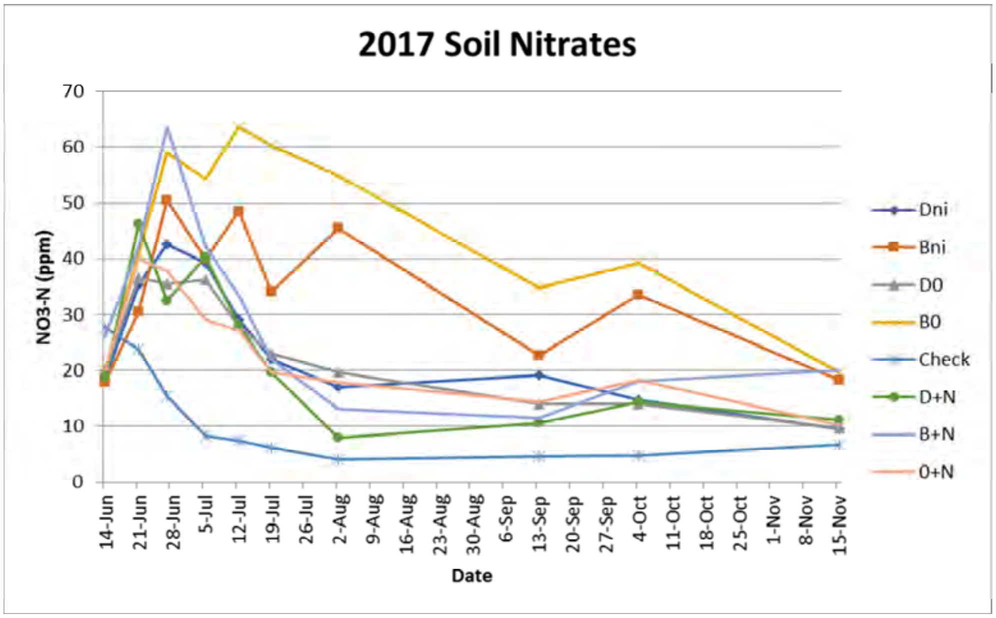

Figure 30: Soil nitrate-N of Site 2 corn plots

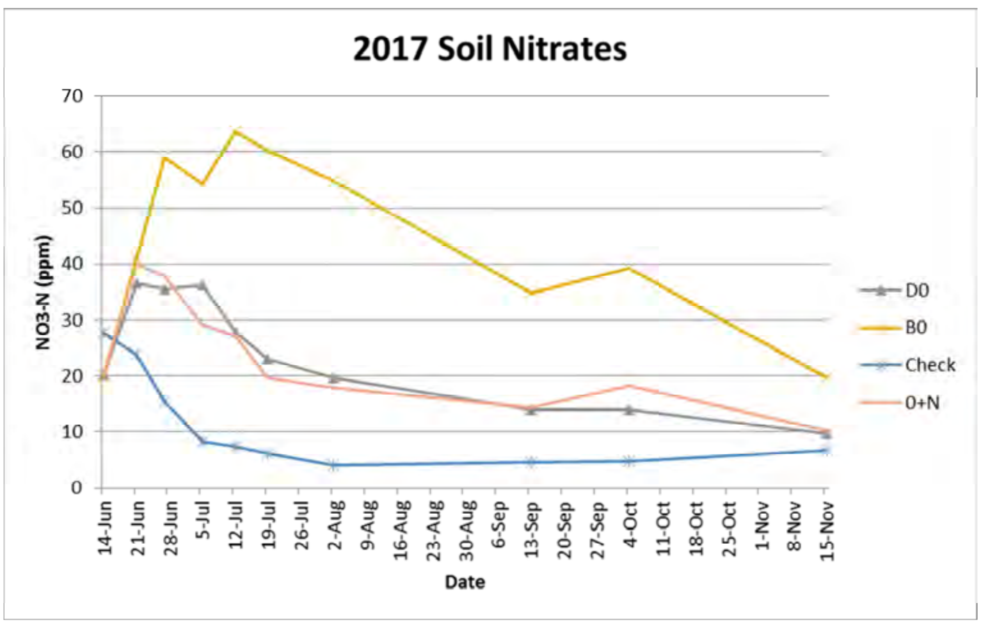

Figure 31: Average soil nitrate-N for amendments of Site 2 corn plots

When considering the lower NH_4-N levels of the soil, the Bni treatment had significantly higher levels than the other treatments for the first month of the growing season (Fig. 32). This may indicate that the addition of inhibitor acted to maintain nitrogen longer in the NH_4-N form before conversion to NO_3-N. The effect of the inhibitor with the Dni treatment was not observed.

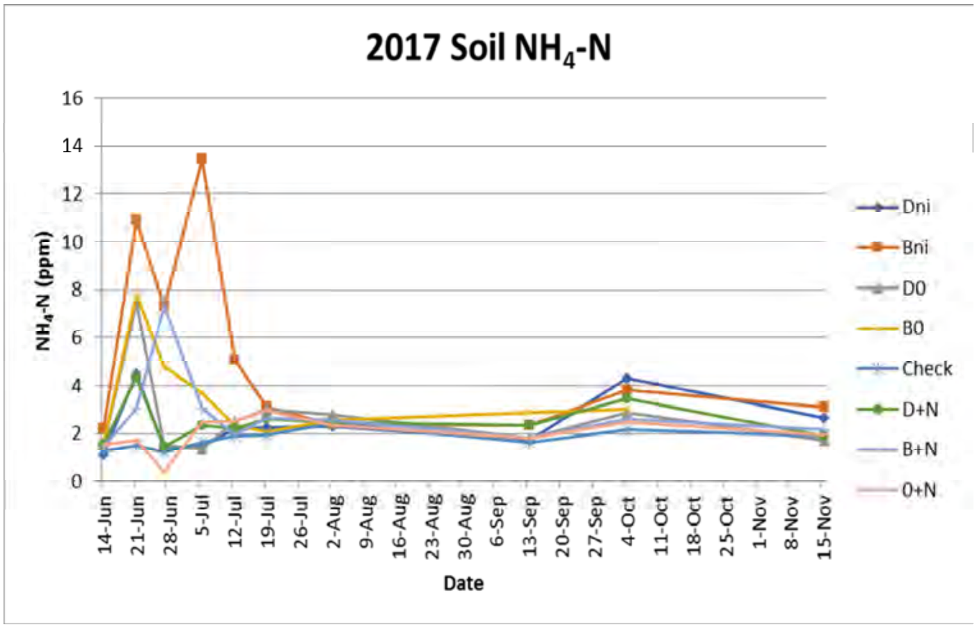

Figure 32: Soil ammonium-N of Site 2 corn plots

Soil Water Extractable Phosphorus

Soil water extractable phosphorus was measured at low levels of detection for 2 of the 5 sampling times (Fig. 33). In comparing the result of applying nearly 2.5 times as much P to the soil with the biosolid treatment as to the digestate application, there was no significantly measurable increase in the biosolid WEP soil samples taken (Fig. 34). The laboratory analytical methods used may not have been accurate enough to measure significant differences in WEP at these low concentrations, limiting any clear treatment effects.

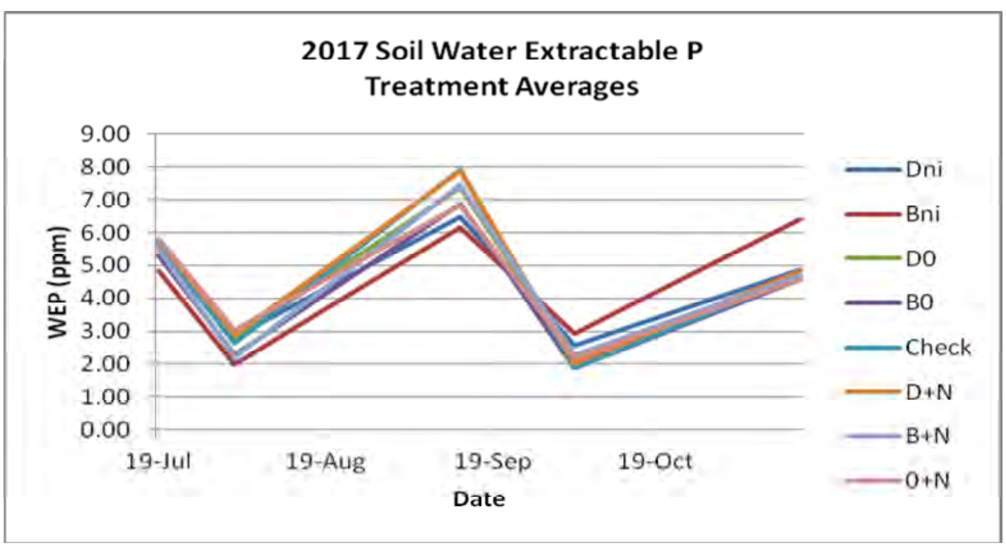

Figure 33: Water extractable P of Site 2 corn plots

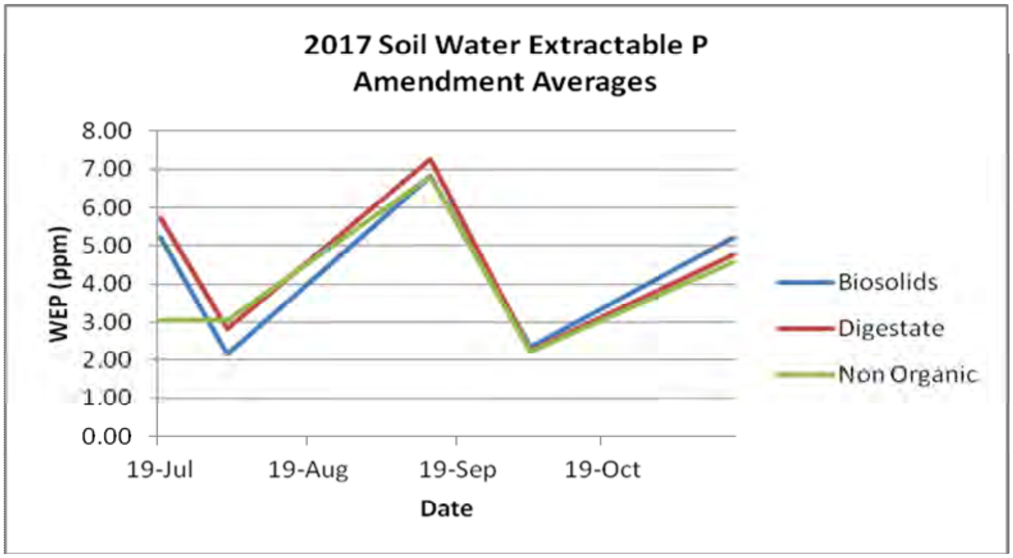

Figure 34: Average water extractable P by amendment of Site 2 corn plots

Soil Phosphorus and Potassium

Soil phosphorus concentration at Site 2 was also relatively low. The measured soil test P (STP) levels for the organic amendment treatments, however, did increase after application (Fig. 35). Even though the biosolid application resulted in more than a doubling the rate of P applied to the soil than the digestate application (rates based on N requirement), an increase in soil P was not observed. Other than the avoidance of the application trench while sampling, another factor to consider of the little change in STP may have been an influence of material pH and the form of P in the material. The biosolid material has a somewhat basic pH of 8.1 and at these pH levels available P may be more greatly bound by calcium (Ca) in the material. Once fixed by Ca, phosphorus would be unavailable to be released into the soil in the short term. In comparison, the pH of the digestate material is lower at 7.8 (considering pH is log10 scale) and more of the digestate P may become available to the soil solution. The effect of pH on P availability in the soil is shown in Figure 36. The increase of STP after application was lower in the D+N and B+N treatments that may be attributed to the two-third rate of P application when compared to the full rate application of the material.

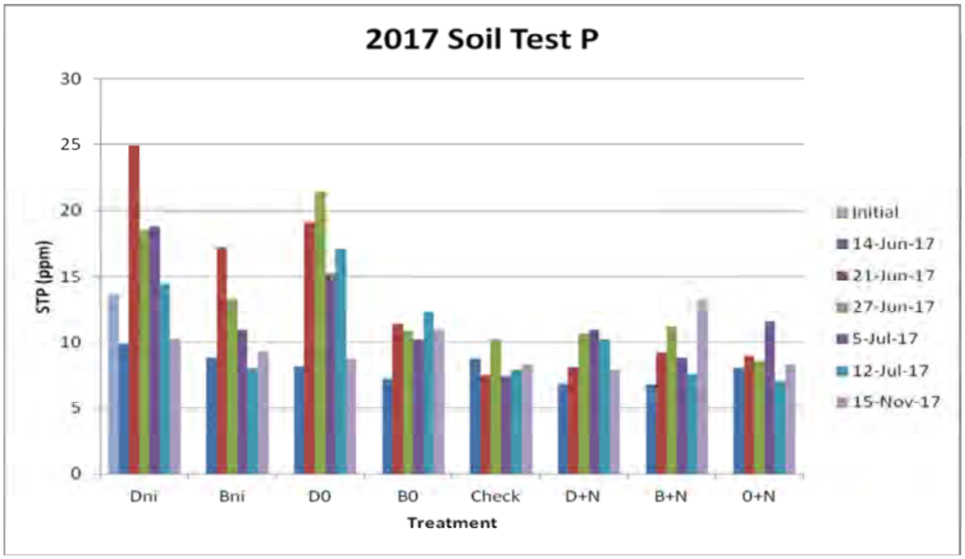

Figure 35: Soil test phosphorus (Olsen) of Site 2 corn plots

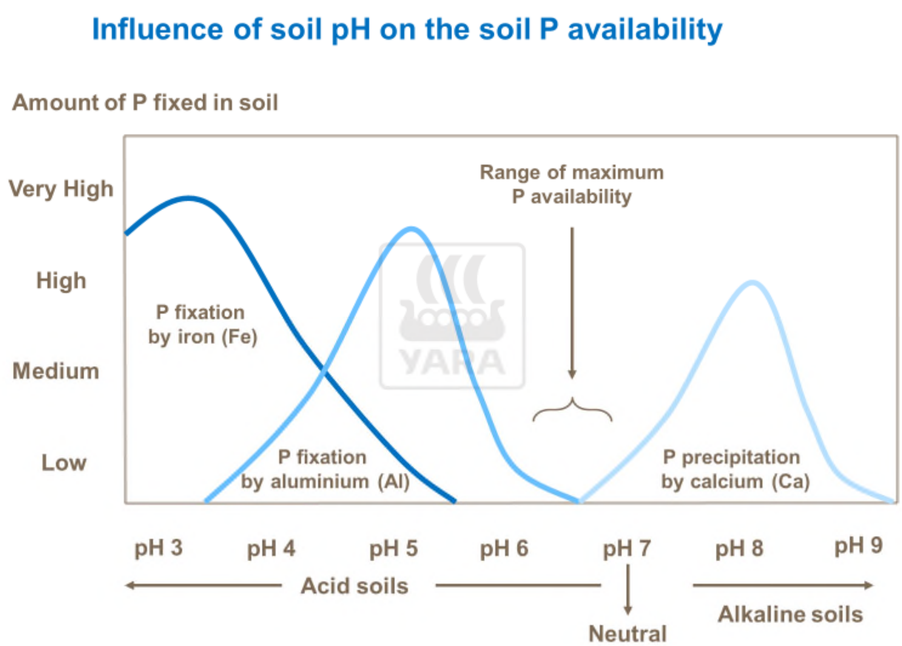

Figure 36: Influence of soil pH on soil P availability (from http://www.yara.co.uk/crop-nutrition/crops/grassland/yield/phosphorus/)

Soil test potassium (STK) levels followed a similar trend as STP. The addition of a treatment application also increased STK levels from pre-application levels when compared to the check plots (Fig. 36). The differences over the course of the experiment increased or decreased by sample date and were likely due to low analytical or field variations. However, it was observed by the end of the year that all plots had lower STK than after application, likely indicating crop uptake had reduced the measurable levels.

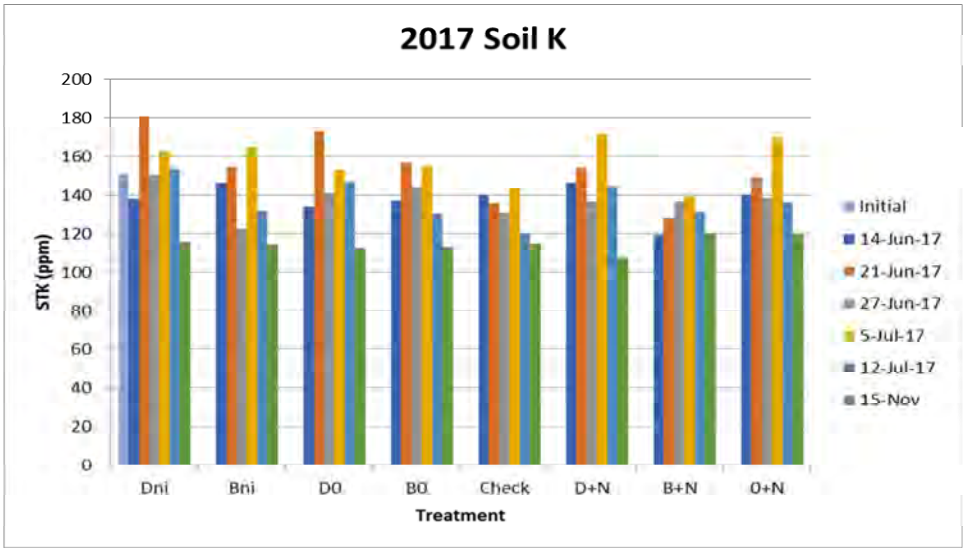

Figure 37: Soil test potassium of Site 2 corn plots

Soil Organic Matter
Soil organic matter test levels were similar for all treatment plots over the season and did not appear to have been impacted by treatment (Fig. 38). A change in soil organic matter due to a change in the nutrient sources would likely take many years to be significant and measurable.

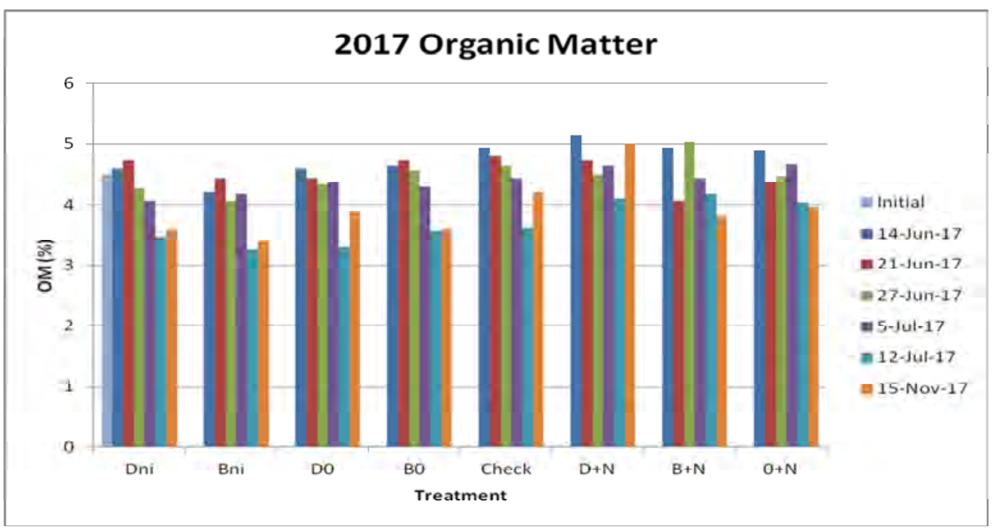

Figure 38: Soil organic matter of Site 2 corn plots

3.2.3 Plant Tissue Observations

Plant tissue analysis carried out at corn silking at Site 2 showed that all nutrient concentrations except P were above the critical limits (red lines in graphs Figs. 39-43). Tissue N levels were found to be lowest in the check control (no added N) and 0+N treatments (Fig. 39). Though N application was the same between treatments, a large rainfall event shortly after fertilizer application may have contributed to losses early in the season. The biosolid and digestate material have readily available N in the inorganic form plus organic N which is less immediately available but would become available for crop uptake throughout the growing season. Corn tissue P levels indicated a potential deficiency across all treatments (Fig. 40); however, the levels were close to the critical limit and any impact on yield was unclear. The tissue P concentrations were highest in the digestate treatments even though the biosolid treatments had significantly more P applied. This may indicate that P in the digestate was more available for uptake than P in the biosolid which may be due to the lower pH of the material as discussed above. The tissue P levels followed a similar pattern as the soil P amongst the treatments with higher soil P for a treatment resulting in higher tissue P in the plant. The correlation between tissue nutrient concentrations and yields, however, was weak. Yield and tissue K concentrations (Fig. 41) was the strongest (R^2=0.12), an observation from Site 1 in 2016 as well but with a much stronger relationship. Tissue Mg (Fig. 42) and Ca (Fig. 43) content were not affected by the amendment addition.

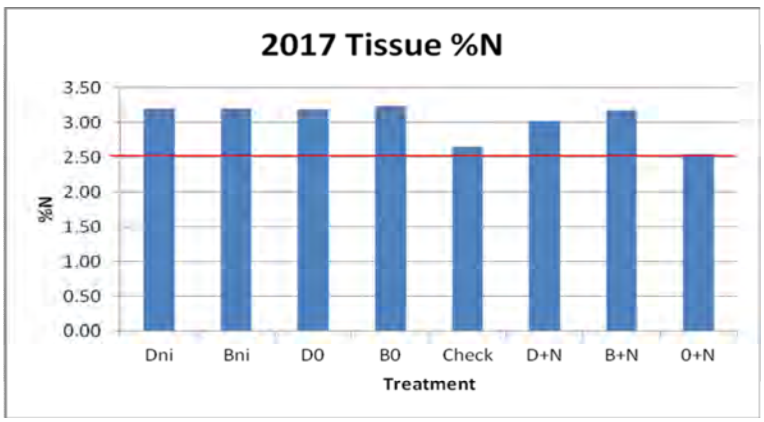

Figure 39: Tissue N of Site 2 corn plots

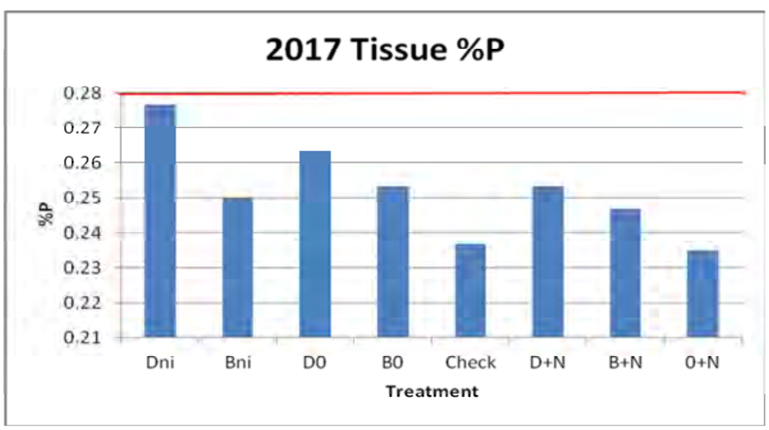

Figure 40: Tissue P of Site 2 corn plots

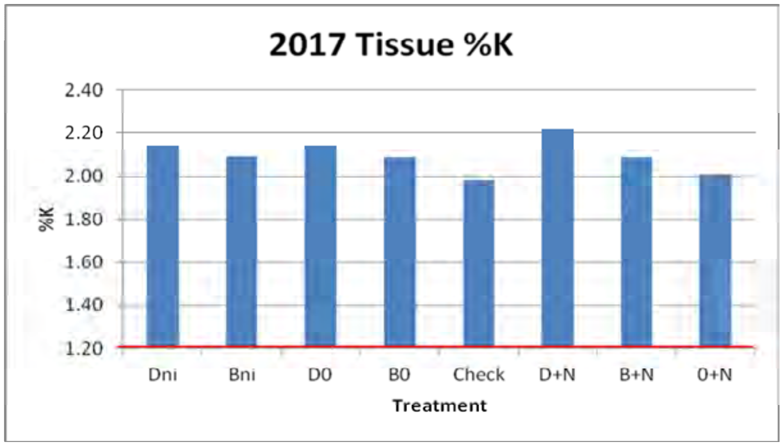

Figure 41: Tissue K of Site 2 corn plots

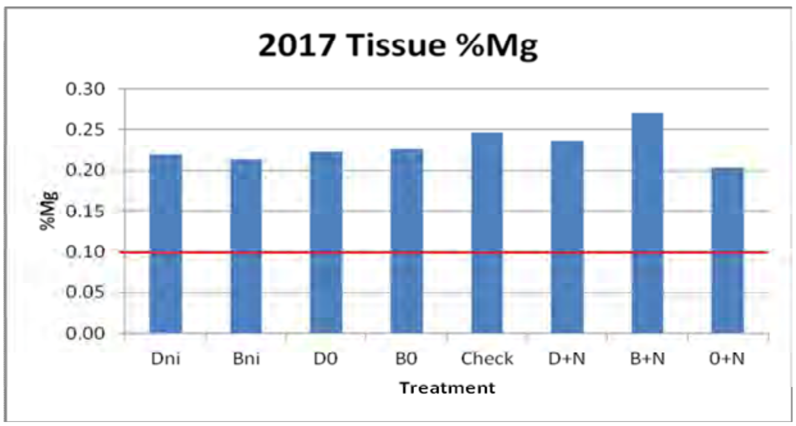

Figure 42: Tissue Mg of Site 2 corn plots

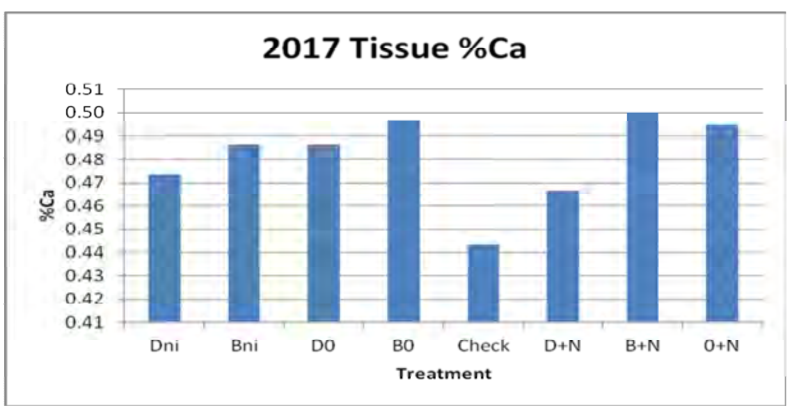

Figure 43: Tissue Ca of Site 2 corn plots

3.2.4 Crop Yield

At Site 2, all treatment applications were significantly higher than the check indicating a reasonable response from the different applications. The response in yield was similar to the treatment results in Year 1. The use of organic amendment for supplying corn nutrients again yielded similarly or greater than the fertilizer N treatment (Fig. 44). Low soil phosphorus levels at Site 2 appeared not to be limiting as was the low soil potassium that limited the nitrogen fertilizer treatment yield at Site 1. The significantly higher yielding treatments were the two-third N rate of digestate with fertilizer nitrogen treatment and the biosolid with nitrogen inhibitor treatment. The use of the nitrogen inhibitor on yield was not conclusive for both amendment materials though it would appear not to limit corn yield. For the digestate treatment, there was no statistical difference in yields with or without inhibitor. The high yielding biosolid 'ni' treatment may be associated with later season N release from the biosolid when the inhibitor was present over the biosolid treatment alone and longer season N availability in general. The split application of fertilizer and organic amendment treatments appeared more favourable for the digestate material but was not limiting for either materials split application yield result.

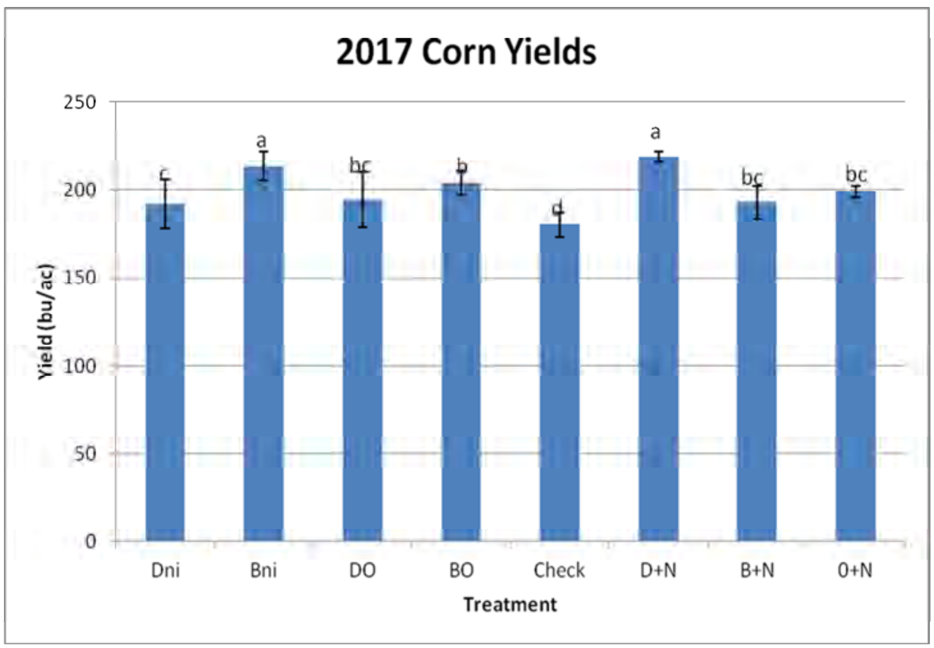

Figure 44: Yields of Site 2 corn plots (letters indicate significant differences among treatments)

3.3 Non Growing Season Use of Organic Amendments

3.3.1 General Observations

The location of the non-growing season field site (Fig. 45) was after a winter wheat crop that was untilled on a uniform very gentle 2% slope. The soil type was similar to Site 1 as a Listowel Silt Loam. Use of cover crops into the wheat stubble was compared between a winter kill mixture and an overwintering mixture in utilizing organic amendments.

Figure 45: 2016/17 Cover crop field plot site approximate location

Schedule of non-growing season field activities

1. Study initiated: *August 30, 2016*
2. Cover crop seeding:
   a. cc1 (winter kill mixture: tillage radish and oats); planted *August 30, 2016*
   b. cc2 (overwintering mixture: tillage radish, oat and rye); cc1 was killed off and re-planted with cc2 mid-*September 2016* (Fig. 46)
3. Soil sampling 2016/2017: (composite across row width and location by subplot)
   a. *August 30* (pre application) and *September 8* (1 week post application): basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)
   b. *September 15, October 6, October 15*: NO_3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)

c. *November 18*: basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N and NH_4-N (12in:lab analysis), water extractable P (WEP; 6in), soil moisture (6in)
d. *April 28*: basic soil test (6in:pH, organic matter, P, K, Ca, Mg), NO_3-N and NH_4-N (12in:lab analysis and scanner), water extractable P (WEP; 6in), soil moisture (6in)

4. Sub-plot sampling of cover crops biomass:
   a. *October 14* (% N, P, K, Mg, Ca)
   b. *November 17* (protein, fibre analyses, N, Ca, P, K, Mg, Na, Cu, Mn, Zn, Fe, Organic C, C:N ratio)
5. Soil Health Parameters (*June 2017*)
   a. Potentially mineralization N (PMN, 6in)
   b. Depth of soil A horizon
   c. Residue counts
   d. Aggregate stability
   e. Earthworm counts
   f. Nematode counts

Figure 46: Cover crop field site in fall 2016 showing a bare patch in the plot area where the cc1 cover crop mixture was terminated with herbicide to plant the cc2 mixture

Cover Crop Site Nutrient Amendment Information

Table 5: Amendment analysis		
Date: Aug 31, 2016	**Amendment**	
Sample ID:	Digestate	Biosolid
Dry Matter %	3.21	5.71
EC (mS/cm)	21.8	16.87
Nitrogen (%)	0.51	0.62
Ammonium - N (ppm)	2870	2560
Phosphorus (%)	0.07	0.18
Potassium (%)	0.10	0.10

Table 6: Cover Crop Plot Layout and Treatment Details

	Dni	Bni	D0	B0	0cc1[1]	Dcc1[1]	Bcc1[1]	0cc[2]	Dcc2[2]	Bcc2[2]
Product	digestate	biosolid	digestate	biosolid	0	digestate	biosolid	0	digestate	biosolid
N inhibitor	yes	yes	0	0	0	0	0	0	0	0
Rate (imp gal)	5500	4000	5500	4000	0	5500	5500	0	5500	5500
Number of rows	6	6	6	6	6	6	6	6	6	6
Product N applied (lb/ac)	93	93	93	93	0	93	128	0	93	128
Product P applied (lb/ac)	72	286	72	286	0	72	393[3]	0	72	393[3]
Product K applied (lb/ac)	47	82	47	82	0	47	113	0	47	113

[1] cc1 (winter kill mixture: tillage radish and oats)

[2] cc2 (overwintering mixture: tillage radish, oat and rye)

[3] Note: application rate for Bcc1 or Bcc2 plots was not reduced so applied P rates very high

Weather Data

Weather data continued to be collected at Site 1, less than 4km from the cover crop site through September 2016 (Fig. 47). Precipitation accumulation levels were below normal for the month after application during September at 34.8mm. Long-term average normal precipitation for September is 93.1mm for Fergus, Ontario.

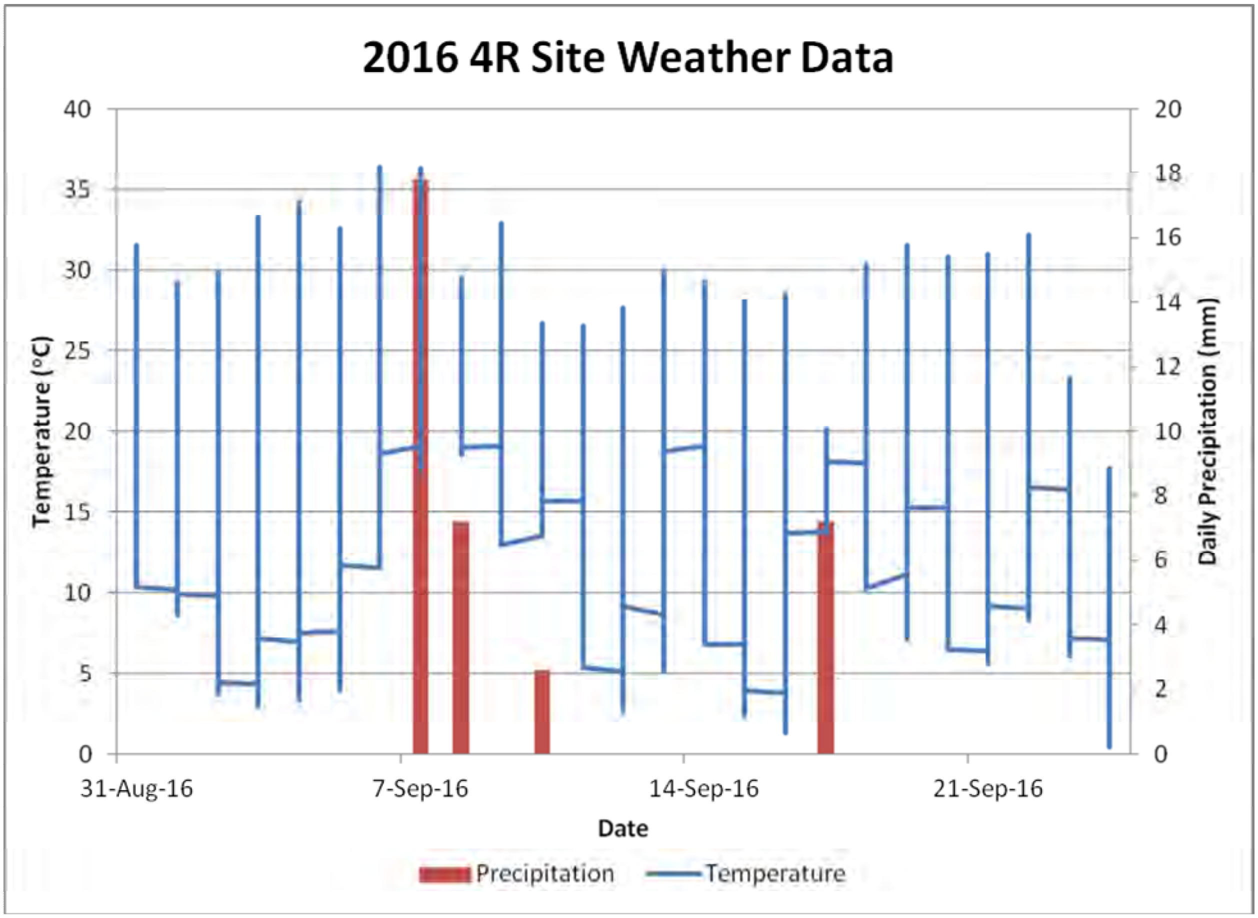

Figure 47: 2016 Fall weather data for cover crop site

3.3.2 Soil Observations

Soil Moisture
The soil moisture levels increased gradually from around 20% at the start of the trial during the fall season beginning soon after treatment application as there were 4 rainfall events before the middle of September.

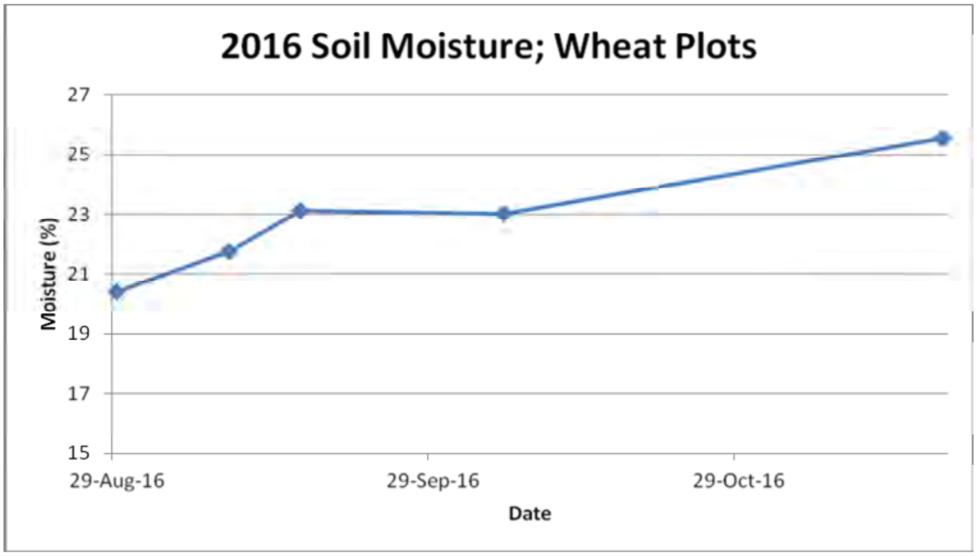

Figure 48: Soil moisture levels at cover crop site

Soil Nitrogen
Soil nitrate-N concentrations of the cover crop plots prior to the organic amendment applications were low at less than 11ppm (Fig. 49). There was a significant increase in soil nitrate-N of the application treatment plots after the first week over the check plots that remained the same. Over week two, there was an increase for all treatments. The check plots likely increased due to the wetting up of the soil from rainfall events allowing greater microbial activity and a release of mineralized nitrogen to the soil; however, levels dropped below the application treatments soon after. Peak nitrate-N levels were observed after two weeks for most treatments (up to 32ppm NO3-N) as levels either levelled out or declined after one month. The digestate and biosolid organic amendment plots with N inhibitor were lower than other applications at the two week mark; however, the levels continued to increase and were observed to peak, 52ppm and 40ppm respectively, nearly a month after application. By the middle of November, the level of nitrate-N in the plots with N inhibitor remained above 30ppm. Plots without inhibitor or that had two months of cover crop growth had reduced soil nitrate-N levels as plants could be credited in taking up nitrogen.

The difference in having a fall cover crop (cc1) and an overwintering cover crop (cc2) and with those plots without cover were observed the following spring (Fig. 50). In the spring, the general trend was that plots with cover crops had the lowest nitrate-N levels (less than 15ppm) and the amendment plots with no cover crops had the highest nitrate-N levels (more than 25ppm) (Fig. 50). This indicates the cover crop only plots had retained a significant amount of nitrogen in the plant tissue. There was no clear trend between the over wintering cover crop and the winter kill cover crop treatments.

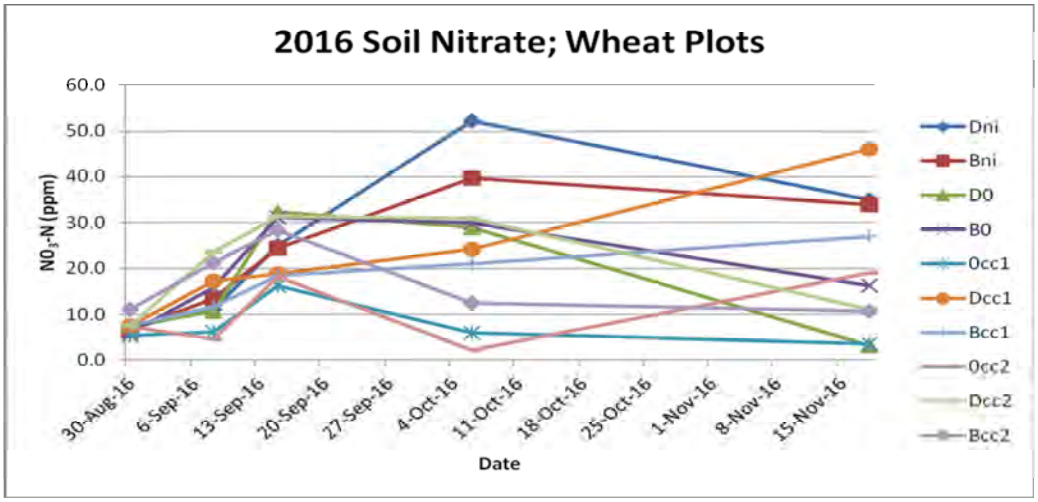

Figure 49: Soil nitrate-N of cover crop plots in fall 2016

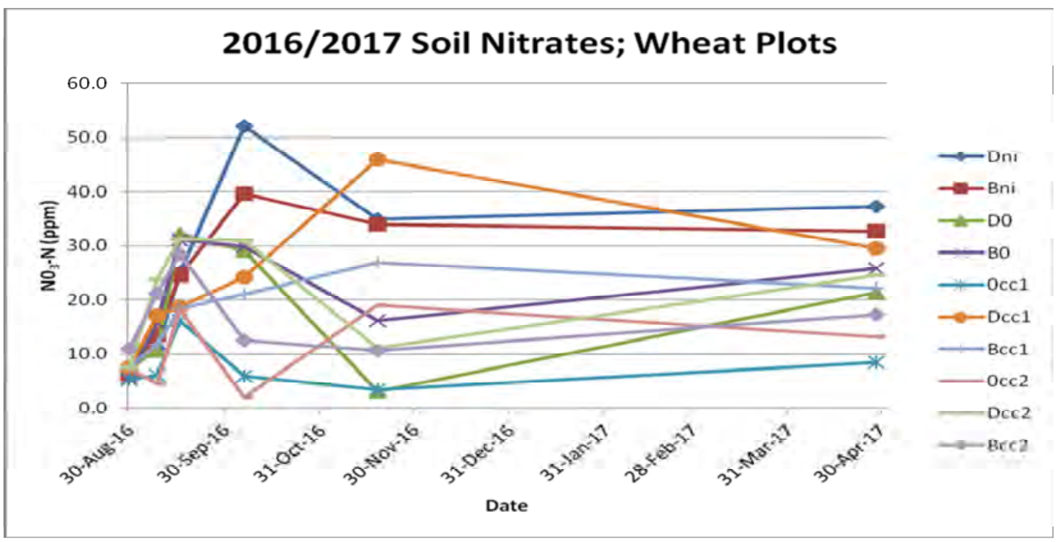

Figure 50: Soil nitrate-N of cover crop plots in fall 2016 to spring 2017

The levels of NH_4-N measured in the soil were considerably lower than soil NO_3-N levels (Fig. 51). There were no clear inhibitor effects on the NH_4-N concentrations in the soil. The plots with organic amendments and the cc2 mixture had higher NH_4-N levels at the beginning of October followed by all plots with cover crop mixtures and an amendment had the highest NH_4-N levels until the end of the season. The overwintering cover crop plots (cc2) had higher soil NH_4-N levels in the spring which may have to do with any surviving plant tissue being a source of C and N for microbial conversion to NH_4-N. Figure 52

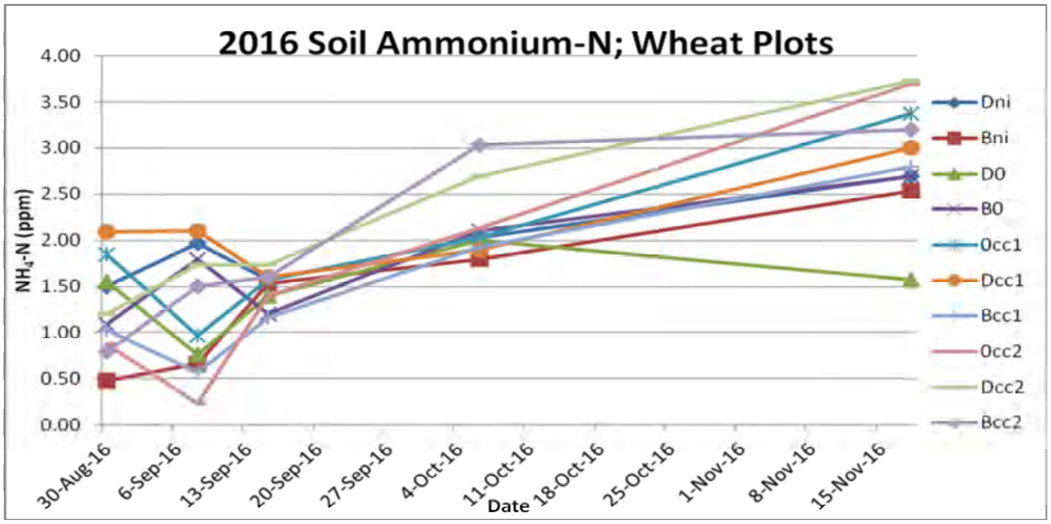

Figure 51: Soil ammonium-N of cover crop plots fall 2016

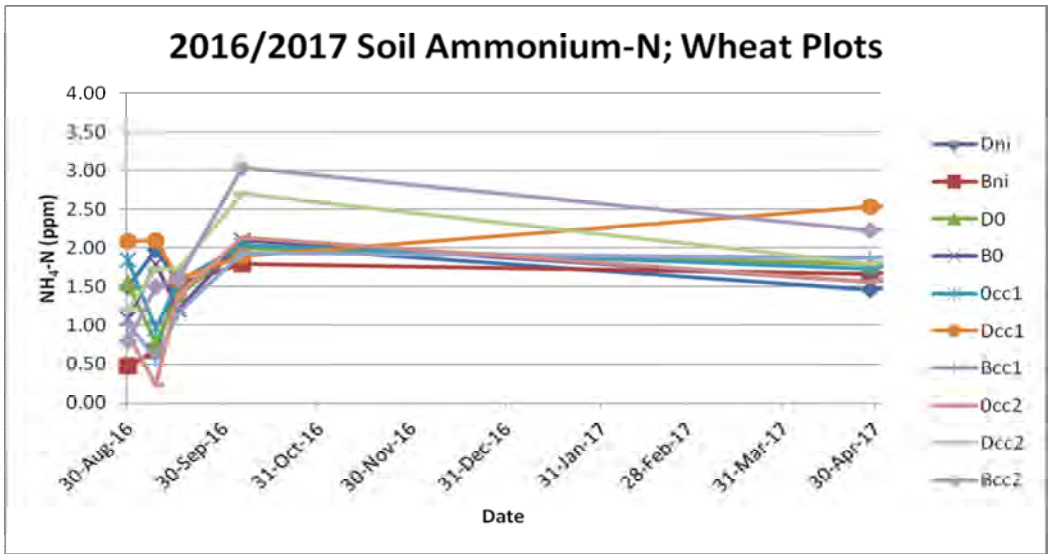

Figure 52: Soil ammonium-N of cover crop plots fall 2016 to spring 2017

Soil Water Extractable Phosphorus

Soil water extractable P (WEP), i.e. P available for loss with precipitation, was similarly low (below 4ppm) to Site 1 and 2 results and near the analytical detection limit (Fig. 53). A significant drop in WEP after initial measurement and soon after application was suspected to be laboratory error. The subsequent increase in WEP levels to the highest levels measured in mid-November followed a killing frost of the cover crop plots at the beginning of November. Cover crop senescence and the breakdown of plant tissue may have contributed to an increase in available soil nutrients. The cc2 plots had slightly higher WEP levels possibly due to greater growth of the tillage radish and oats releasing more P than in the cc1 plots. Results from the following spring indicated two of three of the overwintering cc2 treatments had the lowest WEP indicating that the overwintering rye plants may have retained nutrients in the tissue and root systems overwinter more so than the other species in the cover crop mixtures. The winter survival of the cc1 and cc2 plant mixtures is visible in Figure 54.

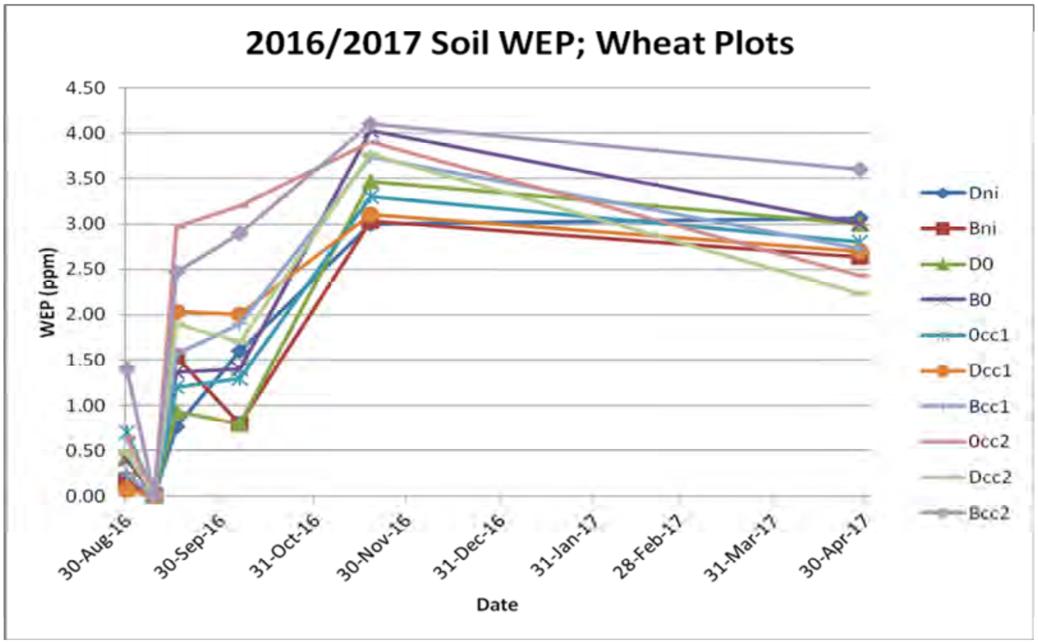

Figure 53: Soil water extractable P of cover crop plots

Figure 54: Cover crop winter kill mix plot (left) and overwinter mix plot (right) in spring 2017

Soil Phosphorus and Potassium

Soil P concentration results prior to application indicated low fertility levels on the cover crop field site of 6ppm on average (Fig. 55). The resulting soil test P (STP) for all plots treated with organic amendments increased after application, including the check plots (Occ1, Occ2) that did not receive an amendment. The application rate of P of the biosolid material was much higher than the digestate application (rates based on N requirement) though soil tests did not reflect a consistent change. However, levels analyzed in the spring were elevated in three of the four biosolid treatments with the winterkill cover crop biosolid treatment showing the lowest level measured. As a result, there were no clear effects of cover crops on the STP.

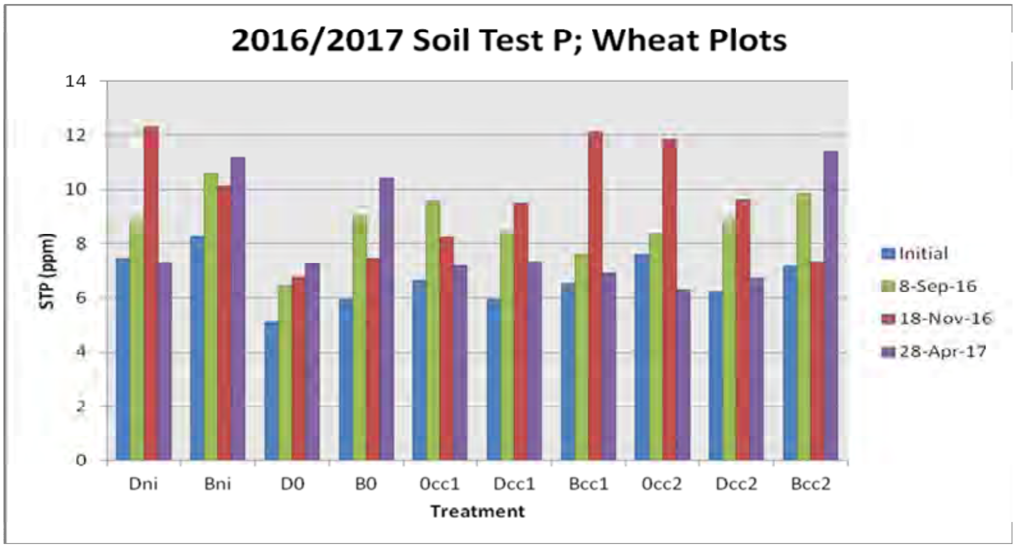

Figure 55: Soil test P of cover crop plots

Soil K levels were also low in the field (96ppm on average) and followed a similar trend as STP (Fig. 56). Treatments with applied amendments increased in STK from pre-application levels. The changes over the course of the experiment did not seem to follow a trend and are likely due to field variation.

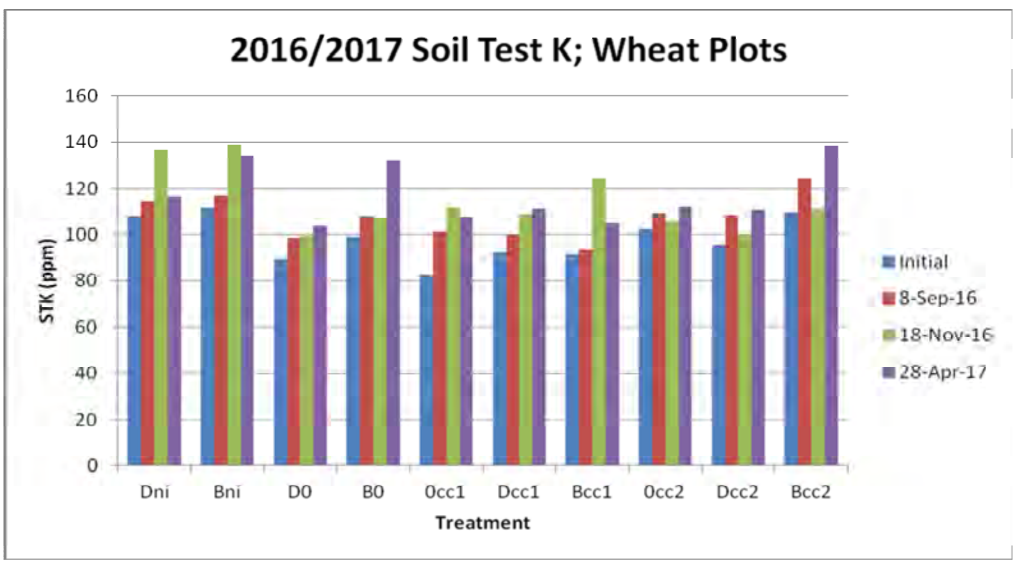

Figure 56: Soil test K of cover crop plots

Soil Organic Matter

Soil organic matter levels remained fairly consistent from initial levels over the study period and between treatments, including the check plots (Fig. 57). Change in levels would not be expected as it would take many years of organic additions to change the organic matter level of a soil. The higher OM in the last treatment on the graph is believed to be related to a previous field boundary location (old fence row removed in 2001) rather than the treatment effect.

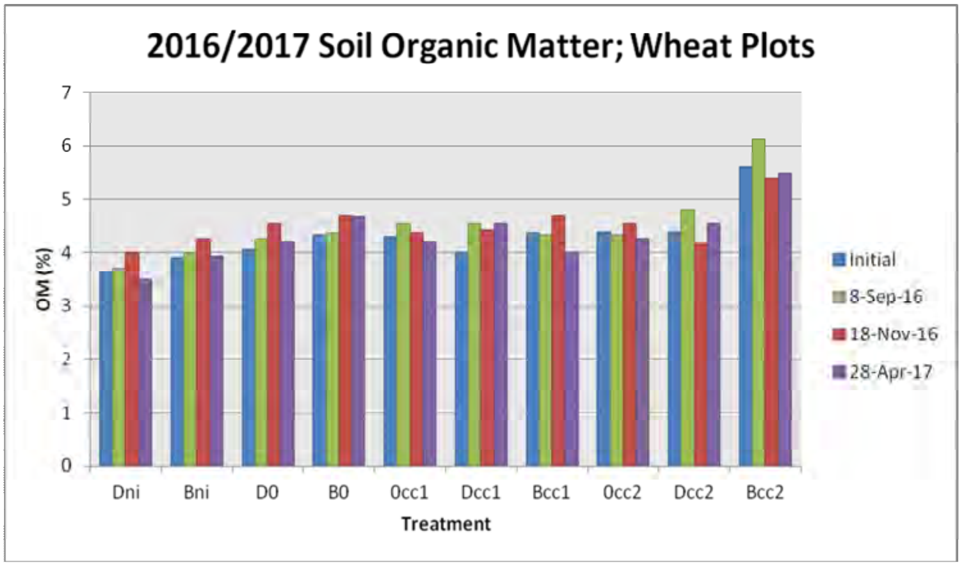

Figure 57: Soil organic matter of cover crop plots

Soil pH remained consistent between treatments at the cover crop plots at around 7.4 through to the following spring (Fig. 58). The statistically lower value of the Bcc2 plot at neutral pH of 7.0 is a further reflection of the historic near native condition of the plot soil. An increase in pH in the adjacent field area may be due to past mixing of some subsoil material into the topsoil layer.

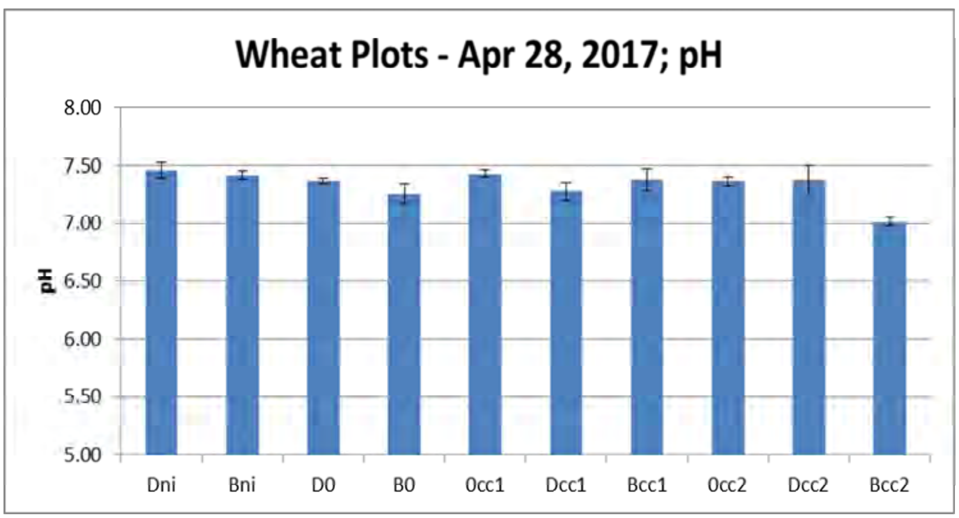

Figure 58: Soil pH of cover crop plots in spring

3.3.3 Cover Crop Observations

Cover Crop Biomass

The above ground biomass of the cover crop plots was harvested at two times in the fall from each of the subplots. Visual indications from the cover crop plot harvest were that the application of the digestate or biosolid amendments responded significantly to the added nutrients (Fig. 59, 60). Harvest data and statistical comparisons of the plants dry weight from the October harvest for cc2 was higher than for cc1 plots which was unexpected as the cc1 plots were planted 2 weeks before the cc2 plots (Fig. 61). By the November harvest, the cc2 plots were only slightly greater than cc1 plots on a dry weight basis (Fig. 62). Plant growth of the cc2 plants appeared to be senescing to a greater extent by this time. The plant tissue C:N ratio also reflected the increased uptake of nitrogen from the amendment applications with a lowering of values (Fig. 63). Higher tissue concentration of Ca, Mg, P, N, Na, Zn, K, Cu, and Fe were also measured and supplied by the amendment treatments (data not shown).

Figure 59: Cover crop biomass harvest showing growth difference

Figure 60: Cover crop treatment growth difference with amendments

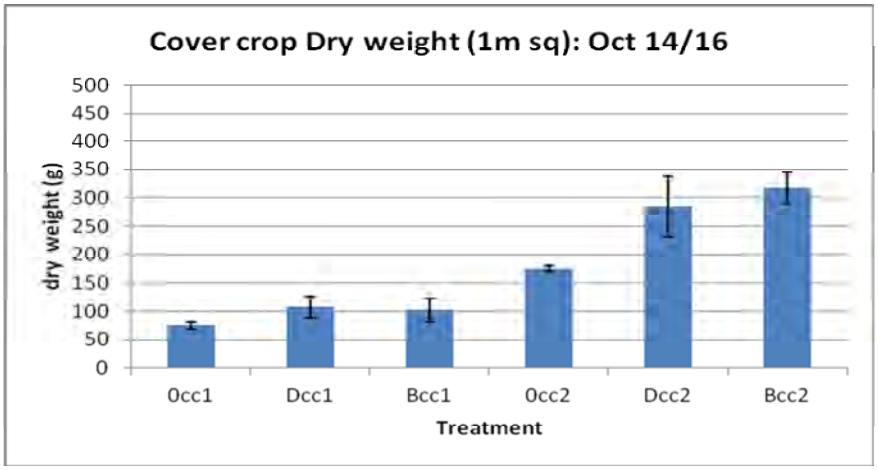

Figure 61: Cover crop dry weight ($1m^2$) October 2016

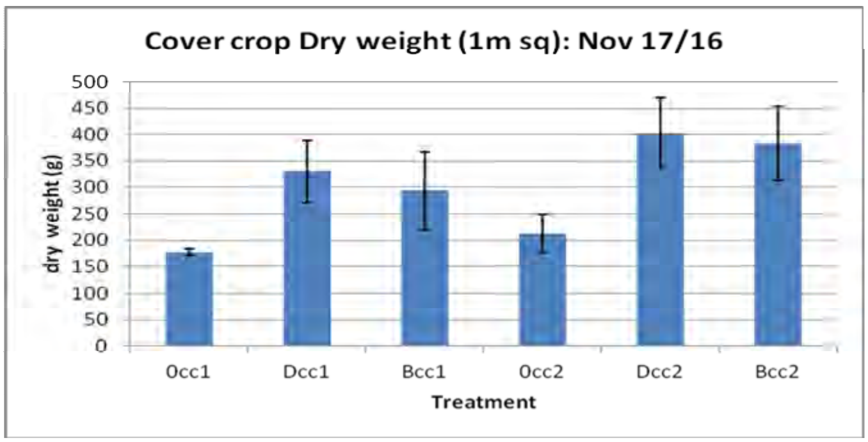

Figure 62: Cover crop dry weight ($1m^2$) November 2016

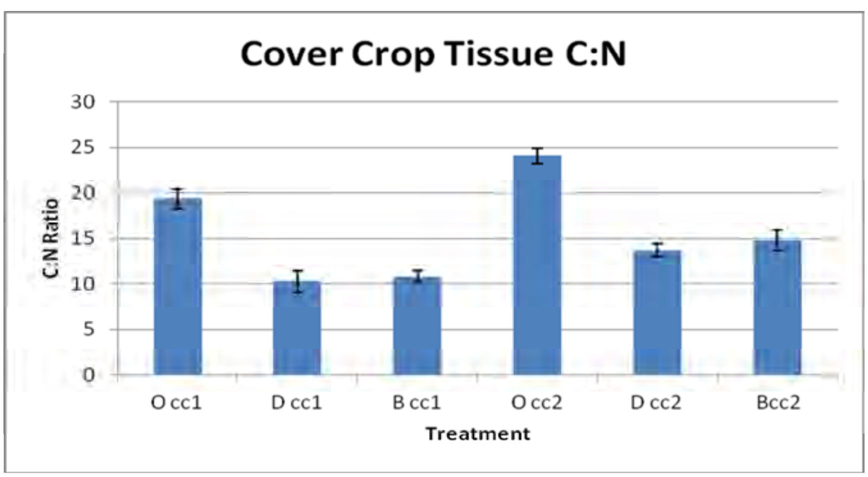

Figure 63: Cover crop tissue C:N ratio November2016

3.3.4 Soil Health Measurements

Several soil health measurements were taken in June 2017 after the fall 2016 application of organic amendments and fall cover crop treatments. Treatment effects were not expected to change the soil health conditions enough to be measured the following spring though differences were observed.

Potentially Mineralizable Nitrogen

Potentially mineralizable N (PMN) that measures the fraction of organic N that could be converted to plant available (mineral) forms under specific conditions of temperature, moisture, aeration, and time were closely associated with organic matter levels though some significant treatment differences were observed. Higher PMN in the cc2 plots (Fig. 64)may be a result of a release of N from overwintering tissue, though the significantly higher PMN in the Bcc2 plots were more likely due to higher organic matter levels (Fig. 57) related to previous field history (old fence line before 2001). The lowest levels measured in plots with the nitrogen inhibitor treatment were also found to be lowest in corresponding organic matter levels.

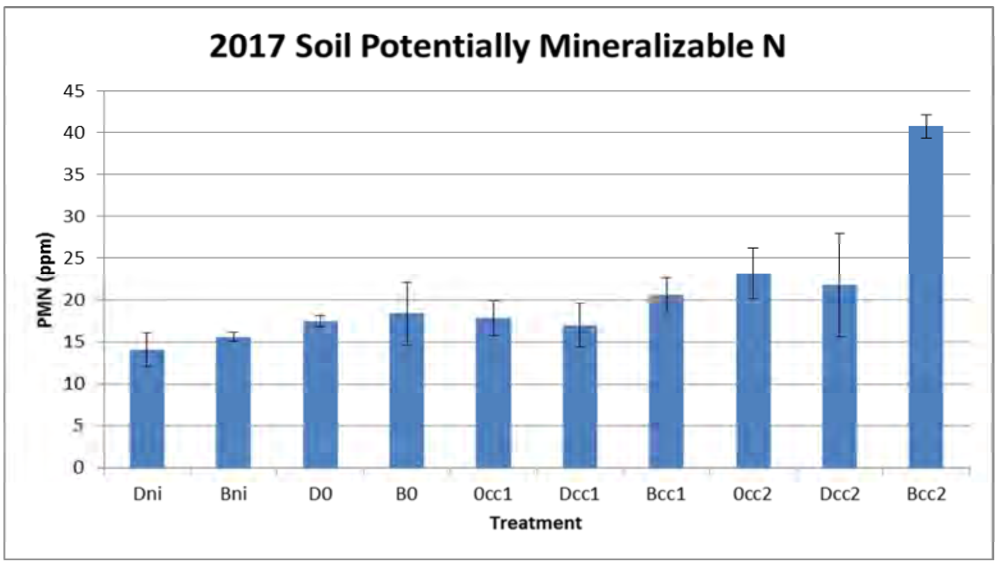

Figure 64: Potentially mineralizable N of cover crop plots

Depth of Soil A Horizon

The plot depths of the soil A horizon at the cover crop field site were very similar though there appeared to be a slight increase across the width of the plots. Depths ranged from 6.5 to 7.5in in the first plot, Dni to a consistent 8in depth in the last plot, Bcc2 (Fig. 65).

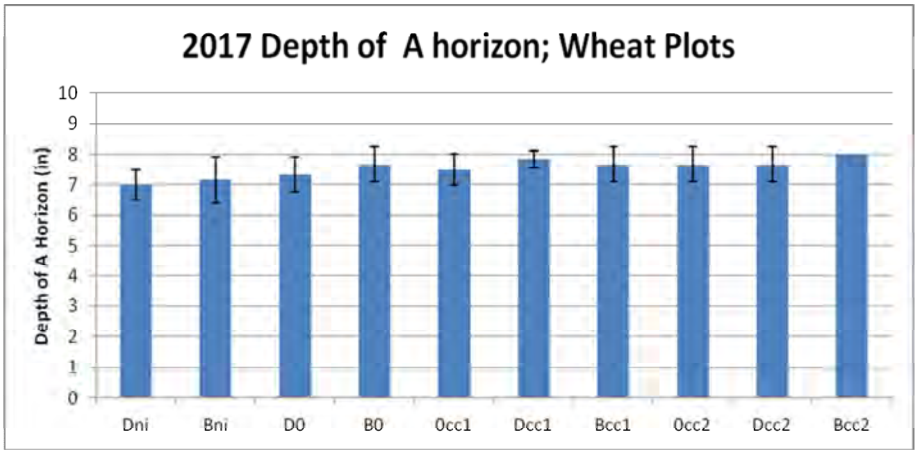

Figure 65: Depth of soil A horizon of cover crop plots

Crop Residue Counts

The level of crop residue (wheat stubble, cover crop tissue, etc.) on the surface of the plots measured using a residue rope the following spring varied across the treatment plots. The cover crop plots Occ1 and Occ2 without an amendment application had significantly higher residue counts than all subplots, but one, over those plots with the addition of an amendment with the same cover crop mixture (Fig. 66). This may be due to more residue incorporation with the amendment pass, and may be with the addition of nitrogen in the amendment, the C:N ratio was lowered and encouraged microbes to decompose more of the plant tissue. The highest level measured in the cc2 treatments was from the greater cover crop biomass produced in those plots with the addition of the overwintering rye species.

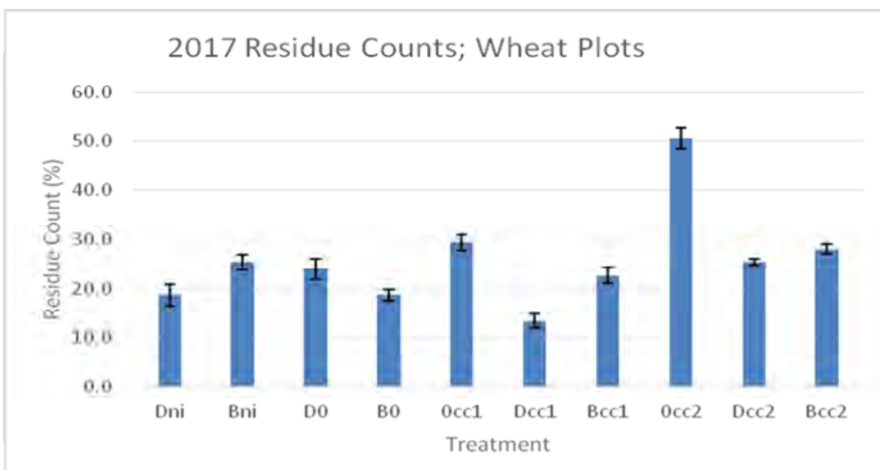

Figure 66: Crop residue counts of cover crop plots

Water Stable Soil Aggregates

The level of water stable aggregates as a measurement of how well the soil holds together in water (indication of soil structure), was variable across treatments with no clear effect of amendment type or addition of cover crop type (Fig. 67). The only clear difference in the water stable aggregate measurement was with the Bcc2 plot that again was likely a reflection of a historical field fence line in that location that continued to provide bettter soil structure after 16 years of cropping.

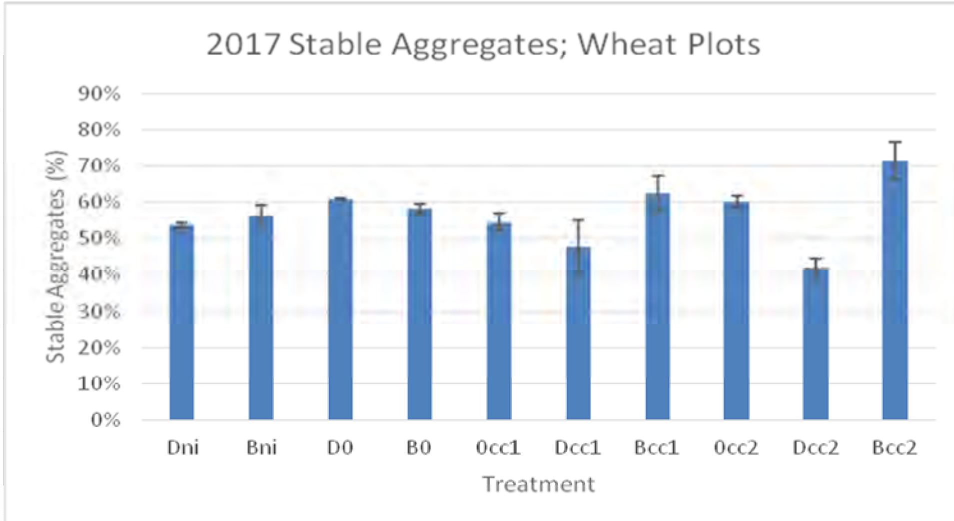

Figure 67: Soil water stable aggregates of cover crop plots

Earthworm Counts

The presence of earthworms measured in a 25cm square profile of the A horizon was used as an indication of the condition of the soil environment and possible improved growing conditions of a soil. Plots with cover crops did have a statistically significant and positive effect on earthworm activity over the treatments without a cover crop. The highest level of earthworm activity was observed in the combination of the digestate amendment and either cover crop mixture in number of earthworms (Fig. 68) and weight of earthworms (Fig. 69). The differences observed between amendment types with cover crops was not observed without cover crops suggesting the higher pH of the biosolid was not likely a factor and also, there was no significant increase between treatments in soil pH sampled for all areas outside the narrow application trench after application through to the following spring.

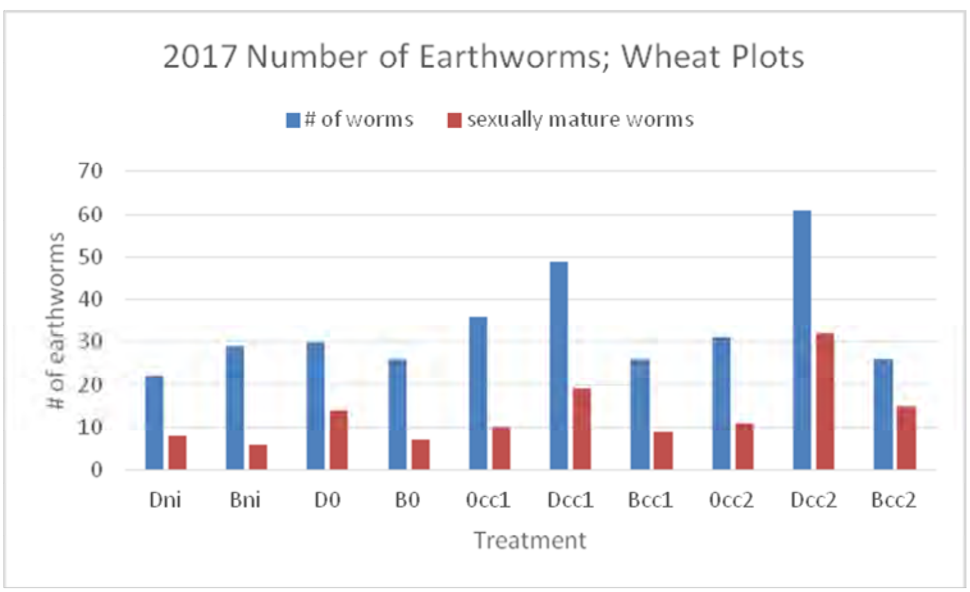

Figure 68: Earthworm number counted from cover crops plots

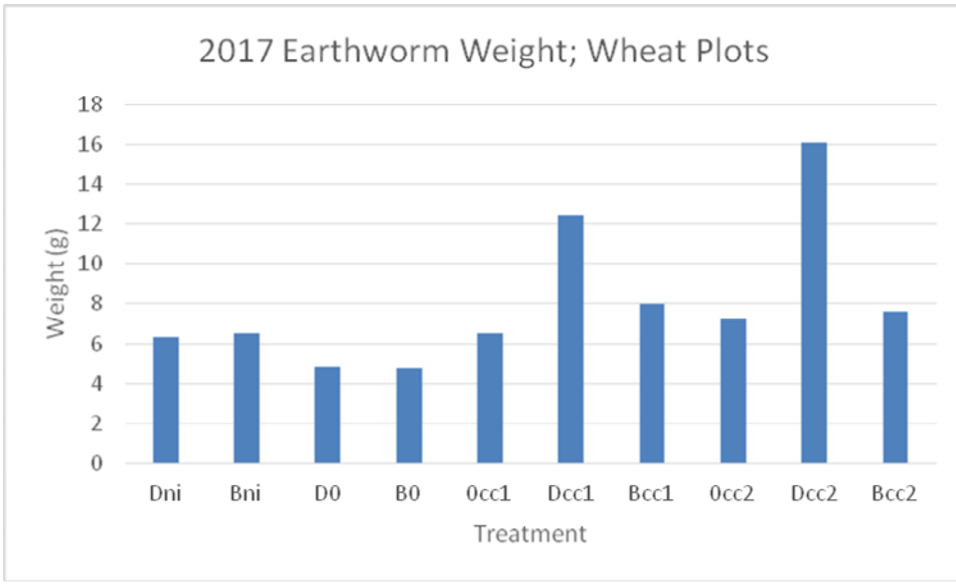

Figure 69: Earthworm weight from cover crop plots

Nematode Counts
Counts of all nematodes as well as the detrimental nematodes such as root lesion, stunt and spiral species taken from soil samples in the spring did not indicate a positive effect of using cover crops in either a reduced number of 'bad' nematodes or the percent of bad to good nematodes (Fig. 70). There was also no signficant difference in nematode counts between the type of amendment applied.

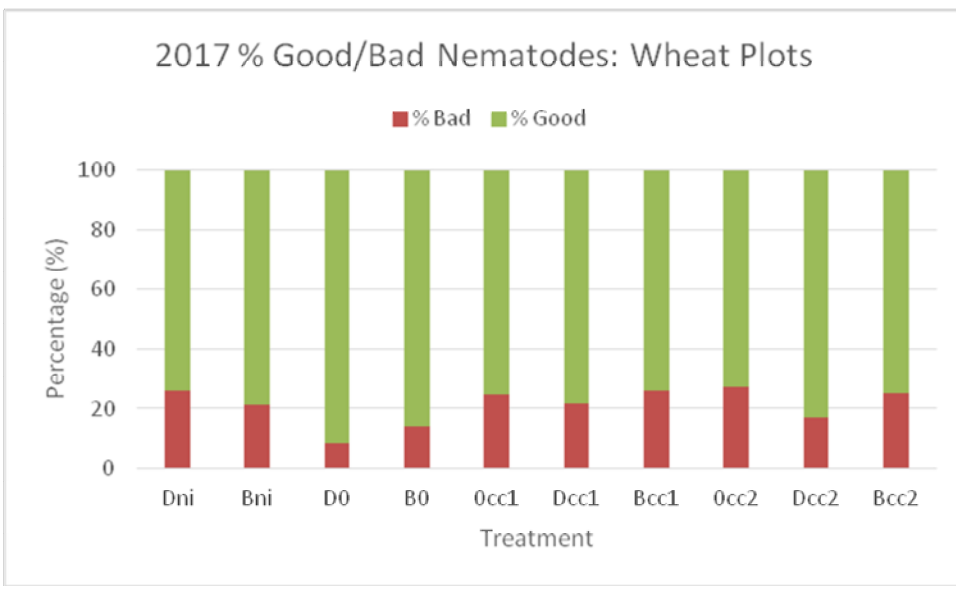

Figure 70: Nematode counts of cover crop plots

3.4 Summary

The use of a digestate and biosolid organic amendment in a 4R approach was assessed over two contrasting growing seasons of 2016 and 2017. Soil N dynamics were affected differently by the heat and drought of 2016 in reducing the available nitrate-N levels from the higher moisture conditions of 2017. Soil nitrate-N peak levels were higher and for a longer period in the plots that received an organic amendment application as an injected side-dress application over the side-dressed nitrogen fertilizer and check plots at both Site years. In 2017, the biosolid application remained higher in soil nitrate throughout the season. The difference in amendment results may be due to the forms of organic nitrogen present in the materials and how quickly organic N may be converted to nitrate N. A detailed N analysis would need to be conducted on both materials to clarify this observation.

The addition of a nitrogen inhibitor to the organic amendments did not have consistent results over the two Site years for the corn plots. The higher soil nitrate levels found in the biosolid treatment of 2017 were reduced with the inhibitor over the plots without its addition. In the 2016/2017 fall application on the cover crop plots, the organic amendment plus inhibitor applications had consistently higher soil nitrates in the fall and into the spring compared to the amendments without the inhibitor added. Further tracking the effect of using the inhibitor would require intense sampling frequency and N speciation which was not within the scope of this project to differentiate between factors such as the rate of nitrate production or plant uptake or nitrate leaching.

In the cover crop trial, including the overwintering cover crop resulted in a lowering of soil nitrate levels in the spring compared to the fall winter kill cover crops. This would likely indicate that nitrogen was retained in the living plant roots and tissue and that an overwintering cover crop would be an effective BMP to help retain N especially if an organic material is applied in the fall.

Measurement of water extractable P, as an indication of what could be lost in tile or overland runoff, was at such low levels that a reasonable comparison of treatments was prevented. High rates of P were applied, however, because application rates were based on recommended N rates. Changes to the soil WEP with an application of an amendment were still not detected as the levels were approaching low laboratory detection limits.

Soil test levels of K and P were low (at or below sufficiency range) at all the field sites. There was not a consistent or substantial increase measured after the application of the nutrient rich amendments. Some increases in soil K and P were observed in 2017 corn and 2016/2017 cover crop plots but not in the 2016 corn plots. This may have been related to soil moisture as 2016 was droughty for most of the growing season and mobile nutrients (K) may not have diffused as much from the application band into the soil sampling zone. Similarly, the lack of significant response in measured soil P concentrations following excessive P additions in the organic amendments was likely due to the intentional avoidance of the application band while soil sampling and the immobility of phosphorus in the soil.

Soil organic matter did not change over the course of these experiments. A measureable increase in soil organic matter takes years of organic carbon inputs and other organic matter building BMPs.

Plant tissue levels of nutrients measured in the two corn crop years reflected the low soil levels of nutrients in most cases. In 2016, the STK was low which contributed to low tissue K samples and also likely contributed to lower yields in plots not receiving an organic amendment. Furthermore, there may have been an antagonistic relationship between high levels of Ca added to soil in the amendment and plant uptake of Mg in the amended plots in 2016 though this effect was not evident in 2017. The application of amendments in a narrow band may affect the availability of micronutrients especially in a dry year when applied materials remain concentrated in the soil.

The corn harvest results from both field sites indicated that the organic amendment treatments applied at crop recommended rates were similar or greater in yield than the fertilizer N treatment.

4.0 Conclusions

The study over the 2016 and 2017 growing seasons had differing weather conditions, site conditions and management histories and illustrated that municipal organic amendments can be effectively used under a 4R approach in providing a corn crop with sufficient available nutrients and result in similar yields when compared to commercial fertilizer using the same nitrogen rate.

Fall application of these amendments after the growing season with cover crops proved to be a successful BMP. Cover crops helped to retain nitrogen as well as other nutrients from loss to the environment overwinter to the following spring. The addition of macro and micronutrients and organic matter present in the municipal organic amendments contributed to improved crop growth and soil health.