Tracking Post-Harvest Soil Nitrate in Agricultural Fields in the Hullcar Valley in 2018-19

Final Report

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Short title: 2018-19 Post-Harvest Nitrate Study: Hullcar Valley

Final Report

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Summary

The nitrate left in the soil profile after harvest is particularly susceptible to leaching to groundwater during non-cropped months when precipitation exceeds evapotranspiration. Measuring the nitrate remaining after crop harvest is conducted through a post-harvest nitrate test (PHNT), a measure for both environmental and agronomic objectives. In 2018, post-harvest nitrate tests were completed on 39 fields lying above Aquifer 103 in the Hullcar Valley of the North Okanagan to a 90 cm depth. Overall, 80% of the total sampled land area (31 fields) had PHNT values less than 100 kg NO_3-N ha^{-1} in the 0-90 cm profile. The area-weighted average PHNT was 25% greater (15 kg N ha^{-1}) in 2018 than in 2017, and the median PHNT of the overall study area was 36% (18 kg N ha^{-1}) greater in 2018 than in 2017. These measures decreased in fields cropped with corn silage and increased in fields cropped with alfalfa/grass, from 2017 to 2018. This indicates that nitrogen management practices in alfalfa/grass are likely the main driver of the increase in PHNT values and may need to be re-evaluated if the trend continues. However, the reduction in fields cropped with corn silage indicates an improvement in N management.

Among the fields sampled, 64% of the nitrate in the top 90 cm of soil was found in the 0-30 cm layer on average, while 19% and 17% was found in the 30-60 cm and 60-90 cm layers, respectively. This distribution of nitrate suggests that most nitrate had not leached below the 30-cm soil depth during the 2018 growing season. The nitrate found in the uppermost layer is less likely to leach below the root zone before the 2019 growing season, compared to nitrate in the deeper layers.

A Benchmark study was also established at six sites to determine the potential for nitrate leaching over the non-growing season. From October 2018 through April 2019, nitrate was found to have leached out of either the 0-30 cm, 30-60 cm, or 60-90 soil layer in five of the six sites. Additionally, nitrate leached below the 90-cm depth in four of the six sites over the course of this period. These results show that nitrate leaching occurred much more frequently during this study period than in previous study periods. While the nearby Vernon North weather station was not functional for much of the Benchmark period, it is likely that a greater than average amount of precipitation was responsible for the greater than usual nitrate leaching based on the soil moisture content of samples taken during the Benchmark study.

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1 Introduction

Agricultural activity in the Hullcar Valley in the North Okanagan of British Columbia is dominated by forage crops grown for livestock feed, and a smaller portion of the agricultural area has other cropping systems (Poon and Code 2017). In recent years, the water quality of Aquifer 103 in this area has had elevated nitrate concentrations. Environmental impact studies suggest that the elevated nitrate concentrations observed in Aquifer 103 now are due to significant over-application of nitrogen (N) on some agricultural fields in the past, perhaps decades ago since the time of travel for nitrate to move through the unsaturated zone to the water table of this aquifer may be several years or even in the order of decades (Associated Environmental 2016; 2017a; 2017b). To minimize the potential for additional nitrate losses from agricultural activity in the future, it is important for producers to minimize the amount of nitrate left in the soil root zone after crop harvest, which can be measured using a post-harvest nitrate test (PHNT).

Results of a PHNT can be used as both an agronomic and an environmental tool as PHNT values are useful in evaluating nutrient management decisions and to aid in evaluating the risk of nitrate leaching to groundwater. To interpret PHNT results, the difference between the agronomic N and crop N removal rates needs to be understood. The agronomic N rate is the N application rate at which crop growth and yield is not limited. This rate is always greater than the crop N removal rate, which is the amount of N that the crop removes from the soil. Since no crop uses all N in the soil, a certain amount of post-harvest nitrate is expected. The amount depends on several factors, including crop, soil type, and weather. If PHNT values exceed what is expected, then it can indicate an overapplication of N or a miscalculation in the field's N budget.

In 2016 and 2017, PHNT testing was completed in the region to determine year-to-year trends in PHNT levels and determine if there was an opportunity to improve N management practices (Poon and Code 2017; Poon and Code 2018). Results in 2017 showed that PHNT values were below the 'High' rating of 100 kg NO_3-N ha^{-1} in most fields and that PHNT values were reduced in many fields when compared to 2016 results. Sampling and testing of post-harvest nitrate in the fall of 2018 was used as an opportunity to continue evaluation of PHNT values in the study area.

In addition to monitoring for post-harvest nitrate, Benchmark testing was completed in 2016 to 2017 and 2017 to 2018 to determine the movement of nitrate through the soil profile during the non-growing season. Previous studies (Kowalenko et al. 2009; Poon and Code 2017) showed limited movement within the 0-90 cm soil profile while recent data (Poon and Code 2018) showed that nitrate can leach below the 0-90 cm depth over the course of the non-growing season. While precipitation is the main determining factor in nitrate leaching in soil and an above-average amount of precipitation was observed during the noted study period, it is clear that nitrate movement below 90 cm has the potential to occur between growing seasons. Therefore, additional monitoring is needed to determine the relative frequency of nitrate leaching based on actual environmental conditions in the Hullcar Valley.

The objective of this report is to 1) determine the amount and distribution of post-harvest nitrate in sampled fields in the Hullcar Valley in order to inform area producers' decisions on N management and 2) to monitor the movement of nitrate through the soil profile in order to assess the use of post-harvest nitrate testing as an environmental tool.

Primary Questions

1. Overlying Aquifer 103 and the nearby area, how many agricultural fields had elevated levels of post-harvest soil nitrate in the 0-90 cm layer of soil in 2018?
2. How is nitrate distributed throughout the three soil sampling depths (0-30, 30-60, and 60-90 cm) in 2018?
3. How did PHNT levels compare between 2017 and 2018 in fields that had the same crop type?
4. Does nitrate leach through and below the 0-90 cm layer of soil between growing seasons in the area overlying Aquifer 103?

Hypotheses

1. Most agricultural fields in the area had less than 100 kg N ha^{-1} of post-harvest soil nitrate (0-90 cm soil layer) in 2018.
2. The majority (>50%) of nitrate was found in the 0-30 cm soil layer for each crop type in 2018.
3. PHNT levels did not increase from 2017 levels.
4. Soil nitrate leached within but not below the 90 cm depth of soil between growing seasons.

Out of Scope

- Measuring nitrate leaching during the growing season, possibly due to over-irrigation or quantities of rainfall significant enough to cause leaching
- Measuring nitrate leaching from non-cropped areas, such as manure storage areas
- Measuring N transformations, such as mineralisation or denitrification, that influence soil and water nitrate concentrations
- Measuring N uptake or N use efficiency of harvested crops
- Measuring soil water movement or retention
- Update nutrient management plans, including assessing relationships between nitrogen management practices and PHNT results

2 Materials and Methods

Study area

The study area was mostly overlying Aquifer 103 in the Hullcar Valley of the North Okanagan, located south of Grindrod, B.C. The agricultural activity, crops, and soils of the region have previously been described by Poon and Code (2017). The average annual precipitation of the study area is 480 mm and the daily mean temperature ranges from a low of -2.3C in January to a high of 20.2C in July.

The period of N management and post-harvest sampling ranged from May through October of 2018. During this period, the study area received 248 mm of precipitation compared to the long-term average (LTA; 1981-2010) of 306 mm of precipitation for the same period (Table 1), though fields in the survey area received supplemental irrigation. Additionally, monthly average air temperature exceeded that of the LTA for three of the six survey months.

Table 1. Cumulative precipitation and average temperature for summer through fall of 2016 - 2018 and the long-term average (LTA; 1981-2010) values at the Vernon North station.

	Cumulative precipitation (mm)				Temperature (°C)			
Month	2016	2017	2018	LTA	2016	2017	2018	LTA
May	35.4	76.3	22.5	59.4	14.8	13.9	16.8	12.5
June	32.0	12.4	78.3	65.7	17.1	17.4	16.5	16.2
July	35.1	0.8	22.8	46.1	19.4	21.0	20.1	19.1
August	15.5	2.4	21.6	37.5	20.2	20.0	18.3	18.5
September	44.8	12.7	77.5	43.4	13.1	15.4	13.0	13.2
October	85.3	42.2	25.2	54.2	8.2	6.8	6.7	6.7
Total	248.1	146.8	247.9	306.3	-	-	-	-

Data: Environment Canada 2018.

2.1 Post-Harvest Soil Testing

Field Selection and Sampling Methodology

Thirty-eight of the thirty-nine fields sampled for post-harvest nitrate in 2017 were sampled again in 2018 (Supplemental Figures 1 & 2). One field was removed from production while another was added, leading to a total of thirty-nine fields sampled for PHNT in 2018. Within a field, nitrogen was applied at the same rate and method. All of the original nine fields that were split into two sampling areas were also split in 2018. These splits were originally made to due to differences in soil types or to reduce the total area of a field to under 25 ha. In summary, there were 39 fields and 48 sampling areas in 2018. The numbering system for sampling areas used in 2017 was also used in 2018. Changes to the numbering system from 2016 through 2018 is summarized in Supplemental Table 1.

The total area sampled increased to 791 hectares in 2018 from 776 in 2017 (Table 2). Alfalfa/grass was grown on one additional sampling area than in 2017 but the total cropped area was reduced from 344 to 335 hectares. Silage corn was grown on the same number of sites as 2017 and increase in total cropped area from 323 to 369 hectares. Both nursery trees and winter wheat were grown on 68 and 19 hectares in 2018, respectively, while canola was no longer grown in the study area during this period.

The soil sampling methodology was consistent with those used previously in 2016 and 2017 (Poon and Code 2017; Poon and Code 2018). For each sampling area, one composite soil sample was taken at the 0-15, 15-30, 30-60, and 60-90 cm depths from twenty random locations throughout each field. In 2018, fields were sampled from 20 September through 23 October, and each field was sampled within 10 days of harvest.

Analyses

The laboratory and data analyses were the same as in previous years (Poon and Code 2017; Poon and Code 2018). After sampling, soil samples were refrigerated during delivery to prevent changes in nitrogen concentrations through microbial activity. Samples were then air-dried, sieved, extracted with potassium chloride, and analyzed by A&L Canada Laboratories (London, ON).

The concentration of extractable soil nitrate-nitrogen was converted to kg NO_3-N ha^{-1} using soil bulk densities of 1300 kg m^{-3} for the 0-30 cm soil layer and 1500 kg m^{-3} for the 30-60 and 60-90 cm soil layers. The total amount of nitrate-nitrogen found in the 0-90 cm soil layer were categorized into four categories (Kowalenko et al. 2009): Low (0-49 kg NO_3-N ha^{-1}), Medium (50-99 kg NO_3-N ha^{-1}), High (100-199 kg NO_3-N ha^{-1}), and Very High (≥ 200 kg NO_3-N ha^{-1}).

2.2 Benchmark Testing

Six benchmark sites were established for four rounds of soil sampling from mid-October 2018 through early April 2019 in order to determine NO_3-N movement over the non-growing season. As in previous years of Benchmark Testing, the sites were located within larger fields previously sampled for Post-Harvest Nitrate Testing. Five of the six sites had previously been used for Benchmark Testing in the 2017 Post-Harvest Nitrate Study (Sites 6, 17, 26, 31, and 38) while one was previously unused (Site 4) (Poon and Code 2018). A range of soil types were represented within the Benchmark study area (Table 2).

Each site was roughly 70 to 140 m^2 in size and evenly divided into three replicate blocks. In each replicate block, one composite soil sample was taken at the 0-30 cm, 30-60 cm, and 60-90 cm depths each. Twelve 4.4-cm diameter soil cores were taken for each composite soil sample. Samples were taken from each replicate block in mid-October 2018, mid-November 2018, mid-March 2019, and early April 2019.

Table 2. Soil descriptions at the Benchmark sites. Bulk density was estimated using the podotransfer function described by Saxton and Rawls (2006) based on proportions of sand, clay, and organic matter content.

Site/ Layer	Sand%	Clay%	Textural Class	Organic Matter%	Estimated bulk density (kg m^{-3})
			Site 4 (alfalfa/grass)		
0-30 cm	73	10	Sandy loam	4.2	1350
30-60 cm	79	8.9	Loamy sand	1.6	1520
60-90 cm	87	5.9	Loamy sand	0.9	1530
			Site 6 (corn silage)		
0-30 cm	54	13	Sandy loam	2.3	1470
30-60 cm	58	10	Sandy loam	1.5	1530
60-90 cm	69	4.7	Sandy loam	1.2	1530
			Site 17 (alfalfa/grass)		
0-30 cm	34	10	Silt loam	2.5	1420
30-60 cm	35	9.4	Silt loam	1.0	1560
60-90 cm	53	5.1	Sandy loam	0.9	1570
			Site 26 (corn silage)		
0-30 cm	65	10	Sandy loam	5.4	1250
30-60 cm	71	6.0	Sandy loam	1.2	1530
60-90 cm	93	0.4	Sand	1.2	1450
			Site 31 (corn silage)		
0-30 cm	64	8.0	Sandy loam	5.4	1330
30-60 cm	79	4.6	Loamy sand	2.3	1510
60-90 cm	94	0.3	Sand	1.8	1460
			Site 38 (corn silage)		
0-30 cm	33	20	Loam	6.5	1110
30-60 cm	31	26	Loam	1.5	1460
60-90 cm	25	34	Clay loam	1.4	1420

3 Results and Discussion

3.1 Post-Harvest Soil Testing

2018 Results

Overall, 27% of the total sampled land area had a 'Low' PHNT rating (9 fields), 53% had a 'Medium' rating (22 fields), 18% had a 'High' rating (7 fields), and 2% had a 'Very High' rating (1 field) (Figure 1). This supports the hypothesis (Hypothesis 1) that most fields had PHNT values less than 100 kg NO_3-N ha^{-1} in 2018.

Table 3. Sampling area and post-harvest nitrate test statistics for the 2018 post-harvest soil sampling period.

Crop type	No. of sampling areas	Area sampled	Area-weighted average PHNT[a]	Maximum PHNT	Median PHNT	Minimum PHNT
	-	(ha)	-------------------kg NO_3-N ha^{-1}			-------------------
Alfalfa/grass	20	335	80	137	71	37
Silage corn	23	369	69	185	57	18
Winter wheat	2	19	206	212	195	179
Nursery trees	3	68	40	47	42	36
All crops	48	791	75	212	68	18

[a] In an area-weighted average, sampling areas that were larger in size contributed more to the average PHNT value compared to areas that were smaller. In contrast, all areas contribute equally to a simple average regardless of the size of the area.

There were differences in average post-harvest nitrate (0-90 cm) between crop types in 2018 (Table 3). Winter wheat had the greatest area-weighted average PHNT while nursery trees had the lowest, though they only accounted for 2.4% and 8.6% of the

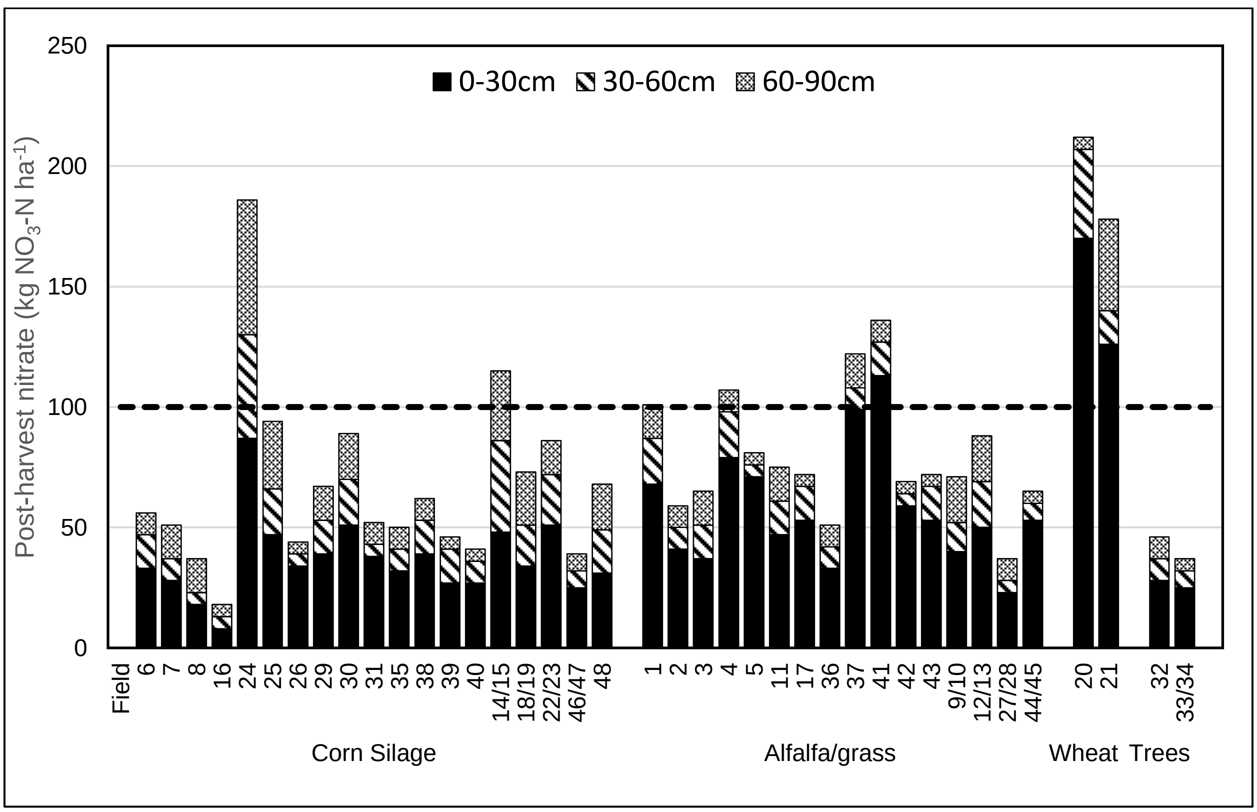

Figure 1. The PHNT value (0-90 cm) of each sampled field in the study area in 2018. The dotted line represents 100 kg NO_3-N ha^{-1}, the point at which the PHNT value is considered 'High' (Kowalenko et al. 2009).

total sampled land area, respectively. Alfalfa/grass had the next largest area weighted average PHNT with 80 kg N ha^{-1} while silage corn had a lower value of 69 kg N ha^{-1}, giving both crop types an area-weighted average 'Medium' rating. These crops accounted for 42% and 47% of the total sampled land area, respectively. Unlike in 2016 and 2017, the area-weighted average PHNT was not split between annual/perennial crops.

Of the nine fields that were split into two sampling areas, all sampling areas had the same agronomic PHNT rating as their complementary sampling area (Table 4). This suggests that these fields could be sampled as one unit if there are no differences in management or soil characteristics. However, differences in soil characteristics in one field that affect soil microbial N transformations may cause future agronomic PHNT ratings to differ. These soil characteristics include soil texture, organic matter content, and soil bulk density. Therefore, the nine fields will continue to be split into two sampling areas to monitor any differences in PHNT levels for future reports.

Table 4. 2018 Post-harvest nitrate test (PHNT) levels in fields that were split into two sampling areas.

	Paired sampling areas				Combined areas[a]	
Crop type	Sampling Area #	Area (ha)	PHNT (kg N ha^{-1})	Agronomic PHNT rating[b]	PHNT (kg N ha^{-1})	Agronomic PHNT rating
Alfalfa/grass	9	13	61	Medium	71	Medium
	10	15	80	Medium		
Alfalfa/grass	12	20	77	Medium	88	Medium
	13	21	98	Medium		
Corn silage	14	20	123	High	115	High
	15	21	107	High		
Corn silage	18	14	71	Medium	72	Medium
	19	15	72	Medium		
Corn silage	22	15	87	Medium	86	Medium
	23	10	85	Medium		
Corn silage	27	15	30	Low	37	Low
	28	15	43	Low		
Nursery trees	33	17	29	Low	36	Low
	34	24	43	Low		
Alfalfa/grass	44	14	61	Medium	64	Medium
	45	16	67	Medium		
Corn silage	46	17	37	Low	40	Low
	47	8	43	Low		

[a] Combined PHNT results are an area-weighted average of the two sampling areas of a field.
[b] Ratings: Low (0-49 kg NO_3-N ha^{-1}), Medium (50-99 kg NO_3-N ha^{-1}), High (100-199 kg NO_3-N ha^{-1}), and Very High (≥ 200 kg NO_3-N ha^{-1}).

Some inferences on N application rates can be made. An assumed N uptake of 50% of applied N (Hermanson et al. 2000), along with guidance from Sullivan and Cogger (2003) for the area-weighted average PHNT value for silage corn, indicated that N was applied at an agronomic rate. The area-weighted average PHNT value for alfalfa/grass, however, suggests that N applications can either be reduced or more effectively timed as PHNT values for alfalfa/grass can be expected to be lower than for silage corn (Kowalenko et al. 2007, Kowalenko et al. 2009, Sullivan and Poon 2016). This relative difference is because of the perennial lifecycle of alfalfa and grass, and their extended growing season compared to silage corn (Sullivan and Cogger 2003). The high area-weighted average PHNT results for the winter wheat fields (206 kg N ha^{-1}) do not necessarily indicate that N applications were excessive or timed poorly; rather, the high nitrate levels increased because the farmer ploughed the soil before PHNT sampling, after the crop had failed.

In 2018, a significant portion of total nitrate for each field was found in the uppermost 0-30 cm sampling zone (Fig. 2), supporting the hypothesis (Hypothesis 2) that most of the residual nitrate was found in this zone. Overall, the average area-weighted portion of nitrate in the 0-30 cm layer was 64%, while the 30-60 cm layer and 60-90 cm layer had 19% and 17%, respectively. In this study, the additional value of the nitrate data from sampling to a lower depth (from 30 cm to 60 cm, or 60 cm to 90 cm) may not have warranted the extra effort required to sample to lower depths. At some depth, certainly at depths below the root zone, sampling deeper describes excess nitrate that originated from previous cropping years, rather than the nitrate not used during the cropping year that immediately passed before sampling.

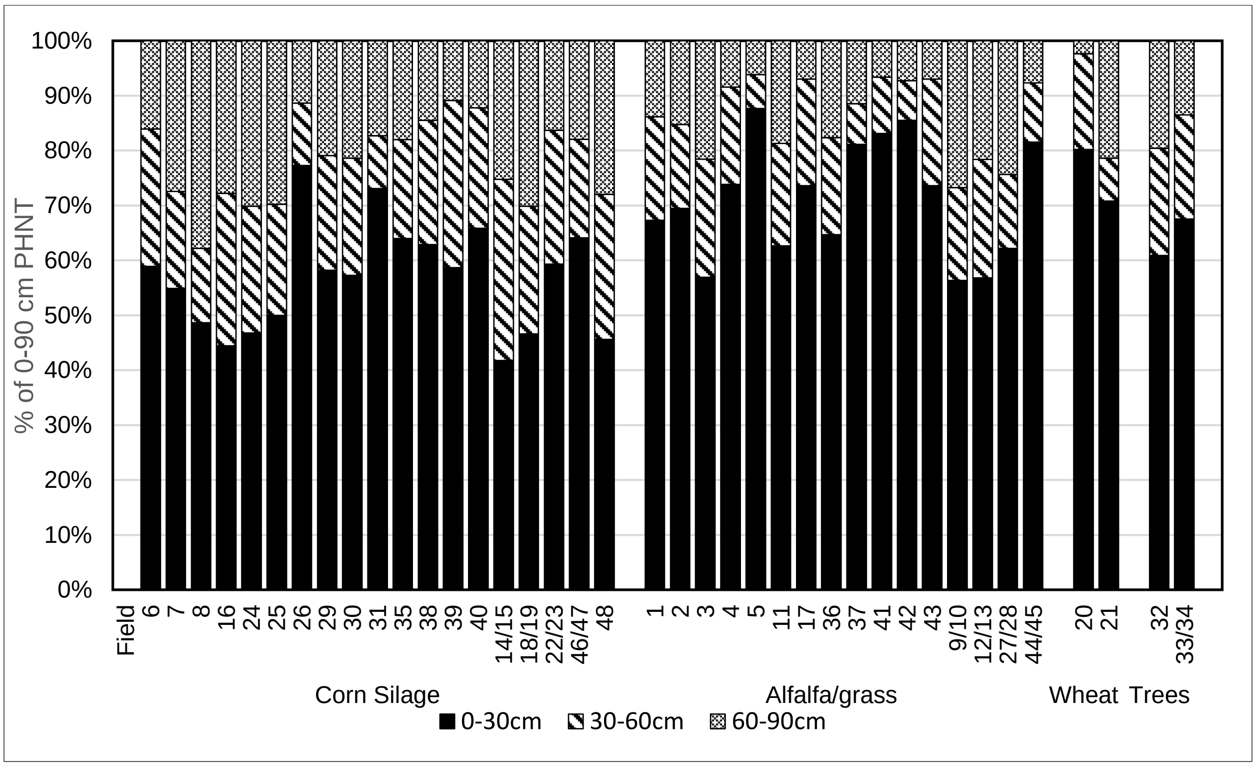

Figure 2. The percentage of total nitrate found in the 0-30, 30-60, and 60-90 soil layers for fields that were sampled in 2018.

Comparisons between years

Overall, a greater percentage of the sampled land area and number of fields had 'Medium', 'High' or 'Very High' post-harvest nitrate in 2018 than in 2017, indicating an overall increase in PHNT levels (Table 5, Supplemental Figures 3 & 4). This does not support the hypothesis (Hypothesis 3) that PHNT levels did not increase from 2017. However, these values were lower than when PHNT sampling and analysis was first conducted in 2016.

Table 5. The percent land area and number of fields in the sampling area that had a 'Low', 'Medium', 'High', or 'Very High' PHNT rating from 2016 - 2018.

	2016		2017		2018	
Agronomic PHNT rating[a]	% land area	No. fields	% land area	No. fields	% land area	No. fields
Low	16.7	5	50.4	18	27.5	9
Medium	39.0	16	41.3	16	52.7	22
High	35.9	14	7.6	4	17.9	7
Very High	8.4	4	0.7	1	2.0	1

[a] Ratings: Low (0-49 kg NO_3-N ha^{-1}), Medium (50-99 kg NO_3-N ha^{-1}), High (100-199 kg NO_3-N ha^{-1}), and Very High (≥ 200 kg NO_3-N ha^{-1}).

When compared to results from 2017, both the area-weighted average PHNT value and median PHNT value of the entire study area were greater in 2018 (Supplemental Table 2, Table 3). However, these measures decreased in fields cropped with corn silage and increased in fields cropped with alfalfa/grass. This indicates that N management practices in alfalfa/grass is likely the main driver of the increase in PHNT values and may need to be re-evaluated if the trend continues. However, the reduction in fields cropped with corn silage indicates an improvement in N management.

Year-to-year trends in PHNT values for a given field can only be compared if the crop is the same between years. From 2017 to 2018 in such fields, 5 corn silage fields had no change in PHNT values (±25 kg NO_3-N ha^{-1}), 5 fields had an increase in PHNT values, and 8 fields decreased (Supplemental Table 3). In alfalfa/grass fields, however, there was no change in PHNT values for 5 fields from 2017 to 2018, 9 fields had an increase, while 2 fields had a decrease in PHNT values (Supplemental Table 4). Both fields planted with trees did not see a change in PHNT values from 2017 to 2018 (Supplemental Table 5).

One factor that potentially led to an increase in PHNT values from 2017 to 2018 is a dramatic increase in rainfall during the growing season, which was more than 100 mm (Table 1). Combined with several months of temperatures that were above the long-term average, increased mineralisation and nitrification of soil organic matter could have exceeded crop demand.

3.2 Benchmark Testing

Half of the Benchmark sites did not have significant changes in NO_3-N concentrations in the 0-30 cm layer during the study period (Sites 6, 17, and 31) while there were significant changes at the remaining sites (Sites 4, 26, and 38) (Figures 3-5, Supplemental Table 7). Sites 4, 26, and 38 all had significant increases and then decreases over the sampling period, likely from the mineralization and nitrification of soil organic matter or recently applied manure into NO_3-N which was then leached from the uppermost soil layer.

Three of the six Benchmark sites had significant changes in NO_3-N concentrations at the 30-60 cm depth. Concentrations of NO_3-N increased and later decreased at this depth at Sites 4, 26, and 31 (Figures 3 & 4, Supplemental Table 7), indicating a movement of NO_3-N from the uppermost soil layer and later down into the 60-90 cm layer.

Sites 17 and 26 both had significant increases and decreases in NO_3-N concentration at the 60-90 cm depth due to NO_3-N movement into the soil layer and later out of the sampled soil profile (Figure 4, Supplemental Table 7). Site 4 also showed a significant decrease in NO_3-N concentration at the 60-90 cm depth over the course of the monitoring period (Figure 3, Supplemental Table 7). Three sites (Site 6, 31, and 38) had no significant changes in NO_3-N concentration at the 60-90 cm depth (Figures 3 & 5, Supplemental Table 7). However, Site 38 did have a loss of approximately 75 kg NO_3-N ha^{-1} from the soil profile over the course of the monitoring period.

Results do not support the hypothesis that NO_3-N leaching only occurred within but not below the 90-cm depth during the non-growing season (Hypothesis 4). Overall, five of the six sites had significant movement of NO_3-N among the three soil layers and four of the six sites leached NO_3-N below the 90-cm depth. Only one site, Site 6, did not have any significant changes in NO_3-N concentration or loss from the soil profile during the monitoring period. While no significant changes were observed at this site, the trend does indicate that NO_3-N leaching through and below the sampled soil profile may have occurred (Figure 3, Supplemental Table 7).

As weather data was not available at the Vernon North weather station for much of the monitoring period, it is hard to determine the effect that precipitation had on soil moisture or that temperature had on mineralization and nitrification of organic matter. However, the movement of NO_3-N below the 90-cm sampling depth, along with relatively high soil moisture contents at several sites (Supplemental Table 6), does imply that precipitation was fairly significant. In fact, NO_3-N movement both within and below the sampled profile occurred more frequently than in previous studies (Poon and Code 2017, Poon and Code 2018), suggesting that precipitation during the non-growing season may have been more substantial during this monitoring period than during previous Benchmark studies. In previous studies (Poon and Code 2017, Poon and Code 2018), as well as another study in the North Okanagan (Kowalenko et al. 2009), NO_3-N leaching was rarely observed below the 90-cm depth.

The NO_3-N concentration at the 30-60 and 60-90 cm depths was generally low, indicating that the concentration of NO_3-N did not pose a significant risk to groundwater quality when it moved below 90 cm. Since leaching below the 90-cm depth was observed at four of the six Benchmark sites, however, it would still be prudent to manage soil N appropriately.

4 Conclusions

Overall, N was managed optimally in most fields in 2018. While a smaller percentage of the sampled land area was below 100 kg NO_3-N ha^{-1} in 2018 than 2017, the vast majority (80%) was still below the 100 kg NO_3-N ha^{-1} threshold. Some leaching of NO_3-N below the sampled soil profile was observed; however, concentrations of leached NO_3-N were not likely to have a significant impact on groundwater quality. As NO_3-N movement below the 90-cm sampling depth was more widespread than in previous studies, it is likely that the North Okanagan region is more susceptible to NO_3-N leaching than previously assumed. Therefore, producers should continue to manage N to reduce the potential of N loss to groundwater.

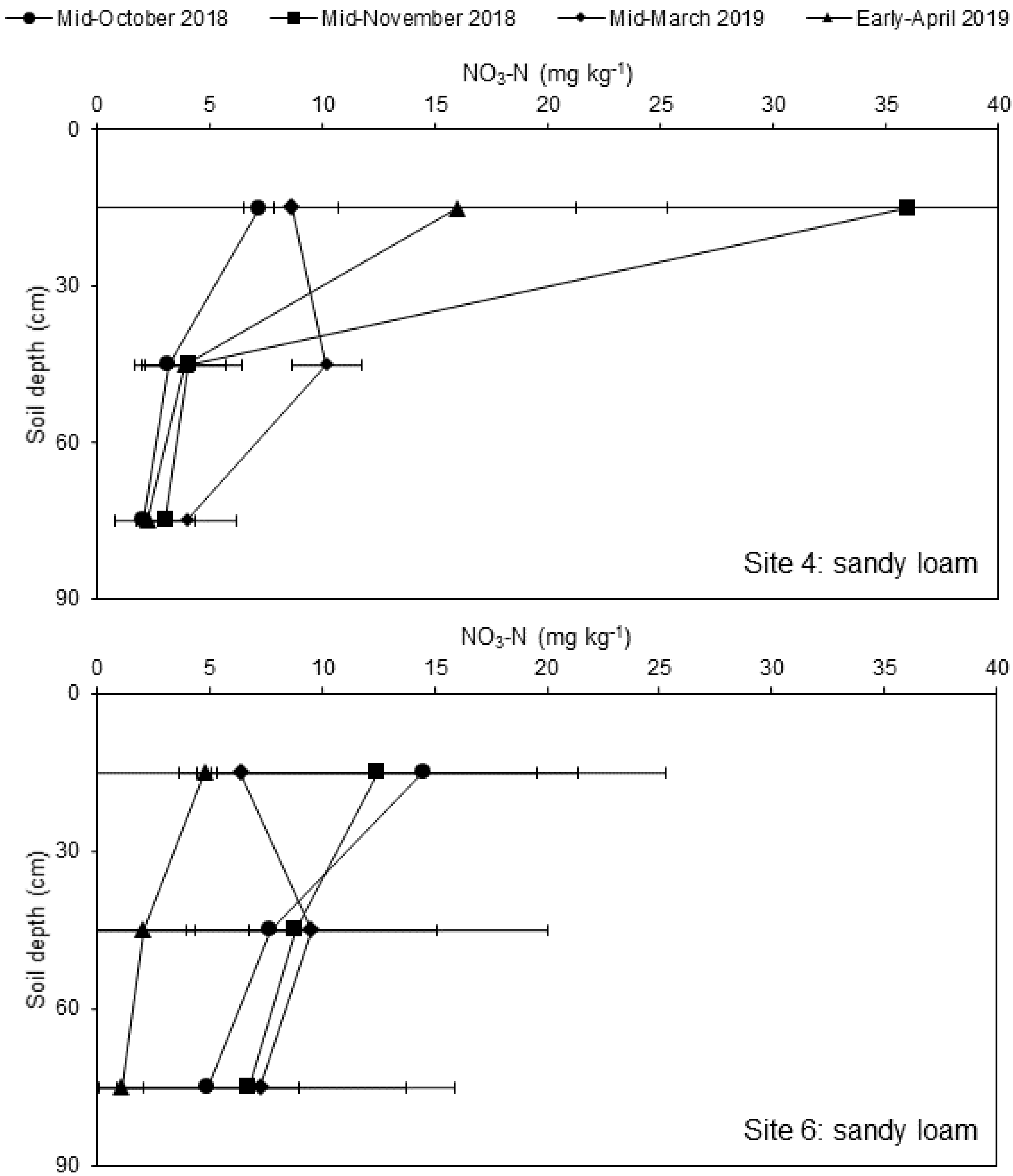

Figure 3. Changes in NO_3-N concentration at two sites (Sites 4 and 6) from October 2018 through April 2019. Points represent the midpoint of each 30-cm sampling layer. Errors bars represent two standard deviations from the mean (95% confidence interval).

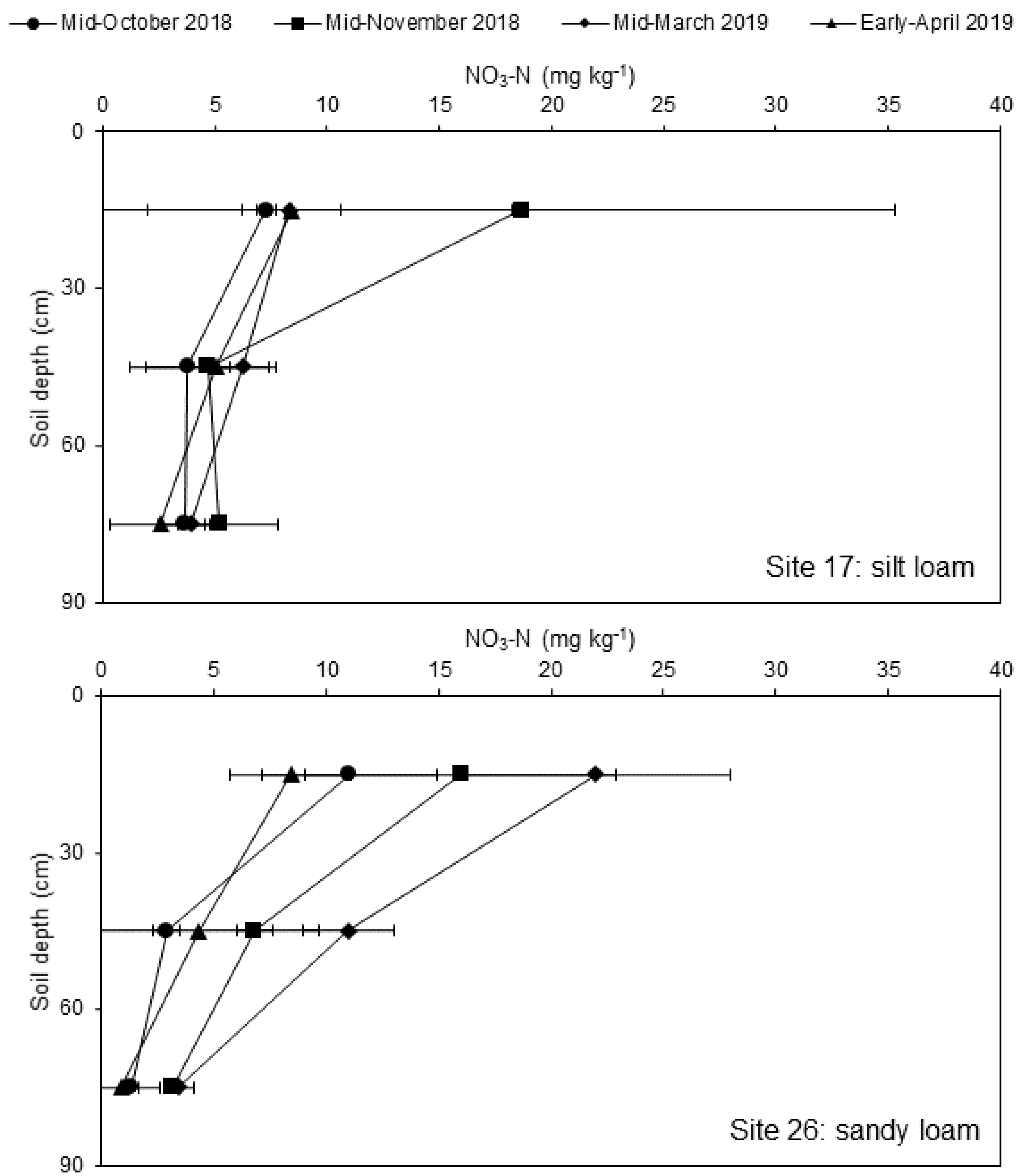

Figure 4. Changes in NO_3-N concentration at two sites (Sites 17 and 26) from October 2018 through April 2019. Points represent the midpoint of each 30-cm sampling layer. Errors bars represent two standard deviations from the mean (95% confidence interval).

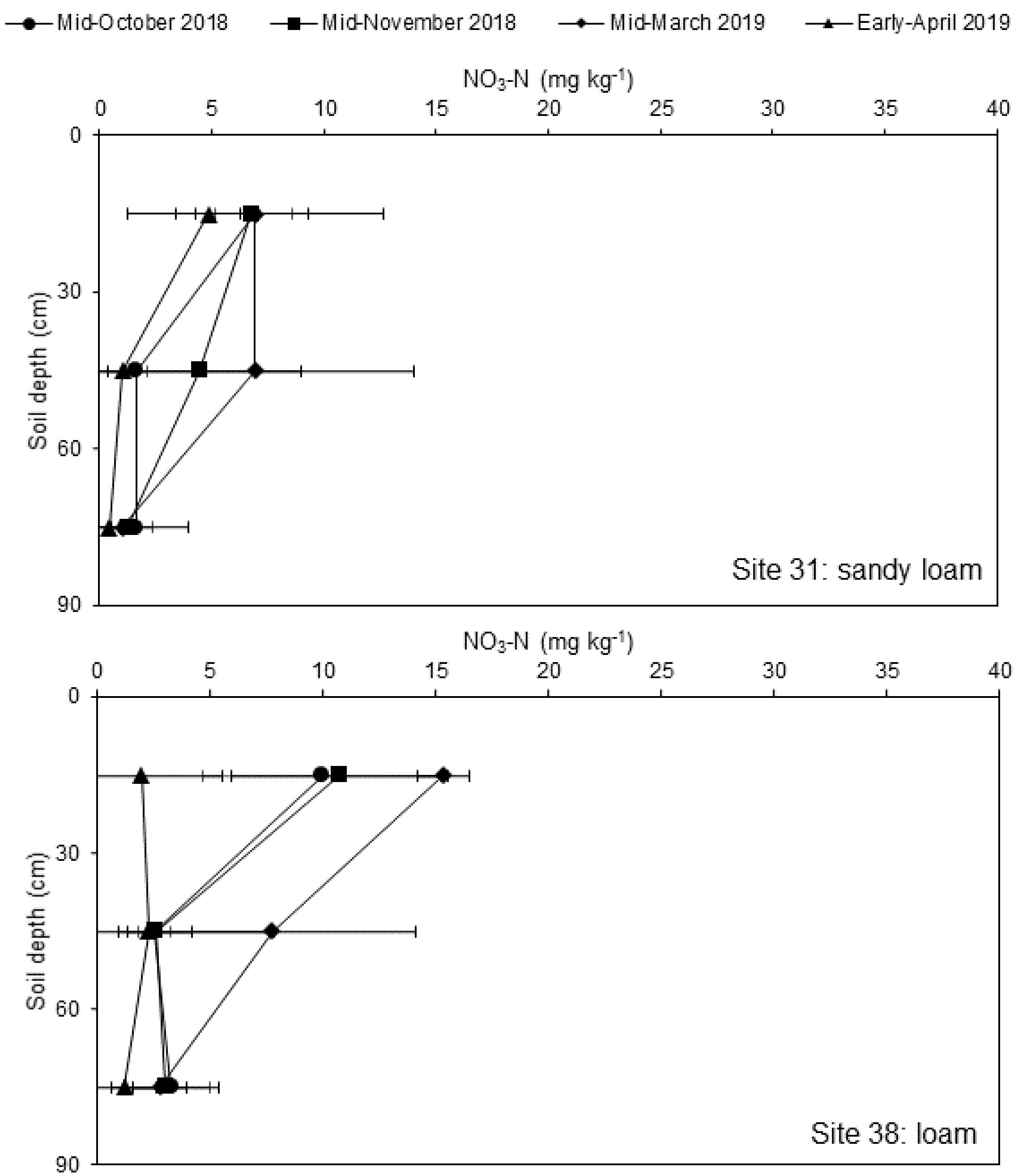

Figure 5. Changes in NO_3-N concentration at two sites (Sites 31 and 38) from October 2018 through April 2019. Points represent the midpoint of each 30-cm sampling layer. Errors bars represent two standard deviations from the mean (95% confidence interval).

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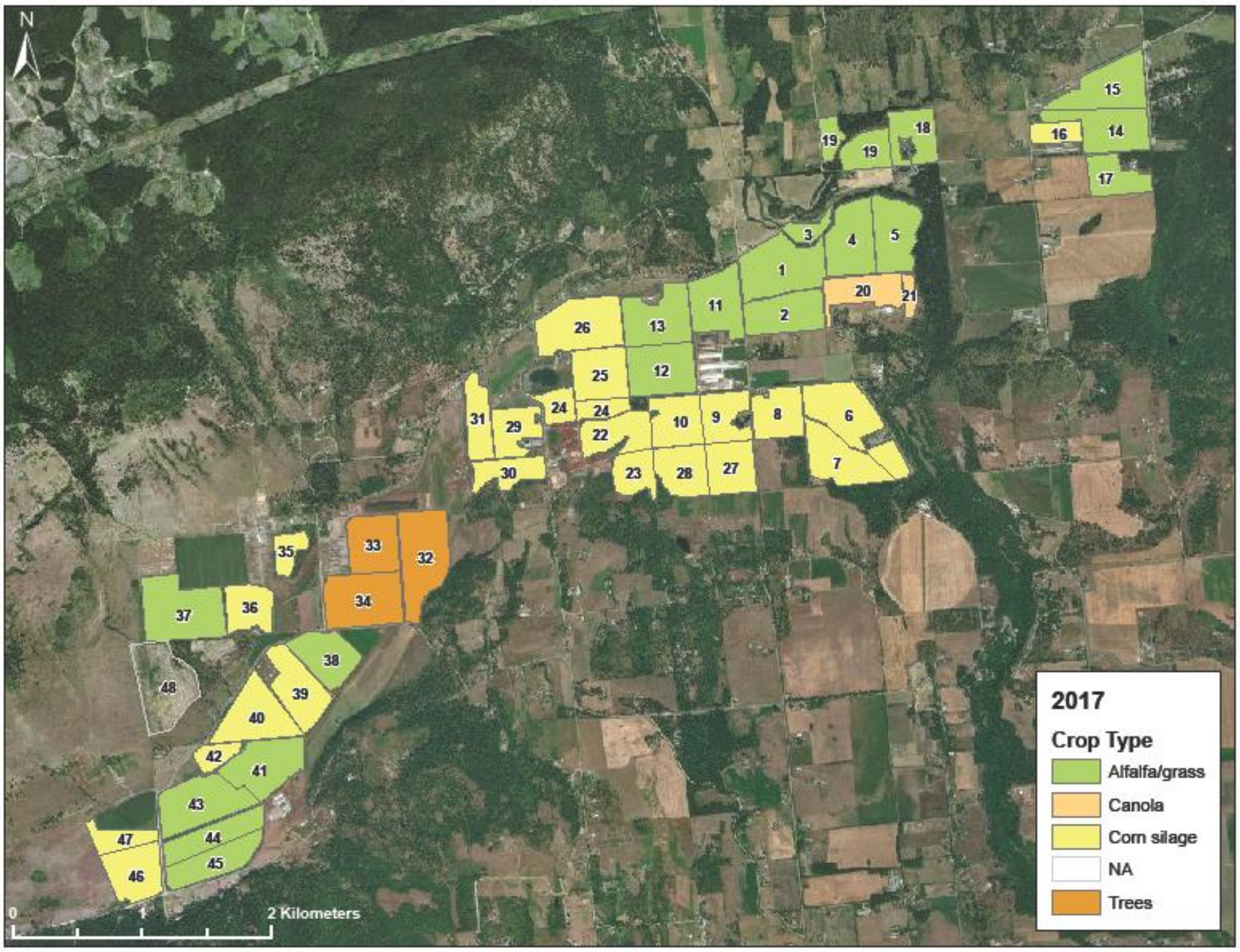
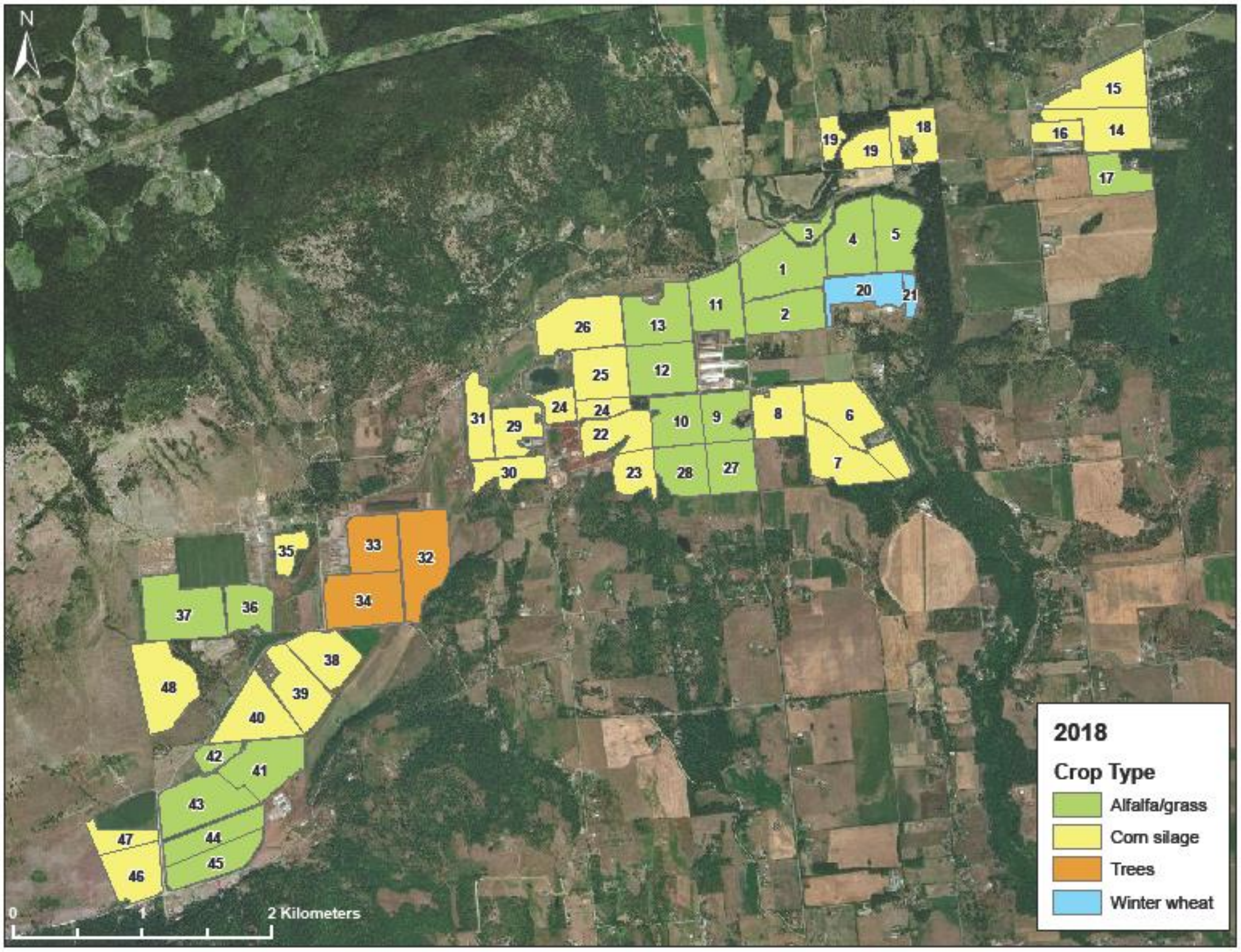
6 Supplemental Materials

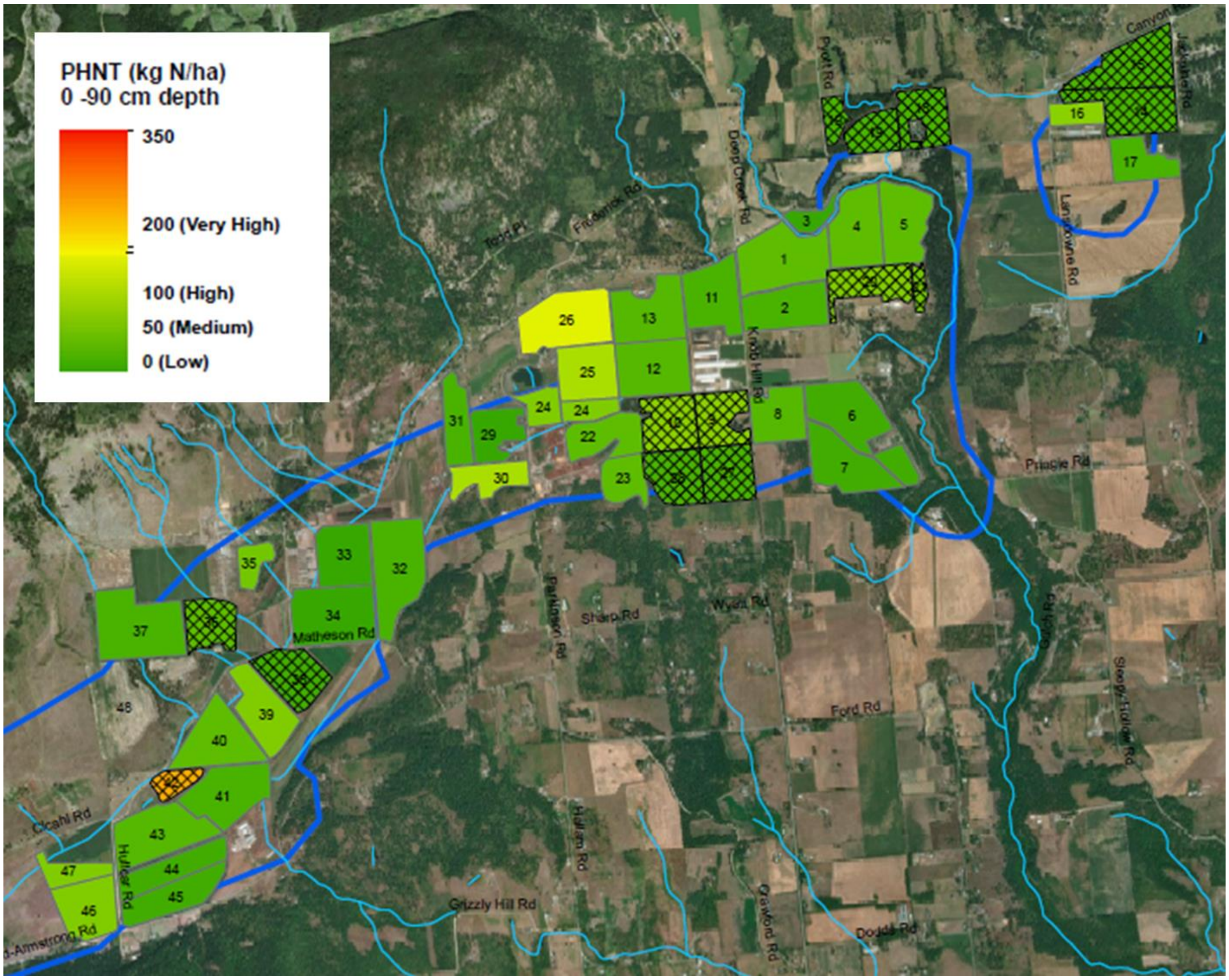
Figures



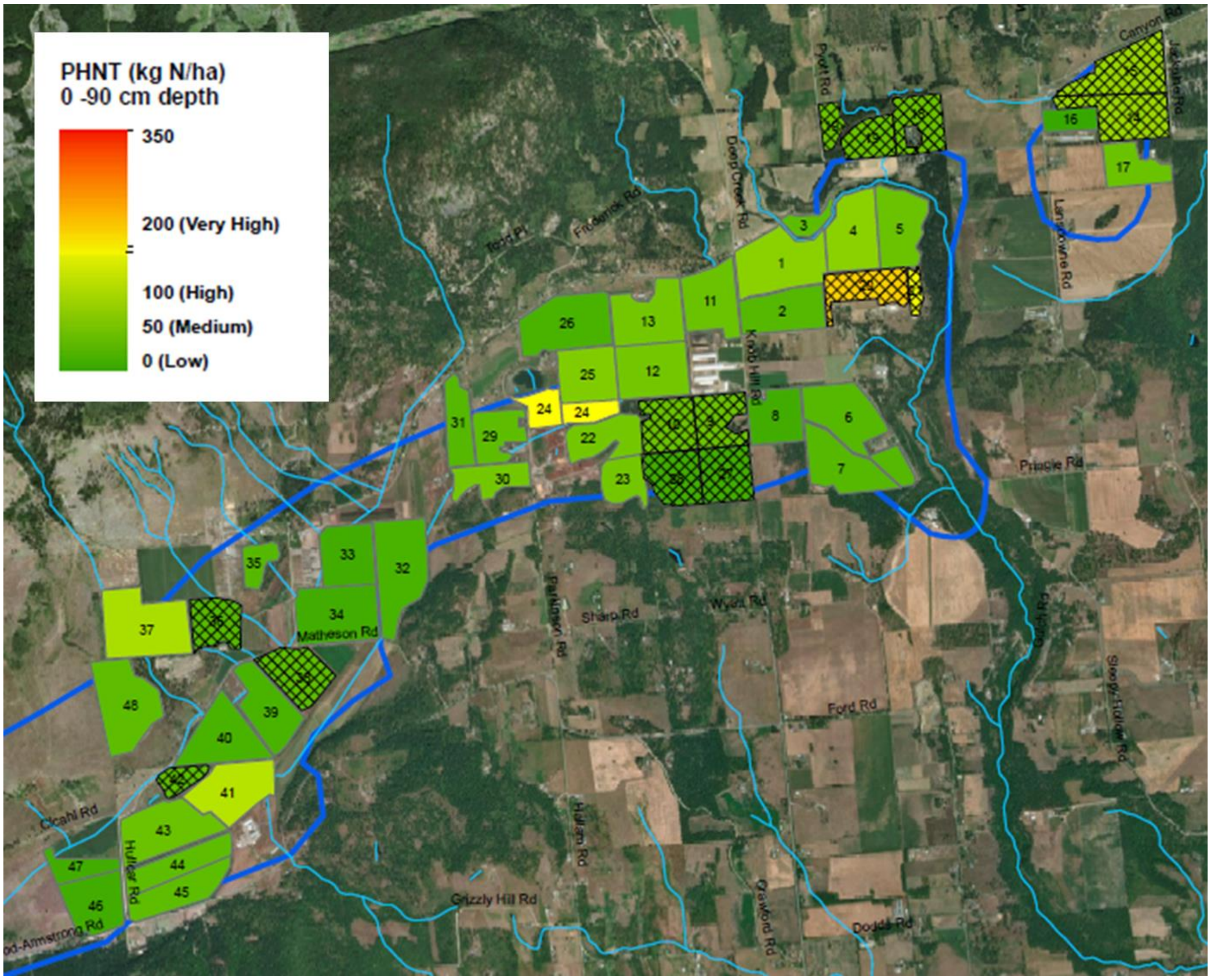
Supplemental Figure 1. Crop type in the study area during the 2017 growing season. The field ID numbers are based on sample area IDs used in 2018.



Supplemental Figure 2. Crop type in the study area during the 2018 growing season. The field ID numbers are based on sample area IDs used in 2018.



Supplemental Figure 3. Post-harvest nitrate test (PHNT) ratings in fall of 2017. Sampling areas with a cross-hatch pattern had a change in crop type from 2017 to 2018. The field ID numbers are based on sample area IDs used in 2018.



Supplemental Figure 4. Post-harvest nitrate test (PHNT) ratings in fall of 2018. Sampling areas with a cross-hatch pattern had a change in crop type from 2017 to 2018. The field ID numbers are based on sample area IDs used in 2018.

Tables

Supplemental Table 1. Changes in Field IDs for PHNT sampling in 2016 - 2018.

2016 Field ID	2017-18 Field ID	2016 Field ID	2017-18 Field ID
1	1	21	37
2	2	22	36
3	3	23	38
4	4	24	39
5	5	25	40
6	6	26	22/23
7	7	27	24
8	8	28	25
9	9/10	29	26
10	12/13	30	29
11	11	31	27/28
12	14/15	32	43
13	16	33	44/45
14	18/19	34	41
15	30	35	42
16	31	36	46/47
17	32	37	17
18	33/34	38	48*
19	35	39	20
20	-	40	21

**In 2018, sampling unit 48 was changed from a site on Farm 4 to a new site on Farm 5 as the original field #48 was no longer in production.*

Supplemental Table 2. Sampling area and post-harvest nitrate test statistics for the 2017 post-harvest soil sampling period.

Crop type	Area sampled (ha)	No. sampling areas	Area-weighted average PHNT[a] (kg N ha^{-1})	Median PHNT (kg N ha^{-1})	Minimum PHNT value (kg N ha^{-1})	Maximum PHNT value (kg N ha^{-1})
Alfalfa/grass	344	19	47	45	21	69
Corn, silage	323	23	83	83	21	233
Other perennial[b]	92	4	28	23	19	45
Canola	17	2	91	91	91	91
All	776	48	60	50	19	233

a. In an area-weighted average, sampling areas that were larger contributed more to the average PHNT value compared to areas that were smaller. In contrast, all areas contribute equally to a simple average regardless of the acreage of the area.

b. 'Other perennial' is fields in nursery trees or a field in grass hay.

Supplemental Table 3. Post-harvest nitrate by soil layer (depth) in fields that were silage corn in 2017 and 2018.

		2017					2018				
Field	**Sampling Depth**	**NO_3-N (ppm)**	**kg NO_3-N ha^{-1}**	**kg NO_3-N ha^{-1} (0-90cm)**	**PHNT Rating**	**Crop**	**NO_3-N (ppm)**	**kg NO_3-N ha^{-1}**	**kg NO_3-N ha^{-1} (0-90cm)**	**PHNT Rating**	**Crop**
6	0-30 cm	3	12				8.5	33			
	30-60 cm	3	14	34	Low	Corn silage	3.2	14	57	Med	Corn silage
	60-90 cm	2	9				2.1	9			
7	0-30 cm	3	12				7.3	28			
	30-60 cm	4	18	39	Low	Corn silage	2.1	9	52	Med	Corn silage
	60-90 cm	2	9				3.2	14			
8	0-30 cm	4	16				4.7	18			
	30-60 cm	2	9	52	Med	Corn silage	1.1	5	37	Low	Corn silage
	60-90 cm	6	27				3.1	14			
16	0-30 cm	13	51				2.1	8			
	30-60 cm	6	27	109	High	Corn silage	1	5	18	Low	Corn silage
	60-90 cm	7	32				1.1	5			
22/23	0-30 cm	10	39				13	51			
	30-60 cm	3	14	66	Med	Corn silage	4.7	21	86	Med	Corn silage
	60-90 cm	3	14				3.2	14			
24	0-30 cm	13	51				22.2	87			
	30-60 cm	3	14	96	Med	Corn silage	9.5	43	185	High	Corn silage
	60-90 cm	7	32				12.4	56			
25	0-30 cm	19	74				12.1	47			
	30-60 cm	4	18	124	High	Corn silage	4.2	19	94	Med	Corn silage
	60-90 cm	7	32				6.3	28			
26	0-30 cm	15	59				8.8	34			
	30-60 cm	8	36	167	High	Corn silage	1	5	43	Low	Corn silage
	60-90 cm	16	72				1	5			
29	0-30 cm	4	16				10	39			
	30-60 cm	1	5	25	Low	Corn silage	3.1	14	67	Med	Corn silage
	60-90 cm	1	5				3.1	14			
30	0-30 cm	17	66				13.1	51			
	30-60 cm	7	32	129	High	Corn silage	4.2	19	89	Med	Corn silage
	60-90 cm	7	32				4.2	19			
31	0-30 cm	7	27				9.8	38			
	30-60 cm	2	9	50	Low	Corn silage	1	5	52	Med	Corn silage
	60-90 cm	3	14				2.1	9			
35	0-30 cm	12	47				8.3	32			
	30-60 cm	4	18	83	Med	Corn silage	2	9	51	Med	Corn silage
	60-90 cm	4	18				2.1	9			
38	0-30 cm	6	23				10	39			
	30-60 cm	1	5	32	Low	Alfalfa/ grass	3.1	14	62	Med	Corn silage
	60-90 cm	1	5				2.1	9			
39	0-30 cm	16	62				6.8	27			
	30-60 cm	4	18	98	Med	Corn silage	3.1	14	45	Low	Corn silage
	60-90 cm	4	18				1.1	5			
40	0-30 cm	12	47				6.8	27			
	30-60 cm	3	14	69	Med	Corn silage	2.1	9	41	Low	Corn silage
	60-90 cm	2	9				1.1	5			
46/47	0-30 cm	13	51				6.5	25			
	30-60 cm	6	27	96	Med	Corn silage	1.6	7	40	Low	Corn silage
	60-90 cm	4	18				1.6	7			
48B	0-30 cm	NA					7.9	31			
(2018)	30-60 cm	NA					4.1	18	68	Med	Corn silage
	60-90 cm	NA					4.2	19			

Supplemental Table 4. Post-harvest nitrate by soil layer (depth) in fields that were grass/alfalfa in 2017 and 2018.

		2017					2018				
Field	Sampling Depth	NO_3-N (ppm)	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop	NO_3-N (ppm)	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop
1	0-30 cm	8	31	67	Med	Alfalfa 4	17.4	68	101	High	Alfalfa 5
	30-60 cm	4	18				4.2	19			
	60-90 cm	4	18				3.1	14			
2	0-30 cm	9	35	44	Low	Alfalfa 4	10.4	41	59	Med	Alfalfa 5
	30-60 cm	1	5				2.1	9			
	60-90 cm	1	5				2.1	9			
3	0-30 cm	4	16	29	Low	Grass	9.5	37	65	Med	Grass
	30-60 cm	2	9				3.2	14			
	60-90 cm	1	5				3.1	14			
4	0-30 cm	12	47	69	Med	Alfalfa 4	20.2	79	107	High	Alfalfa 5
	30-60 cm	3	14				4.2	19			
	60-90 cm	2	9				2.1	9			
5	0-30 cm	11	43	61	Med	Alfalfa 4	18.1	71	80	Med	Alfalfa 5
	30-60 cm	2	9				1	5			
	60-90 cm	2	9				1	5			
11	0-30 cm	8	31	45	Low	Alfalfa 2	12	47	75	Med	Alfalfa 3
	30-60 cm	2	9				3.2	14			
	60-90 cm	1	5				3.1	14			
12/13	0-30 cm	8	31	54	Med	Alfalfa 1	12.8	50	88	Med	Alfalfa 2
	30-60 cm	3	14				4.3	19			
	60-90 cm	2	9				4.2	19			
17	0-30 cm	9	35	44	Low	Alfalfa 2	13.7	53	72	Med	Alfalfa 3
	30-60 cm	1	5				3.1	14			
	60-90 cm	1	5				1	5			
37	0-30 cm	7	27	41	Low	Alfalfa/ grass	25.3	99	123	High	Alfalfa/ grass
	30-60 cm	2	9				2.1	9			
	60-90 cm	1	5				3.2	14			
41	0-30 cm	8	31	49	Low	Alfalfa/ grass 1	29.1	113	137	High	Alfalfa/ grass 2
	30-60 cm	2	9				3.2	14			
	60-90 cm	2	9				2.1	9			
43	0-30 cm	6	23	55	Med	Alfalfa/ grass 1	13.5	53	71	Med	Alfalfa/ grass 2
	30-60 cm	3	14				3.1	14			
	60-90 cm	4	18				1	5			
44/45	0-30 cm	6	23	32	Low	Alfalfa/ grass 2	13.5	53	65	Med	Alfalfa/ grass 3
	30-60 cm	1	5				1.6	7			
	60-90 cm	1	5				1.1	5			

Supplemental Table 5. Post-harvest nitrate by soil layer (depth) in fields that were trees or had a crop change in 2017 and 2018.

		2017					2018				
Field	Sampling Depth	NO_3-N (ppm)	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop	NO_3-N (ppm)	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop
9/10	0-30 cm	12	47				10.2	40			
	30-60 cm	4	18	101	Med	Corn silage	2.7	12	71	Med	Alfalfa 1
	60-90 cm	8	36				4.2	19			
14/15	0-30 cm	7	27				12.4	48			
	30-60 cm	2	9	41	Low	Alfalfa (mature)	8.5	38	115	High	Corn silage
	60-90 cm	1	5				6.4	29			
18/19	0-30 cm	8	31				8.6	34			
	30-60 cm	2	9	45	Low	Alfalfa 4	3.7	17	72	Med	Corn silage
	60-90 cm	1	5				4.8	22			
20	0-30 cm	12	47				43.5	170			
	30-60 cm	6	27	92	Med	Canola	8.3	37	212	Very High	Winter wheat
	60-90 cm	4	18				1.1	5			
21	0-30 cm	10	39				32.4	126			
	30-60 cm	7	32	89	Med	Canola	3.2	14	179	High	Winter wheat
	60-90 cm	4	18				8.4	38			
27/28	0-30 cm	7	27				5.8	23			
	30-60 cm	2	9	50	Low	Corn silage	1.1	5	37	Low	Alfalfa 1
	60-90 cm	3	14				2.1	9			
32	0-30 cm	8	31				7.3	28			
	30-60 cm	2	9	45	Low	Trees	2.1	9	47	Low	Trees
	60-90 cm	1	5				2.1	9			
33/34	0-30 cm	4	16				6.3	25			
	30-60 cm	1	5	25	Low	Trees	1.6	7	36	Low	Trees
	60-90 cm	1	5				1	5			
36	0-30 cm	9	35				8.5	33			
	30-60 cm	2	9	62	Med	Corn silage	2.1	9	52	Med	Alfalfa 1
	60-90 cm	4	18				2.1	9			
42	0-30 cm	31	121				15.2	59			
	30-60 cm	20	90	233	Very High	Corn silage	1.1	5	69	Med	Alfalfa 1
	60-90 cm	5	23				1.1	5			

Supplemental Table 6. Changes in volumetric soil moisture content (%) over the non-growing season at the six Benchmark sites in 2017/18 and 2018/19.

	2017/18				**2018/19**		
Date	0-30 cm	30-60 cm	60-90 cm	Date	0-30 cm	30-60 cm	60-90 cm
Site 6	Sandy loam	Sandy loam	Sandy loam	**Site 4**	Sandy loam	Loamy sand	Loamy sand
6-Oct	10.7	8.6	11.0	21-Oct	21.6	16.7	12.0
31-Oct	12.8	9.6	9.8	07-Nov	21.2	15.4	10.6
16-Nov	19.8	8.8	8.4	25-Mar	30.6	21.3	11.1
04-Apr	33.1	21.9	20.2	01-Apr	21.6	16.5	11.9
12-Apr	25.0	20.8	19.4				
04-May	19.4	15.8	15.2				
Site 17	Silt loam	Silt loam	Sandy loam	**Site 6**	Sandy loam	Sandy loam	Sandy loam
6-Oct	13.0	11.9	14.2	21-Oct	28.4	23.5	22.4
31-Oct	15.2	12.5	14.0	07-Nov	25.5	20.9	18.9
16-Nov	19.8	12.8	13.9	25-Mar	36.8	27.5	25.5
04-Apr	31.9	32.9	35.2	01-Apr	28.9	25.0	24.5
12-Apr	28.5	33.5	36.7				
04-May	24.3	28.8	35.3				
Site 26	Sandy loam	Sandy loam	Sand	**Site 17**	Silt loam	Silt loam	Sandy loam
6-Oct	21.8	12.0	5.3	21-Oct	28.4	33.8	37.2
31-Oct	22.4	11.9	5.8	07-Nov	28.9	32.2	34.5
16-Nov	19.2	11.9	7.6	25-Mar	44.0	33.8	39.3
04-Apr	29.2	14.9	9.6	01-Apr	31.2	38.5	39.3
12-Apr	24.0	13.2	7.4				
04-May	20.6	12.6	6.7				
Site 28	Silt loam	Silt loam	Silt loam	**Site 26**	Sandy loam	Sandy loam	Sand
6-Oct	11.9	6.6	5.4	21-Oct	20.4	15.2	9.1
31-Oct	13.1	6.5	5.7	07-Nov	20.8	14.3	8.3
16-Nov	20.1	6.4	5.3	25-Mar	32.5	19.9	9.4
04-Apr	31.7	24.1	23.9	01-Apr	22.1	16.3	10.0
12-Apr	26.1	22.9	24.0				
04-May	19.1	20.8	21.8				
Site 31	Sandy loam	Loamy sand	Sand	**Site 31**	Sandy loam	Loamy sand	Sand
6-Oct	17.8	8.2	4.7	21-Oct	21.3	12.1	10.3
31-Oct	20.8	9.2	4.9	07-Nov	20.4	13.3	6.9
16-Nov	19.9	10.9	6.8	25-Mar	29.7	18.6	7.6
04-Apr	27.9	12.5	7.1	01-Apr	20.8	13.2	9.1
12-Apr	23.4	12.2	6.6				
04-May	18.0	9.3	5.4				
Site 38	Loam	Loam	Clay loam	**Site 38**	Loam	Loam	Clay loam
6-Oct	18.9	11.7	10.4	21-Oct	21.5	21.9	24.1
31-Oct	21.7	11.4	10.6	07-Nov	20.4	21.9	23.7
16-Nov	21.1	16.1	15.5	25-Mar	28.9	23.4	23.7
04-Apr	25.3	19.7	20.7	01-Apr	21.5	24.8	26.5
12-Apr	26.9	19.5	20.1				
04-May	23.9	18.2	20.0				

Supplemental Table 7. NO_3-N concentrations (mg kg^{-1}) at the 0-30, 30-60, and 60-90 cm depths at the six Benchmark sites over the non-growing season in 2018/19. Concentrations followed by the same letter within each site and soil depth are not significantly different ($p<0.05$).

Date	0-30 cm	30-60 cm	60-90 cm
Site 4			
21-Oct	7.2a	3.1a	2.0a
07-Nov	36.0b	4.0a	3.0ab
25-Mar	8.6ab	10.2b	4.0b
01-Apr	16.0ab	3.9a	2.2ab
Site 6			
21-Oct	14.5a	7.7a	4.9a
07-Nov	12.5a	8.8a	6.7a
25-Mar	6.4a	9.5a	7.2a
01-Apr	4.8a	2.0a	1.1a
Site 17			
21-Oct	7.3a	3.8a	3.7ab
07-Nov	18.7a	4.7a	5.2a
25-Mar	8.3a	6.2a	3.9ab
01-Apr	8.4a	5.1a	2.6b
Site 26			
21-Oct	11.0ac	2.9a	1.3a
07-Nov	16.0ab	6.8b	3.1b
25-Mar	22.0b	11.0c	3.4b
01-Apr	8.4c	4.3ab	0.9ac
Site 31			
21-Oct	6.9a	1.6ab	1.6a
07-Nov	6.8a	4.5ab	1.2a
25-Mar	6.9a	6.9b	1.0a
01-Apr	4.8a	1.0a	0.4a
Site 38			
21-Oct	10.0a	2.5a	3.3a
07-Nov	10.8ab	2.6a	3.0a
25-Mar	15.3b	7.7a	2.8a
01-Apr	2.0c	2.3a	1.2a